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Abstract

The paper aims to investigate the economies of scale of Water Users' Associations (WUA) in Tunisia. During the last years there has been a lot of discussion in Tunisia about the optimal size of WUAs, which allows more efficient management of the water resources at the local level. In this work we propose to see if the size of the WUA in the governorate of Nabeul (Central-Eastern part of Tunisia) would have to increase or decrease in order to maximize their efficiency. Apart from this qualification we also quantify the scale efficiency and scale elasticity of the WUA using Data Envelopment Analysis (DEA) models. The results show that the output space (volume of water distributed and number of ha managed and irrigated) of the WUA that attain a high level of scale efficiency is highly diverse, indicating that the number of ha irrigated and the volume of water distributed are not explaining the differences in the scale efficiency of WUA. The calculation of scale elasticity of the WUA shows that 41% of the WUA are operating at decreasing returns to scale (DRS) while 16% and 43% operate at constant (CRS) and increasing (IRS) returns to scale, respectively. The scale orientation was found to be depending on the output density rather than on the output size. Thus, WUA located in more irrigation-intensified areas were found to be IRS oriented. WUA operating at CRS were found to have the minimum costs, which is in line with the theoretical predictions that suggest that the average productivity is maximized when the scale efficiency is equal to 1.

1. Introduction

During the water sector decentralization process which started in Tunisia in the early 1970's various actions were undertaken to improve regional and local water management capacities. Improvements in technical irrigation capacity, staff training, creation of specialized regional administrative entities with specific decision making power, adaptation of juridical texts, etc. are some examples of the reforms undertaken. The creation of Water Users' Associations (WUA) as an organizational entity, grouping together all farmers belonging to a given irrigated area, was a main step in the decentralization process. The aim of the creation of these associations was to increase farmers' participation in decision making and resource management. They were also expected to play a crucial role in the irrigation cost recovery strategy of the government through fees collection and investments in irrigation development.

WUA in Tunisia are established through government funding and are given the responsibility for the collection of water fees as well as service related fees (infrastructure maintenance, investments, etc.). The number of WUA for irrigation water management has risen sharply from about 100 in 1987 to 1250 in 2006 (MARH, 2008) managing around 200,000 ha or 75% of the public irrigated areas in Tunisia.

Each WUA is responsible for establishing its own budget. The WUA has the right to determine the water price and to decide whether the water fees charged to farmers should be based on the water volume produced or distributed by the association. Furthermore, they can base the water fees on the level of projected investments and operational and maintenance costs. Broadly the WUA has following costs: operation and maintenance of canals, repair of irrigation infrastructure, functioning of the association and investments. The financial revenues of WUA comprise the contribution of users for adherence to the association, water fees and the revenues from other activities that the WUA undertakes. The water charges established by the WUA and charged to farmers should cover water buying charges, energy fees, maintenance, reparation and functioning expenditures, WUA management expenditures, refunding of loans. They should also be high enough to deal with investments and unexpected expenditures.

It is clear that the complexity of the tasks of WUA and possibly their performance is depending, among others, on the size of the WUA. The performances of water distribution utilities could also be related to the notion of "economies of density" in terms of volume distributed by customer and number of customer per a given length of network (Bottasso and Conti, 2009). In this paper, we will investigate these performance-output relationships in more detail. The effect of the operational scale and density of WUA outputs on their performance will be assessed for a set of Tunisian WUA. A dataset of 37 WUA operating in the Cap bon region (Central-

Eastern Tunisia) will be used for this aim. Technical efficiency, scale efficiency, the orientation of the scale efficiency (i.e. if there are inefficiencies due to increasing or decreasing returns to scale), as well as the scale elasticity scores of these WUA will be calculated using Data Envelopment Analysis (DEA) .

Many studies have used DEA to analyse organizational efficiency. The applications range from the bank sector over health care and education to forest organizations, airlines and railway companies and water and gas industries (Luo, 2003; Kirigia *et al.*, 2004; Siddharthan *et al.*, 1999; Kao *et al.*, 1993; Viitala, 1998; Joro and Viitala, 1999; Balaguer-Coll *et al.*, 2007; Erbetta and Rappuoli, 2008; Bottasso and Conti, 2009). Furthermore, in the irrigation and drainage sector, DEA is often applied to estimate production efficiency for large irrigated systems and districts at regional level (Malana and Malano, 2006; Diaz Rodriguez *et al.*, 2005; Malano *et al.*, 2004; Diaz Rodriguez *et al.*, 2004). However, the application in this paper, which assesses the efficiency of local water management organizations, is quite unique. To our knowledge, only Umetsu *et al.* (2005) and Frija *et al.* (2009) performed a DEA analysis respectively on Turkish and Tunisian WUA. One of the shortcomings in the paper of Umetsu *et al.* (2005) was however, that, although they encountered significant effects of the WUA size on the efficiency score, they did not consider a variable returns to scale specification of the DEA model and therefore do not provide any estimation of the scale efficiency. Similarly, Frija *et al.* (2009) report the scale inefficiencies of the Tunisian WUA but they do not provide any information about the orientation of the efficiency, neither on the scale elasticity.

At one hand, the current investigation is very important at the national level in Tunisia since it can provide valuable recommendations for the PISEAU II project (project for the investment in the water sector). A main component of this project is related to the reinforcement of the institutional capacities for water management. On the other hand, the empirical application might also be useful in international contexts where the functioning of WUA is a research topic of interest. The rest of the paper is organized into 4 further sections. In the next methodological section, the VRS DEA models will be presented. Section 3 presents the results of the study and section 4 discusses them. Finally section 5 concludes.

2. Methodology

Economies of scale can be studied using DEA. DEA consists of piecewise linear programming to calculate the efficiency or best practice frontier for a sample of Decision Making Units (DMU). The DMU on this technical efficiency frontier will have an efficiency score equal to 1. The DEA technique does not require the development of standards against which efficiency is measured.

Derived ratings are estimated within a set of analysed units (efficiency of less efficient DMU is measured in relation to the frontier). Moreover, different units of measurement for the various inputs and outputs can be combined within the DEA models.

One of the analysis options in DEA is a choice between Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). CRS assumes that there is no significant relationship between efficiency and the scale of operation. This corresponds with assuming that large WUA are just as efficient as small ones in converting inputs to outputs. The use of the VRS specification, first developed by Banker, Charnes and Cooper (1984) will permit the calculation of TE without scale efficiency (SE) effects (in Coelli, 1996). However, we anticipate that the scale of activity (size of the organization) of the WUA has an important effect on its efficiency (Umetsu *et al.*, 2005). Furthermore we assume that changes in the organization's inputs can lead to disproportionate changes to its outputs. Given the objective of this article, the VRS option has been chosen for this study.

A second option is the choice between input-oriented and output-oriented DEA models. If the focus is to use different resources more efficiently (instead of increasing production), then the most suitable model to use is an input-oriented one (Rodríguez Diaz *et al.*, 2004). In our case, it is necessary, as a national objective, that the WUA recover their expenditures to ensure their sustainability. Therefore, the primary objective of the WUA will be to minimise expenditures, which makes it more logical to use an input-oriented model. . Recapitulating, we chose to estimate Variable Return to Scale (VRS) efficiencies through a BCC (Banker, Charnes and Cooper, 1984) input-oriented model.

Following the BCC model, if we consider K DMU ($k=1, \dots, K$), each of them using N inputs variables x_{nk} ($n=1, \dots, N$), for producing M outputs y_{mk} ($m=1, \dots, M$). Each DMU₀ becomes the reference unit and then we have to resolve the following linear program (model 1) k times (one time for each DMU):

$$\text{Min}_{\theta, \lambda} \theta^{VRS} \tag{1.1}$$

s.t.

$$\sum_{k=1}^K \lambda_k y_{m,k} \geq y_{m,o} \tag{1.2}$$

$$\sum_{k=1}^K \lambda_k x_{n,k} \leq \theta x_{n,o} \quad (1.3)$$

$$\sum_{k=1}^K \lambda_k = 1 \quad (1.4)$$

$$\lambda_k \geq 0 \quad (1.5)$$

Where θ^{VRS} is a variable representing the efficiency of the reference DMU₀, and hence the percentage reduction to which the input vector must be subjected in order to reach the production frontier. λ_k is a vector of k elements representing the influence of each DMU in determining the

efficiency of the DMU₀. The term $\sum_{k=1}^K \lambda_k y_{m,k}$ indicates the weighted sum of outputs of all DMU,

which must be superior or equal to the output of DMU₀ (constraint 1.2). In constraint 1.3, θ^{VRS} is the measure of technical efficiency and represents, at the same time, the minimized objective. Thus, constraint 1.3 indicates that the value of θ assessed must shift the production factors toward the production frontier (for a given output level). Equation 1.4 consists of the convexity constraint, which specifies the variable returns to scale option. When deleting this constraint equation model (1) will provide the CRS efficiency scores. According to Coelli et al., (2002), scale efficiency can be obtained by the ratio TE_{CRS}/TE_{VRS} . Obtaining similar values for CRS and VRS efficiencies for a given DMU demonstrates that it is operating at an efficient scale. The DMU whose λ values are positive will be the reference set for DMU₀ under study. In fact, it is the linear combination of those units, which will formulate the situation objective needed to achieve efficiency.

Two approaches can be found in literature for the calculation of scale elasticity in the DEA VRS technology : the direct and the indirect approaches. The indirect approach (Banker et al., 1984; Banker and Thrall, 1992; Førsund and Hjalmarsson, 2004; and Førsund et al., 2007) is employed in most of previous empirical works (Erбетта and Rappuoli, 2008; Morrison Paul et al, 2004). It is attractive because it produces a simple formula for the derivation of scale elasticity expressed in terms of the dual optimal solutions to the VRS model. The alternative direct approach has recently been developed by (Krivonozhko et al., 2004) and (Førsund et al., 2007). It utilises methods of parametric optimisation in order to construct the parts of the boundary of the VRS technology and uses them for the calculation of scale elasticity. Using real data, Førsund et al. (2007) demonstrated a very high correspondence between elasticity scores derived from both approaches. The method adapted in this study is based on dual program of model (1) which can be presented as below (see Førsund et al (2007) for a detailed description).

$$Max \left\{ \sum_{m=1}^M u_m y_{mk} + u_k^{in} \right\} \quad (2.1)$$

s.t.

$$\sum_{n=1}^N v_{nk} x_{nk} = 1 \quad (2.2)$$

$$\sum_{m=1}^M u_m y_{m,k} - \sum_{n=1}^N v_{nk} x_{nk} + u_k^{in} \leq 0 \quad (2.3)$$

$$u_m \geq 0, v_n \geq 0 \quad (2.4)$$

Where u_m , and v_n are shadow prices of the output and input constraints in model (1) and u_i^{in} (in subscript for input orientation) the unrestricted shadow price of the convexity constraint included in (1). Now consider a boundary-point (to the frontier) characterized by the output and input-vectors (Y_k, X_k^*) with $X_k^* = X_k^* \theta_k^{VRS}$ and where (Y_k, X_k) is an inefficient unit with $\theta_k^{VRS} < 1$. Let's assume that the projected point is an interior point on a facet (pricewise on the frontier located between two efficient units). If we assume that the corresponding shadow prices are unique (i.e., that only fully-dimensional facets are considered), then it is proved in Førsund and Hjalmarsson, (2004) that scale elasticity for the hypothetical boundary observation (Y_k, X_k^*) can be calculated as:

$$\mathcal{E}(\theta_k^{VRS} X_k, Y_k) = \frac{\theta_k^{VRS}}{\theta_k^{VRS} - u_k^{in}} \quad (3)$$

This formula assumes a unique solution for inefficient points. On the contrary, a plurality of solutions (shadow prices) arises for efficient points. For these points, we can imagine a hypothetical inefficient point with infinitesimal distance from the efficient point, k , we can then approximate the elasticity value by using (3) and deriving maximum and minimum scale elasticity values:

$$\mathcal{E}^{max}(X_k, Y_k) = \frac{1}{1 - u_k^{in-max}}; \mathcal{E}^{min}(X_k, Y_k) = \frac{1}{1 - u_k^{in-min}} \quad (4)$$

$u_k^{in-max}(u_k^{in-min})$ is calculated by maximizing (minimizing) the shadow prices u_i^{in} in model 2 while making the objective function (2.1) equal to 1 and adding it to the constraints (see Førsund and Hjalmarsson, 2004 for more details).

3. Empirical Application

3.1. Case study and data base

The database used for this analysis was collected by the Agricultural and Hydraulic

Resources Ministry of Tunisia. This central database concerns 37 WUA, which constitutes 82.2 % of the 1 WUA operating in the Cap Bon region (governorate of Nabeul). All of these WUA are managing irrigation water which is provided from a public source (dams and/or deep bore wells). The Cap Bon is located in northern Tunisia and is bounded in the East by the Mediterranean Sea. The total cultivated area of the region is 256,500 ha, of which 183,000 ha consists of arable land and 41,000 ha of irrigable lands. Cereals occupy the greatest land area at 53,000 ha, vegetables occupy 35,000 ha, olives for olive oil 23,500 ha, citrus fruit 13,450 ha and other crops occupy 6,300 ha (CRDA Nabeul, 2006). In 2004 around 22% of the total population in the Cap Bon region were employed in the agricultural sector. Agricultural production in Cap Bon contributes almost 15% to the total national agricultural production. The number of farms in the region is approximately 32,000 (6.6% of total Tunisian farms). Only 25,500 ha (92% of the total irrigated land) are equipped with a public irrigation network and the remaining area is irrigated from dams and other private sources. Currently, irrigated areas in Cap Bon represent about 13.3% of the total Tunisian irrigated lands and it is considered one of the most water-consuming regions in the country. 71% of the irrigated areas belongs to small and average-sized farms.

3.2. Inputs and outputs selection

With regard to the selection of outputs and inputs, as a general rule of thumb, there should be at least three DMU for each input and output variable used in the model, since with less than three DMU per input and output too many DMU will turn out to be efficient (Alfonso and Santos, 2005). According to our database, the WUA' expenditure can be broadly divided into management expenditure, maintenance costs, water purchasing costs, labour costs, repayment of debts and other expenditure. Given that in our empirical application, we focus on the relationship between inputs and outputs of the WUA, we have chosen to aggregate the main financial inputs of the water users' associations into three vectors: management expenditure, maintenance expenditure, and water purchasing expenditures. The use of expenditure vectors is very common in studies which analyse the efficiency of organizations (Kirigia *et al.*, 2004; Alfonso and Santos, 2005; Luo, 2003; Erbetta and Rappuoli, 2008). In our study the management expenditure vector integrates expenses related to the internal organization and functioning of the WUA. The maintenance expenditure vector, on the other hand, in addition to the typical maintenance costs, integrates the costs of labour used for maintenance and the energy fees spent to pump water from drilling.

The outputs considered are the total annual irrigated area (ha), and the total annual amount of irrigation water delivered by the WUA to its adherents ($\text{m}^3 \text{yr}^{-1}$). In literature the annual irrigated area is considered as key descriptor for irrigation and drainage scheme performance (Malano *et*

al., 2004) and likewise the annual irrigation water delivery is one of the most relevant service delivery performance indicators. In the short run these two outputs are the only constant and stable WUA outputs. Other possibly relevant outputs like the financial revenue of the WUA can always change from one year to another according to the association's objectives. For example, in years with high investments in modernization, the revenue will quickly reduce during the studied year and consequently cannot be taken as an efficiency parameter to integrate it in DEA models, which study only one year. Other productive performance indicators which are sometimes used, such as the total gross annual agricultural production in the area managed by the WUA, the total annual value of agricultural production, the output per unit service area etc. are not relevant for this study, because we are interested in the efficiency of WUAs (as decision making units) and not in the efficiency of the national policy for water demand management. According to this input-output choice, an efficient WUA will be the one that has a lower Input/Output ratio (Expenditure/m³ and Expenditure/ha). This consequently reflects better performance in minimizing water rates for farmers.

3.3. Descriptive statistics

The 37 WUAs selected are managing around 14,000 ha of land (9% of the total arable land in the governorate) owned by 7,278 adherent farmers. The total volume of water distributed by those associations is around 87.5 million cubic metres and the average irrigated surface area per WUA is nearly 355 ha.

Table 1. Basic statistics for the data used in the DEA Model

| | | Average | SD | Minimum | Maximum |
|----------------|---------------------------------------|----------|----------|---------|-----------|
| <i>Outputs</i> | 1- Vol of water Distributed (1000 m3) | 1178.2 | 1107.2 | 1.1 | 5888.5 |
| | 2- Nbr of irrigated ha/year | 377.0 | 265.8 | 53.0 | 1 305.0 |
| <i>Inputs</i> | 1- Management expenditure (TDN) | 4 512.3 | 3 349.0 | 173.0 | 13 539.0 |
| | 2- Maintenance expenditure (TDN) | 59 512.0 | 57 517.8 | 137.0 | 228 252.0 |
| | 3- Purchasing water cost (TDN) | 38 573.0 | 24 190.8 | 6 716.0 | 106 185.0 |

From these data it is clear that there is a large spread in the area the WUA is managing and in the water volumes it distributes.. This scale heterogeneity is proved by the observation of the Standard deviations together with the minimum/maximum values of inputs/outputs in our sample (Table 1). Table 2 shows the correlation matrix of inputs and outputs included in the DEA efficiency calculation. The outputs appear to be positively correlated with the Cost variables. This shows that the inputs and outputs exhibit an isotonic relationship and can be thus justified to be included together in our model. The correlation index between each output variable and costs is

very high indicating that the selected outputs have a high explanatory power on the chosen costs.

Table 2. Pairwise correlation test for inputs and output used in DEA calculation

| | Output1 | Output2 | Input1 | Input2 | Input3 |
|---------|----------|----------|----------|----------|--------|
| Output1 | 1 | | | | |
| Output2 | 0.883*** | 1 | | | |
| Input1 | 0.664*** | 0.696*** | 1 | | |
| Input2 | 0.783*** | 0.807*** | 0.726*** | 1 | |
| Input3 | 0.907*** | 0.823*** | 0.723*** | 0.800*** | 1 |

***: significant at 1% level

4. Empirical Results

4.1. Efficiency and elasticity score

General Algebraic Modelling System (GAMS) software was used to calculate the scale efficiency as well as the elasticity of scale of each WUA in our sample. Models 1 and 2 were each resolved 37 times, once for each WUA. Results concerning the VRS technical efficiency, scale efficiency, scale elasticity¹ and scale orientation for each WUA in our sample are presented in table 3.

Table 3. Technical VRS efficiency, scale efficiency, scale direction and average scale elasticity for each WUA

| Name WUA | VRS Efficiency | S Efficiency | Average S Elasticity | Scale Direction |
|---------------|----------------|--------------|----------------------|-----------------|
| Naoualette | 0.775 | 0.929 | 0.864 | DRS |
| Belhouichette | 0.733 | 0.996 | 1.018 | IRS |
| Sidi Grar | 0.707 | 0.992 | 1.027 | IRS |
| El Amrine | 0.785 | 0.996 | 0.986 | DRS |
| El Marja | 0.919 | 0.991 | 1.026 | IRS |
| Bou Charray | 1.000 | 1.000 | 1.000 | CRS |
| Cherifette | 0.817 | 0.938 | 1.110 | IRS |
| Beni Khalled | 0.642 | 0.878 | 0.809 | DRS |
| Z. Jedidi | 0.589 | 0.995 | 1.019 | IRS |
| Gobba Emtieze | 0.954 | 0.998 | 1.020 | IRS |
| Tefelloune | 0.672 | 0.928 | 1.314 | IRS |
| Lebna Village | 0.903 | 0.842 | 1.312 | IRS |
| Lebna Barrage | 0.819 | 0.978 | 0.938 | DRS |
| Semmeche | 0.882 | 0.943 | 0.869 | DRS |

¹ For WUA with VRS technical efficiency equal to 1 (on the frontier), maximum and minimum scale elasticities were calculated. Table 3 presents the average of these elasticity scores. In some other cases, both VRS technical efficiency and scale efficiency are equal to 1 which implies that the scale elasticity is also 1.

| | | | | |
|---------------|-------|-------|-------|-----|
| Fondok Jedid | 1.000 | 1.000 | 1.000 | CRS |
| Turki | 0.760 | 0.990 | 1.048 | IRS |
| Nianou | 0.898 | 0.967 | 1.141 | IRS |
| Diar Hojjaj | 0.620 | 0.791 | 0.795 | DRS |
| Beni Aychoune | 0.674 | 0.923 | 1.174 | IRS |
| SIDI Daas | 0.553 | 0.897 | 1.402 | IRS |
| Tazarka | 0.600 | 0.958 | 1.066 | IRS |
| A.Ouerd | 0.799 | 0.923 | 1.402 | IRS |
| Sidi Jedidi | 1.000 | 1.000 | 1.000 | CRS |
| Takelsa | 1.000 | 1.000 | 1.000 | CRS |
| SIDI Daher | 0.893 | 0.606 | 0.747 | DRS |
| Ettadhamen | 0.754 | 0.992 | 0.978 | DRS |
| Ben Ayed | 0.823 | 0.666 | 0.660 | DRS |
| Houichette.K | 0.552 | 0.863 | 1.402 | IRS |
| Rouihine | 0.627 | 0.961 | 0.691 | DRS |
| Chrraf | 0.451 | 0.996 | 0.744 | DRS |
| Dar Lamine | 0.621 | 0.799 | 0.495 | DRS |
| Ghardaya | 1.000 | 1.000 | 1.000 | CRS |
| Sidi Aissa | 0.809 | 0.774 | 0.685 | DRS |
| Bir Ezzit | 1.000 | 0.939 | 0.500 | DRS |
| Dar Chichou | 0.504 | 0.706 | 0.705 | DRS |
| Taoucht | 1.000 | 0.721 | 1.402 | IRS |
| Hajjar | 1.000 | 1.000 | 1.000 | CRS |
| Average | 0.787 | 0.915 | 0.982 | - |

Results in table 3 shows that the average technical efficiency of WUA in our sample is around 78%, indicating costs of the WUA could be reduced with 22% while continuing irrigating the same area size and distributing the same total volume of water. This inefficiency value is respectively high when considering all WUA at the regional level. It can be also understood as a waste of resources that could be invested in further development of the irrigation infrastructure and water savings. The second remark that can be drawn from table 3 concerns the relatively high values of both average scale efficiency and scale elasticity in our sample. These average values indicate that WUA inefficiencies due to their scale of operation are not significant, when considering of course the regional level and the average values.

These average records are concealing the disparities between WUA of our sample. Minimum values of 0.451 and 0.606 in terms of VRS technical efficiency and SE, respectively, were recorded. Also, the elasticity of scale in our sample is ranging from 0.495 to 1.402 indicating different scale orientations. In fact, 41% of WUA in our sample reveals decreasing return to scale while 16% and 43% reveals constant and increasing return to scale, respectively (Fig 1). In this

context it is important to remind that the average productivity of a given unit is maximized when its scale elasticity is equal to 1.

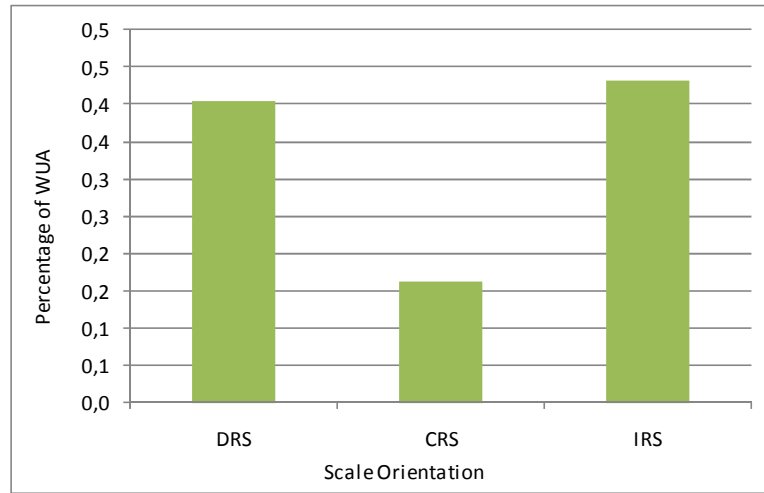


Fig 1. Scale direction of WUA in the Cap Bon region

4.2. Relationship between scale efficiency, scale elasticity and the size of operation of WUA

Existence of scale inefficiency means that a given WUA will not be able to maximize its average productivity even if it becomes fully technically efficient (on the VRS frontier). The solution for such WUA is to adjust its scale of operation. Considering the output space as an indicator of the scale of operation, Fig 2 show the scale efficiency of WUA in our sample, plotted against their total volume of water distributed and their irrigated areas. It shows that WUA are spread in the output space without any significant trend corresponding to a given functional form.

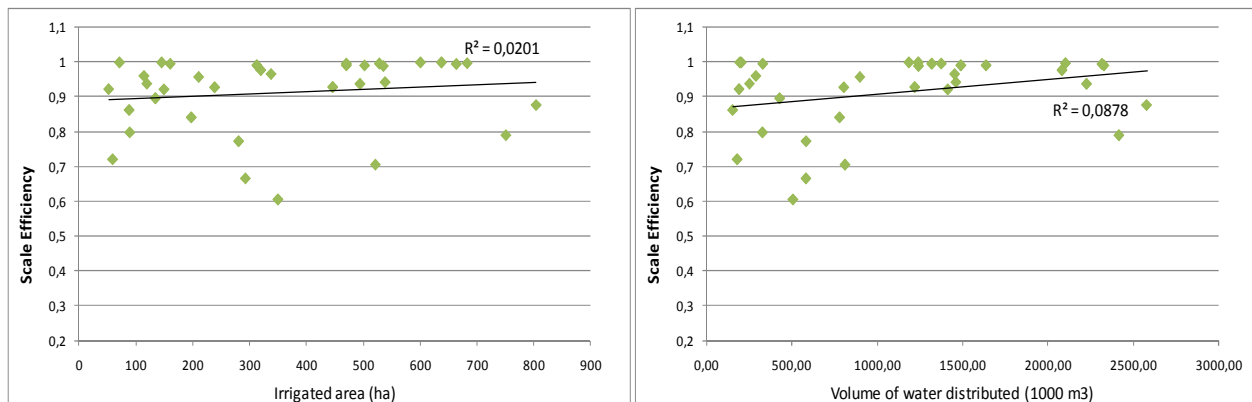


Fig 2. Scale efficiency distribution for different output levels

Scale elasticity is also directly affecting the firm's maximal profit (Forsund & Hjalmarsson, 2002) it furthermore is an important element to consider when making decisions for potential

mergers between WUAs. An elasticity parameter equal to one indicates that the scale is technically optimal, which corresponds to a scale efficiency equal to one and thus to a maximal average productivity of WUAs. In the theory of production it is frequently assumed that the scale elasticity is decreasing with scale (Ringstad, 1974). This theoretical prediction is not confirmed for the case of WUA in our sample. Fig 3 shows that there is a lot of variation in average scale elasticities along the increasing outputs curves. High (>1) and low (<1) elasticity scores are recorded for small and large-size WUA indicating that the output space, considered as indicator of the scale of operation, is not suited well to explain the differences in the scale orientations found in our model results. Nevertheless, figure 3 shows at least that the best elasticities (ranging between 0.8 and 1) were mainly (but not uniquely) recorded for WUA distributing more than 1800 thousand cubic meter and managing more than 560 ha.

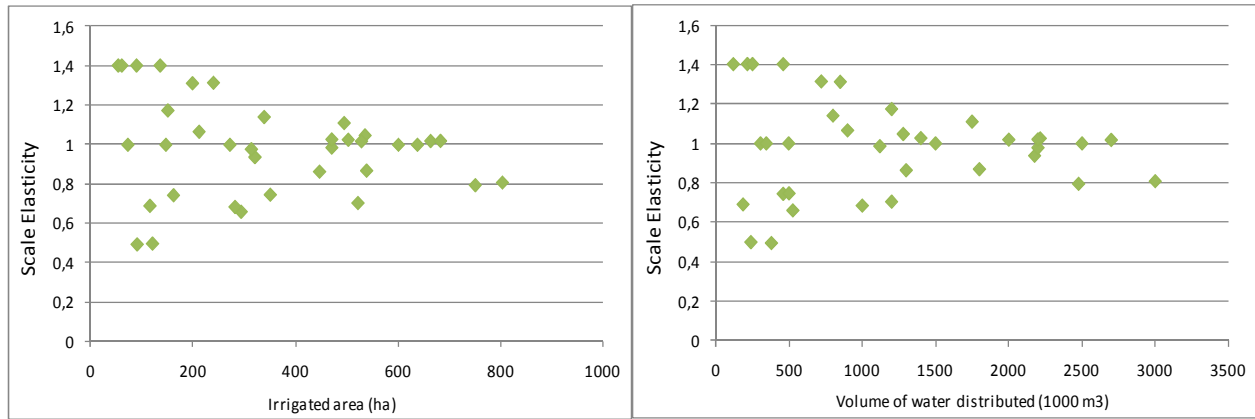


Fig 3. Elasticity of scale distribution for different output levels

4.3. Relationship between scale orientation and economies of density

In a similar study Bottasso and Conti (2009) estimate a variable cost function for 144 panel observations of English water companies and find out that even companies of relatively large dimensions could have small scale economies. In the specialized literature about water distribution companies, response to this variability can be found in the notions of “economies of density” (with respect to output (volume) and customers) (Bottasso and Conti, 2009; Erbetta and Rappuoli, 2008; Torres and Morrison, 2006; etc.). In public water provision, the consumer is a customer who has a special need to satisfy; while for the case of irrigation water providers, the consumer can be considered as 1 ha of land with specific need according to the cultivated crops and to the intensity of cultivation. The economy of density with respect to customers can in our case thus be considered as “economies of density with respect to the irrigated area”.

The economies of volume density arise when the intensity of consumed volume per customer

increase while the number of customers and networks remains unchanged (Erbetta and Rappuoli, 2008). In another word, in our case this means that the intensification level of the irrigated area increases while the irrigated area and the technical capacity of the irrigation network remains unchanged. The economies of customer density arise when volumes and number of customers increase proportionally while keeping the network unchanged. For us, this can be interpreted as a proportional increase in volumes and number of ha irrigated while the network capacity remains unchanged. Economies of scale in the long run deal with the case where volumes, customers and network increase by the same proportion. For the case of Cap Bon region, Fig 4 shows that the economies of density seem to be affecting the financial performances of the WUA. This will be statistically tested in this section.

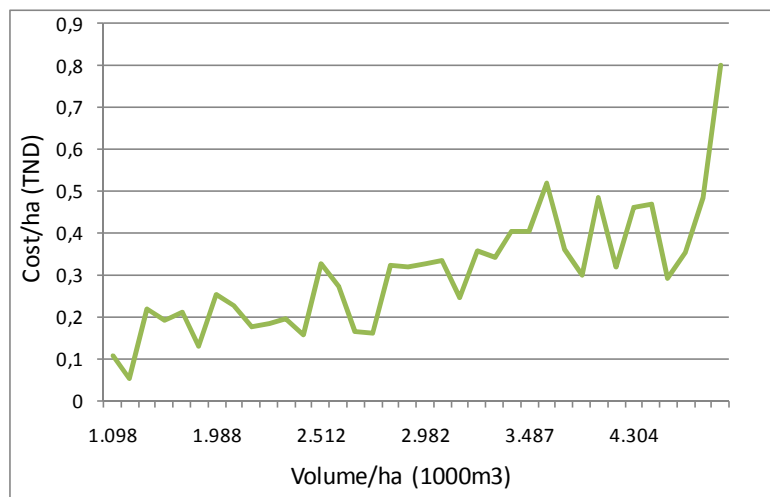


Fig 4. Cost distribution for different intensification rates

A list of indicators was selected and calculated for each scale-orientation-type WUA group (see table 4). These indicators are regrouped into three different categories as: size indicators, density indicators, and costs indicators. Table 4 summarizes the average, minimum and maximum values of these various indicators. From comparison of the latter values, it is clearly shown that the average size indicators (total volume distributed, irrigated area, number of adherents, number of water pipes managed, and length of the irrigation network) are slightly larger for the DRS WUA compared to the IRS WUA. By contrast, when comparing the density ratios calculated from our original database, it is shown that the IRS WUA clearly have more dense activities and are managing a more-intensified irrigated area. CRS WUA show the best costs performance, which is in line with the theoretical predictions suggesting that the average productivity of firms is maximal at the CRS situation. Statistical tests for the comparison of means between groups were carried out and results are presented in the table 5.

Table 4. Average size, technical indicators, and cost indicators for different scale orientations

| | DRS | | | CRS | | | IRS | | |
|---|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| | Average | Min | Max | Average | Min | Max | Average | Min | Max |
| ε | 0.76 | 0.50 | 0.99 | 1.00 | 1.00 | 1.00 | 1.18 | 1.02 | 1.40 |
| Size indicators | | | | | | | | | |
| Volume distributed (1000 m ³) | 1,083.90 | 251.33 | 2,580.68 | 1,502.03 | 194.96 | 5,888.55 | 1,221.51 | 152.53 | 2,330.99 |
| Irrigated area (ha) | 371.40 | 90.00 | 803.00 | 505.17 | 72.00 | 1,305.00 | 334.19 | 53.00 | 682.00 |
| Number of adherent | 209.13 | 44.00 | 584.00 | 215.33 | 24.00 | 803.00 | 178.06 | 26.00 | 751.00 |
| Number of water pipes | 207.80 | 25.00 | 605.00 | 113.67 | 24.00 | 271.00 | 181.56 | 24.00 | 606.00 |
| Length of network (1000 m) | 26.92 | 4.85 | 71.32 | 42.38 | 6.96 | 167.03 | 24.31 | 1.59 | 71.52 |
| Density ratios | | | | | | | | | |
| Adherent/1000m of network | 8.95 | 1.95 | 27.59 | 5.51 | 3.20 | 8.05 | 10.40 | 1.34 | 18.60 |
| Ha/borne | 2.54 | 0.67 | 5.17 | 4.74 | 2.21 | 7.21 | 2.70 | 1.06 | 5.70 |
| Adherent/borne | 1.21 | 0.73 | 2.24 | 1.65 | 0.53 | 4.44 | 1.31 | 0.49 | 2.59 |
| Volume (1000 m ³)/adherent | 6.29 | 1.26 | 20.24 | 7.02 | 2.90 | 16.71 | 8.21 | 2.04 | 18.30 |
| Volume (1000 m ³)/ha | 2,889.18 | 1,445.95 | 6,514.67 | 2,273.34 | 1,097.93 | 4,512.30 | 3,806.76 | 1,713.80 | 9,427.10 |
| Cost ratios | | | | | | | | | |
| Price charged to farmers/m ³ | 0.09 | 0.05 | 0.11 | 0.06 | 0.05 | 0.08 | 0.08 | 0.05 | 0.11 |
| Production Cost/m ³ | 0.10 | 0.06 | 0.15 | 0.07 | 0.04 | 0.10 | 0.10 | 0.06 | 0.15 |
| Cost (TND)/ha | 282.40 | 162.31 | 485.87 | 122.93 | 53.50 | 175.63 | 378.90 | 156.92 | 801.51 |
| Cost (TND)/Adherent | 585.22 | 189.37 | 1,509.50 | 475.21 | 169.24 | 1,158.99 | 801.69 | 206.29 | 2,199.90 |

Permutation based ANOVA tests using Manly's approach (2007) were carried out in order to see whether variability of the indicators between different scale orientation groups presented in table 4 is statistically significant. Here, we first calculate the F for our treatment effect, store those values, and then repeat this procedure another 9999 times by resampling the treatment in different permutation setting. This would leave us with 10000 values of F_{SM} that would reasonably occur under the null hypothesis. We then compare our obtained F against that distribution and calculate the percentage of replications under the null hypothesis where the resampled F_{SM} exceed the obtained F .

Table 5. Statistical test for differences of size indicators, density and costs ratios between scale-orientation WUA groups

| | Permutation based ANOVA test of variance | |
|--------------------------------|--|----------------|
| | <i>Critical F</i> | <i>P-Value</i> |
| Indicators | | |
| <i>Size indicators</i> | | |
| Volume distributed (1000 m3) | 0.305 | 0.601 |
| Irrigated area (ha) | 0.903 | 0.351 |
| Number of adherent | 0.134 | 0.721 |
| Number of water pipes | 0.647 | 0.425 |
| length of the network (1000 m) | 0.743 | 0.416 |
| <i>Density ratios</i> | | |
| Adherent/1000m of network | 1.901 | 0.174 |
| Ha/water pipe | 4.299 | 0.043** |
| Adherent/borne | 0.705 | 0.421 |
| Volume (1000 m3)/customer | 0.691 | 0.421 |
| Volume (1000 m3)/ha | 2.822 | 0.100* |
| <i>Cost ratios</i> | | |
| Price charged to farmers | 4.499 | 0.042** |
| Production Cost/m3 | 5.386 | 0.024*** |
| Cost (TND)/ha | 10.622 | 0.001*** |
| Cost (TND)/Adherent | 1.993 | 0.172 |

Results in table 5 confirm the hypothesis of the effect of output density on the scale economies of WUA. In fact, all size indicators were not significantly variable between the three scale-orientation groups. By contrast, density indicators and costs ratios indicate that the CRS, IRS, and DRS groups differs in terms of intensification of the irrigation (in the area managed by WUA belonging to each group) as well as in terms of their financial performances and thus their ability to charge lower irrigation prices to the farmers.

4. Conclusion

Cost recovery of irrigation water management and water saving at the national level are

important elements considered in the Tunisian national water strategy. WUA are playing an important role in the implementation of this strategy on the field. In fact, their development aims for a more implication of farmers in irrigation investments and local decision making. Much progress was made in Tunisia regarding the establishment of the participative irrigation management “*culture*” through WUA, but also many elements regarding the performances of these latter still needs to be studied and clarified. In this study, we undertake an analysis of the scale economies of WUA and its impact on their performances. Technical and scale efficiency of WUA were calculated as well as their scale qualification (scale orientation) and quantification (scale elasticity).

Results of this paper indicate that technical inefficiencies of WUA (22%) are larger than their scale inefficiencies (8.5%). This shows that policy makers have to focus more on the technical modernization of WUA since that has a bigger effects on the financial performance of WUA than the scale inefficiencies. At the national level, technical and scale inefficiencies can be considered as heavy waste of resources which may instead be invested in the local development of irrigated areas.

Results also show that the output (volume of water distributed and number of ha managed and irrigated) space in which WUA attain their high level of scale efficiency is widespread, indicating that the number of ha irrigated and the volume of water distributed are not explaining the differences in the scale efficiency of WUA. Similarly scale orientation is not linked to the size indicators of the WUA but a link was found with the density of the irrigation activity in the irrigated areas managed by the WUA. For instance, the number of ha/water pipe as well as the volume of water distributed/ha are both significantly different between different scale orientation groups (IRS, CRS, and DRS), with higher averages found for WUA operating at IRS. This suggests that the encouragement of the intensification of the irrigation in some areas managed by DRS WUA will improve their financial performances.

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