Economic efficiency measures and its determinants for irrigated wheat farms in Tunisia: a DEA approach

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Jel classification: Q12, Q18

Abstract

The objectives of this study are twofold. Firstly, we aim to measure the technical, scale and economic efficiencies for a sample of 170 cereal farmers in Chebika region (Central Tunisia) using Data Envelopment Analysis (DEA) method. Secondly, computed efficiency scores are regressed on explanatory variables using a Tobit model, in order to identify its determinants. Results of the DEA model show that average technical, allocative and economic efficiencies under constant returns to scale (CRS) are 70.7%, 85.1% and 59.7%, respectively. By operating at full economic efficiency levels, the sampled farms would be able to reduce their costs of wheat production with around 39.3%. Pure technical efficiency, scale and allocative efficiency levels account respectively for 32.3 %, 34.1% and 33.6 % of the total cost reductions. Results of the Tobit regression indicate the positive effect, on economic efficiency, of variety choices, source of irrigation, membership in water users association, irrigation management and farm size. This suggests that there is potential to improve production efficiency through developing and implementing targeted programs for inefficient farmers, intensification of specific and targeted extension services, and encouragement of farmers' membership to association.

Keywords: *economic efficiency, DEA, irrigated wheat farms, Tunisia.*

Résumé

L'objectif de cet article est double. Dans un premier temps, les scores d'efficacité technique, allocative et économique d'un échantillon de 170 exploitations céréalières de la région de Chebika (Centre de la Tunisie) ont été estimés moyennant l'approche « Data Envelopment Analysis (DEA) ». Dans un deuxième temps, les scores d'efficacité obtenus ont été régressés sur des variables explicatives par le biais d'un modèle Tobit afin d'identifier ses déterminants. Les résultats du modèle DEA indiquent que les moyennes de l'efficacité technique, allocative et économique, sous rendements d'échelle constant (CRS), sont 70.7%, 85.1% et 59.7%, respectivement. Ces résultats montrent l'existence d'un manque à gagner sous forme de réduction du coût de production des exploitations de l'ordre de 39.3% en éliminant les différentes formes d'inefficacité. Les niveaux de l'inefficacité technique pure, d'échelle et allocative représentent respectivement 32,3 %, 34,1% et 33,6 % du potentiel de réduction du coût. Les résultats empiriques du modèle Tobit montrent un effet positif du choix variétal, du nombre de sources d'irrigation, d'appartenance au Groupement de Développement agricole, de l'irrigation d'appoint et de la taille de l'exploitation sur l'efficacité économique. Ceci suggère l'existence d'un potentiel d'amélioration de l'efficacité moyennant l'intensification des services de vulgarisation, la lutte contre le morcellement et le renforcement des groupements de développement agricole.

Mots-clés: *efficacité économique, DEA, blé dur en irrigué, Tunisie.*

1. Introduction

Cereal sector in Tunisia occupies important role in agricultural production, and provides major staple food commodities for Tunisian households. Cereals are cultivated on almost one third of the agricultural areas (1.5 million hectares on average) and create 13% of the total agricultural added value. Cereal productivity in the country remains very low compared to its potential and the current average yield per hectare is below 1.3 Tons/ha (MA, 2010). This low productivity combined to strong climate variability makes importation required each year in Tunisia in order to meet the domestic demand of approximately 3 million tons (INS, 2010). This situation was aggravated by the latest increases of world food prices. Improvement of the cereal productivity in Tunisia became an obligation for policy makers who need to reduce the import bill related to this commodity. One of the main reasons for low cereals productivity, currently observed in Tunisia, is the inability of farmers to fully exploit the available technologies, resulting in lower production efficiencies.

Wheat is the major cereal crop in Tunisia in terms of its output and cultivated area. It occupies about 50% of all cereals area (800,000 Ha on average) and represents almost 55% of the total cereal production (MA, 2010). Irrigated wheat area is around 80,000ha (MA, 2011). This sub-sector faces a lot of difficulties but is also expected to achieve challenges such as food security, sustainability of the cultivated areas, limited water resources for irrigation and an arid climate characterized by frequent droughts (mainly in the center and south of the country) and heat events. Many solutions were proposed including intensification, and extension of the irrigated areas for yields improvements. However, wheat in irrigated areas is still being stabilized around 3.8 tons/ha since 1997 (INGC, 2012).

In Tunisia there is limited scope for further increase in the use of land and water resources to enlarge the cultivated wheat areas. Thus future increases in wheat production have to be originated from improvements in performances of wheat farms.

The aim of this present paper is twofold. First, we want to measure the possibilities for potential productivity gains of Tunisian cereal farms by estimating technical (TE), allocative (AE) and economic efficiencies (EE) for a sample of wheat producers in the region of Kairouan (central semi-arid

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Tunisia). The second objective is to assess the effect of several technical, economic, and demographic farmers' attributes on the estimated production efficiencies. The DEA approach has been used to measure the different production efficiencies.

The remainder of the paper is organized as follows. Section 2 describes the theoretical framework. Section 3 details the methodology used to fulfill the objectives of this work. Empirical results are presented in section 4. Finally, in section 5 concluding remarks are drawn.

2. Theoretical Framework

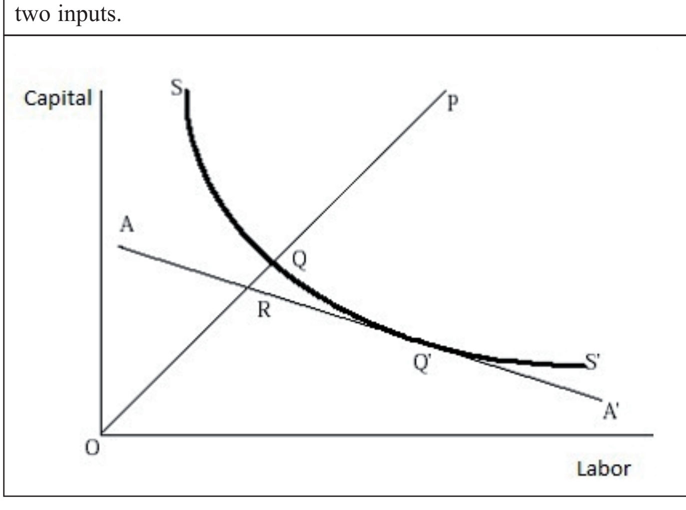
Farrell (1957) proposed that firm efficiency consists of two components: TE, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and AE, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measures are then combined to provide a measure of total economic efficiency or cost efficiency.

The measure of efficiency proposed by Farrell can be summarized as follows: consider a production function that reflects, for example, combinations of capital and labor to produce a given product, the isoquant SS' (shown in Figure 1) represents the different combinations of inputs that efficient firms can use to produce one unit of output. The point Q refers to a technically efficient firm, using two factors of production in the same ratio as the firm located at the point P.

Suppose the firm Q produces the same amount of output as the firm P using only OQ / OP fraction of inputs, the ratio OQ / OP is defined as the level of technical efficiency of the firm located in P. Thus, the ratio is "1" for a perfectly efficient firm (located on SS'), and decreases indefinitely when the amount of inputs for a given level of production becomes increasingly large.

However, to be economically efficient a firm has also to use inputs in the right proportions, given their relative prices. In Figure 1, if AA' shows a slope equal to the ratio of factor prices (isocost curve), then the optimal point of production is Q' and not Q.

Figure 1 - Representation of the measurement of efficiency: case of two inputs.



Indeed, even if TE is 100% at these two points, the production cost in Q' only represents the fraction OR / OQ from those at Q. This ratio is then defined as a measure of the AE at Q. Thus, if the firm located at point P changes the proportion of use of inputs until it is equal to that given point Q', while keeping its index of constant TE, costs will change by the factor OR / OQ. Its index of AE is given by the ratio OR / OQ. Compared to the firm located in P, the perfectly technically efficient and allocatively (one located in Q') firm shows costs that are an OR / OP fraction of those of the first firm. The ratio OR / OP, which is the product of two ratios which define the TE and AE reflects the level of EE of the firm located in P.

2. Methodology

2.1.Data Envelopment Analysis (DEA)

Parametric and non-parametric methods are the two main approaches used to measure economic efficiency. The results from both methods are highly correlated in most cases (Wadud and White, 2000; Thiam *et al*., 2001; Alene and Zeller, 2005). Parametric approaches impose a functional form that assumes the functional form of the border. While non-parametric approaches overcome the disadvantage of the parametric approach because it imposes no functional form and no distribution of inefficiency, but assume no random error (cited in Albouchi *et al*., 2007). A major advantage of non-parametric DEA is that the calculation of AE is relatively straightforward.

The DEA models have been frequently applied in agriculture due to their advantages. Charnes, Cooper and Rhodes (1978) proposed a model which had an input orientation and assumed constant returns to scale (CRS). Banker, Charnes and Cooper (1984) suggested an extension of the CRS DEA model to account for variable returns to scale (VRS) situations. The use of the CRS specification when not all farms are operating at the optimal scale will result in measures of TE which are confounded by scale efficiencies (SE).

In the present analysis, we use input oriented DEA model where the estimated efficiency scores typically indicate how much a farm should be able to reduce the use of all of its inputs as compared to the best performers.

Suppose data on K inputs and M outputs for each of N farms. For farm *i*, input and output data are represented by the column vectors x_i and y_i, respectively. The KxN input matrix X and the MxN output matrix Y represent the data for all N farms in the sample. The DEA model to calculate the technical efficiency is given by equation 1, namely: the input-oriented formulation of the BCC model can be represented as follows.

$$Min_{\theta\lambda}\theta,$$

$$\text{Subject to} \quad \begin{aligned} & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0 \end{aligned} \qquad (1)$$

With θ being a scalar, *N1* is a *Nx1* vector of ones, and λ is an *Nx1* vector of constants. This model is solved for each farm once, in order to obtain a value for θ for each farm *i*. This value ranges between zero and one. It should also be noted that equation (1) has a VRS specification which includes a convexity constraint ($N1'\lambda=1$). Without that constraint (CCR model), equation (1) represents a CRS specification which assumes that farms are operating at their optimal scale. It is interesting to compare the scores from both specifications in order to analyze the scale efficiency at which a farm operates. A measure for scale efficiency is given by dividing the technical efficiency score in CRS specification by the score in the VRS specification (SE = TE_{CRS}/TE_{VRS}). The values of SE can be either one or less than one. A farm is SE when its scale efficiency is equal to one, suggesting that the farm is operating at the most productive scale size, and any alteration of its size will lead to inefficiency. Scale inefficiency occurs for values of SE less than one, due to either increasing (IRS) or decreasing returns to scale (DRS). That is, the CRS technical efficiency measure is decomposed into pure TE and SE. In order to derive the economic efficiency of the farm, the following model is solved

$$\begin{aligned} &\min_{\lambda, xi*} w_i' x_{i*} \\ &st \\ &-y_i + Y\lambda \geq 0 \\ &x_{i*} - X\lambda \geq 0 \\ &\lambda \geq 0 \\ &N1'\lambda = 1 \end{aligned} \quad (2)$$

where w_i is a vector of input prices for the i-th farm and x_i* is the cost-minimising vector of input quantities for the i-th farm, given the input prices w_i and the output levels y_i . EE of the i-th farm is calculated as:

$$EE_i = \frac{w_i' x_i^*}{w_i' x_i}$$

That is, EE is the ratio of minimum cost to observed cost for the i-th farm. The AE is then computed as follows:

AE = EE /TE.

2.2. Tobit model

The present study uses the Tobit regression to analyse the role of farm attributes in explaining EE, TE and AE. This approach has been used widely in efficiency literature (Speelman *et al*., 2008, Naceur *et al*., 2010; Chebil *et al*., 2012). In fact, the values of the dependent variable lie in the interval (0,1). The censored Tobit model can be then used to get consistent estimation. The Tobit regression used in our study is specified as follows:

$$EE_i = \begin{cases} EE_i^* \; if \; 0 < EE^* < 1 \\ 0 \; if \; EE^* \leq 0 \\ 1 \quad if \;\; EE^* \geq 1 \end{cases} \quad (3)$$

Where *EEi* the observed dependent variable for the ith farm; *EEi** is an unobserved latent (hidden) variable for the *ith* IWUE farm that is observed for values greater than 0 and censored for values less than or equal to 1.

$$EE^* = X_i \beta + \varepsilon_i \quad (4)$$

Where *Xi* is a vector of independent variables supposed to influence efficiency. The *β's* are parameters associated with the independent variables to be estimated. The ε is the independently distributed error term assumed to be normally distributed with a mean of zero and a constant variance $N(O,\sigma^2)$. Since the dependent variable of EE varies between 0 and 1, Least Ordinary Square (LOS) would produce biased and inconsistent estimates (Maddala, 1983). Therefore, the maximum likelihood estimation is recommended for Tobit analysis.

3. Study area and data sources

3.1. Data Sources

The data used in the current study is about the production structure of 170 wheat farms located in the irrigated area of Chebika. This semi-arid region is located in Central Tunisia in the governorate of Kairouan and has an annual average rainfall of about 290 mm. The main crops cultivated in the area are: wheat, vegetables, fodder and olives. The number of farmers in the irrigated area of Chebika is around 1000. Total cereals area is about 17500 ha. The irrigated cereal area is around 4500 ha and the average regional yield of the irrigated durum wheat is 3.9 tons/ha (CRDA, 2010). Farmers were randomly selected. In order to ensure homogeneity in land and weather conditions, the farms in the sample have been chosen from the same region and are located within a 15 Km diameter. Chebika is facing growing problems of water scarcity as it belongs to a semi-arid area. Data used in the study were collected in 2011 with the collaboration of the extension service in the region, by face-to-face interviews with cereal-growing farmers.

3.2. Variables in the empirical analysis

One output (production value) and four inputs (water, seeds, chemical fertilizer and machinery), all expressed by ha of land, were used in the DEA models. Elements of descriptive statistics related to inputs use, outputs, and farm-specific variables are presented in Table 1. The output and input prices are considered the same for farmers because they are fixed by the Tunisian government. Prices in 2011 are as follows: Wheat (560 TND/tons), water (0.11 TND/m^3), seed (0.7 TND/kg), chemical fertilizer (0.45 TND/kg), Labor (12TND/day) and machinery (25 TND/hour).

4. Empirical Results

4. 1. Efficiency scores results

The estimation of efficiency scores through DEA models was conducted using the DEAP (Data Envelopment Analy-

Table 1 - *Summary statistics of the variables used in the analysis of efficiency.*

Variable		Mean	SD.	Min	Max
Output	Output value (TND/ha)	2226.26	636.46	1016.00	4370.00
Inputs	Applied water (m3/ha)	2696.24	1110.80	500.00	6000.00
	Seeds (Kg/ha)	163.17	45.18	78.57	220
	Chemical fertilizer (Kg/ha)	316.07	133.38	73.33	751.11
	Labor (TND/ha)	5.53	1.85	2.62	14.89
	Machinery(TND/ha)	15.13	4.69	6.60	52.00
Farm-specific factors	Age (years)	50.43	13.19	22.01	86.00
	Education level (1 if farmer has secondary education level, 0 otherwise)	0.27	0.44	0	1
	Experience (years)	25.78	13.05	2.00	60.00
	Farm size (total cropping area in ha)	14.01	13.34	1.20	95.00
	Water source (1 if the farmer uses two sources, 0 if he uses only one)	0.04	0.19	0	1
	WUA (1 if farmer is a member, 0 not)	0.36	0.48	0	1
	Irrigation management (1 if farmer respects the critical period, 0 not)	0.37	0.49	0	1
	Wheat variety (1 if farmer uses Maali variety, 0 otherwise)	0.35	0.48	0	1
	Pesticide (1 if farmer uses pesticide, 0 if not)	0.42	0.49	0	1

1TND≈0.70$

Table 2 - *Frequency of distribution of TE, SE, AE and EE estimates.*

TE≤50 (%)	*5.9*	*0.6*	*0.6*	*17.6*
50<TE≤80 (%)	*71.8*	*31.7*	*24.2*	*78.2*
TE>80 (%)	*23.3*	*67.7*	*74.7*	*4.1*
Mean (%)	**70.7**	**86.5**	**85.1**	**59.7**
Min (%)	**27.9**	**46.5**	**4.2**	**2.6**
Max (%)	**100**	**1**	**1**	**1**
Std. dev.	**14.9**	**13.1**	**9.6**	**12.5**
IRS (%)		71.7		
DRS(%)		18.9		
CRS(%)		9.4		

*IRS: Increasing returns to scale; DRS: decreasing returns to scale; and CRS: Constant returns to scale.

sis Program) software. Distribution of TE, SE, AE and EE of wheat farms considered in our sample are summarized in Table 2.

The analysis shows that the average TE is about 70.7% under CRS assumption. This reflects that the current level of output can be achieved using 29.3 % less inputs on average. TE varies between a minimum of about 28% and a maximum of 100%. We note that 6% of farms have TE scores less than or equal to 50%; 71.8% of them with efficiency between 50% and 80% and 23.3% of farms with TE strictly greater than 80%. These results provide information on the heterogeneity of the farm's performances and the potential for increasing wheat production in the region of Chebika.

For the SE, results show that 71.7% of farms are experiencing increasing returns to scale; while 18.9 of them have decreasing returns to scale and only 9.4% are scale efficient. Therefore, the majority of farms can increase their production efficiency through increasing their input use. This confirms the major problem of wheat sector in Tunisia which is related to the small size of farms. More than 85% of wheat farms in Tunisia have a surface lower than 20 ha (MA, 2010).

The average allocative and economic efficiencies are 85% and 59.7%, respectively. Thus substantial inefficiencies seem to be the rule characterizing Chebika's farms. We note that 17.1% of farms have EE scores that are less than 50%, besides, 78.2% have an efficiency score between 50% and 80% and only 4.1% of farms have EE strictly greater than 80%.

The results of the AE inputs of farmers are presented in Table 3. The results show that labor is being overused by the majority of farmers (94.2%). Also about 80.6% and 89.3% of farms are overusing seeds and machinery, respectively. However, farms are underusing water and fertilizers. The implications of these findings suggest that, increasing the

Table 3 - *Specific allocative efficiencies of the selected inputs.*					
	Water	Seeds	Fertilizers	Labor	Machinery
Overusing farms (%)	45.4	80.6	43.5	94.2	89.3
Underusing farms (%)	54.6	19.4	56.5	5.8	11.7

use of water and fertilizers, and decreasing the use of labor, machinery and seeds by some farms will increase the AE of farms.

4.2.Tobit model

Tobit regression explaining efficiency, as defined in equation 4 is estimated using Eview (econometric views) package version 5. The results of the Tobit model estimation by Likelihood are shown in Table 4.

Regarding the Tobit model results, the likelihood ratio test rejects a null hypothesis that all slope parameters are simultaneously null. This confirms that Tobit model is statistically significant for the three models. The majority of the estimated coefficients are significant at 5% for the EE model. Furthermore, the estimated Tobit model indicates the positive effect of size, water sources, variety choice, membership in water users association, and irrigation management on EE.

Table 4 - *Tobit estimation results of factors affecting efficiency scores.*

	TE		AE		EE	
Variables	Coefficient	Z-Statistic	Coefficient	Z-Statistic	Coefficient	Z-Statistics
AGE	-0.001	-1.282	0.001	0.542	-0.002	-1.285
EL	-0.036	-1.269	0.013	0.805	-0.039	-1.301
EXP	0.001	1.274	0.001	0.321	0.001	1.240
SIZE	0.001	1.429	0.001	0.616	0.002	2.095*
WS	0.342	4.814*	-0.049	-1.437	0.325	4.537*
GDA	0.055	2.036*	0.002	0.104	0.106	3.673*
IRR	0.024	0.832	0.054	3.182*	0.138	4.486*
VAR	-0.023	-0.825	0.095	5.599*	0.119	3.946*
PES	0.039	1.368	0.005	0.304	0.032	1.033
C	0.692	12.508*	0.763	23.39*	0.520	8.864*
LR1	44.30*		20.81*		77.64*	

* Significant at the 5% level.

5. Discussion

Many studies measuring technical efficiency of Tunisian farms can be found in the literature (Chebil and Bachta, 2002; Dhehibi *et al*., 2007; Albouchi *et al*., 2007; Frija *et al*. 2009; Naceur *et al*., 2010; Chemak, 2010; Chebil *et al*., 2012, Dhehibi *et al*., 2012; Chemak and Dhehibi, 2012; Chebil *et al*., 2013). However, only few of them were focusing on AE and EE (Albouchi, 2005; Chemak, 2010). Concerning cereal crops, many studies measuring cereal farm's TE in Tunisia show that there is a large potential to increase this efficiency indicator (Bachta and Chebil, 2002; Dhehibi *et al*., 2012; Chebil *et al*., 2013). Our study confirms further possibilities of productivity gains by improving AE and EE. Moreover, our sample farmers are, ion average, able to reduce their current cost by 40% without harming their production levels. As shown in table 5, pure technical, scale and allocative efficiency levels account respectively for 32.3 %, 34.1% and 33.6 % of the total costs reductions.

Our econometric estimation shows that variables which are significantly affecting the technical efficiency are different from those affecting the allocative efficiency. However, variables significantly affecting technical and allocative efficiency are also significantly affecting the economic efficiency.

The source of water was found to be significantly affecting the technical efficiency of wheat farmers in the study region. The estimated coefficient of this variable is positive which means that when the number of water sources (two sources, well and public water from WUA) increases the technical efficiency of farmers improves. This indicates the importance of working on enhancing water supply reliability in both public and private areas. As shown by Varghese *et al*. (2011), when farmers perceive a scarce water situation, they become less efficient in using the irrigation water.

Another factor which is positively and significantly affecting the technical efficiency of farmers is their adherence to a local WUA. This seems to be an important factor in rationalizing farmers about water use and irrigation scheduling. The GDAs (Groupements de Développement Agricole) in Tunisia still have some financial and technical difficulties which make their water allocation task less performing. A result of such low performances of GDA decreases farmers' willingness to adhere (Frija, *et al*., 2014). These important aspects have to be carefully considered by the policy makers in Tunisia who should surely provide further attention to enhancing the technical framing of these important local associations.

Finally, based on the empirical results, some suggestions and policy recommendations can be raised such as encouraging farmers' association, dissemination and supporting the use of durum wheat varieties adapted to the region, setting up training programs about irrigation scheduling, and improvement of extension services. All of these measures are needed

[1] $LR = -2(\log L_r - \log L_u)$ where LogL_u is the log-likelihood for the unrestricted model and LogL_r is the log-likelihood for the model with p parameters restrictions imposed. The likelihood ratio statistic follows a chi-square distribution with p degrees of freedom.

Table 5 - *Components of potential cost reductions.*

	Observed cost	Minimum cost	Potential cost reductions at full efficiency levels			
			Pure technical	Scale	Allocative	Total
TND/ha	997.8	595.7	130.0	137.2	134.9	402.1
% of the Total			32.3	34.1	33.6	100

in order to increase the EE of wheat producers in the region of Chebika.

6. Conclusion

During the last few years, the Tunisian wheat sector was characterized by rapid growth in the deficit between consumption and production. The need to improve efficiency of wheat at farms level is accentuated because of the high level of wheat imports and the increasing importation bill in Tunisia. Technical, scale and economic efficiencies have been estimated for a sample of 170 wheat farmers in Chebika region (Central Tunisia) using Data Envelopment Analysis method. The factors, which influence the efficiency scores in wheat production, have been also determined using a Tobit model.

The average technical, allocative and economic efficiencies under constant returns to scale (CRS) are 70.7%, 85.1% and 59.7%, respectively. Therefore, there is a large potential for the studied farms to improve their wheat production efficiency.

The result revealed that 71.7% of farms are experiencing increasing returns to scale; 18.9% decreasing returns to scale and only 9.4% are scale efficient. By operating at full economic efficiency levels, the sampled farms would be able to reduce their costs of wheat production by about 39.3%. Pure technical efficiency, scale and allocative efficiency levels account respectively for 32.3 %, 34.1% and 33.6 % of the total cost reductions.

The results of the Tobit model indicate a positive effect of variety choice, irrigation sources, membership in water users associations, irrigation management and farm size, on economic efficiency. This suggests that there is potential to improve production efficiency through developing and implementing training programs by establishing farmers' field schools and field demonstrations days about best farming and irrigation practices, intensification of extension services for a larger number of farmers, and encouragement of farmers' associations. Therefore, the policy makers in Tunisia should surely work further to enhance the technical framing of water user association and the water supply reliability. This seems to be an important factor in rationalizing farmers about water use and irrigation scheduling, and consequently increasing the efficiency of wheat farms in in the region of Chebika.

Finally, it should be noted that our analysis is based on information on farms in one region. Additional research using panel data would bring more realistic insights in the issues raised in this study.

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