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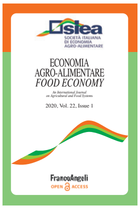

The technical efficiency of the Apulian winegrowing farms with different irrigation water supply systems

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Abstract

Apulia has a considerable demand of irrigation water, however high inefficiency levels of the collective water networks force most of the regional farms to use groundwater, with a consequent worsening of its quality, as well as of soil and crops characteristics. Therefore, the use of sustainable supply methods for irrigation water is desirable both through improvements of the collective networks and by appropriate economic tools. However, making the correct choices in these matters requires knowledge concerning the effects of the present water supply systems on the economic performance of farms.

The objective of this study is to measure and compare the technical efficiency of winegrowing farms in northern Apulia that use different supply systems for irrigation water: groundwater from private wells, irrigation water from collective networks, and irrigation water from both private wells and collective networks. The results enable to understand if and how different supply systems of irrigation water affect the management of productive factors and inputs. These findings also provide useful information for appropriate policies aimed at preserving groundwater and its externalities, as well as at improving the economic performance of Apulian farms.

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Introduction

The use of irrigation water involves both private (production factor) and public (landscape, hydraulic safety, economic supply chain, etc.) goods, therefore this resource can be considered a mixed good (Zucaro, 2014). Assessment of its economic value in the absence of suitable market mechanisms for regulating its demand and supply is a crucial element for the efficient allocation of this resource. Furthermore, its economic value allows the quantification of indicators aimed at highlighting its scarcity, granting efficient user rights, and estimating tariffs in line with the use and the contribution capacity of users (Berbel *et al.*, 2019). Directive 2000/60/EC, i.e. the framework that fixes the fundamental principles for the protection and management of surface, transitional and underground water, highlights the need for member states to implement measures ensuring good qualitative and quantitative conditions of water. Member states should adopt economic instruments aimed at recovering the costs of water services in line with the "polluter pays" principle; these costs include environmental and resource costs related to damage or negative repercussions for the aquatic environment. In particular, the EU directive highlights the need for a pricing policy to guarantee the following conditions: recognition of the correct price for all water uses and services, which takes account of their real economic cost; reduction in the demand for water and decrease in environmental impacts; more efficient allocation of water resources, with positive effects on use and pollution. In this way, it is possible to contribute to the sustainability of water use in the various sectors, and, in particular, to environmental (qualitative and quantitative protection of ecosystems), social (fair sharing and accessibility for all users), economic and financial (rationalization of the management processes to obtain an efficient, effective and economic use) sustainability.

The Apulian irrigation sector is structurally weak, and this situation is exacerbated by the region's low annual rainfall and small hydrographic network, which cause a limited availability of water for the primary sector. The region has a utilized agricultural area (UAA) of over 1.28 million hectares, equal to 10% of the Italian total, of which over 238,000 ha are irrigated (18.6%) using over 655 million cubic meters of water. Overall, Apulia is Italy's fifth most important agricultural region in terms of both irrigated surface area and irrigation volumes used (ISTAT, 2010). The Province of Foggia accounts for a third of the region's irrigated area and a third of its water demand; the crops accounting for the largest irrigated areas are vegetables (38%) and grapes (26%). Irrigation water is mainly supplied by the collective networks managed by irrigation bodies, irrigation consortia and the Regional government (on average 21%), which take water from springs and reservoirs, or else by private wells (on average 68%), which use groundwater and are managed by single or associated farmers. Within this framework, five irrigation consortia play an important role, managing more than 90% of the regional territory, although their equipped area amounts on average to just 11.5% of the managed area, while the actual irrigated area is 4.6% of the equipped area (Distretto Idrografico dell'Appennino meridionale, 2010; ANBI, 2009). Furthermore, the water supplied by these consortia is just 31% of the total water used (655 Mm^3/year) and 23% of estimated needs, i.e. 874 Mm^3/year (Nino and Vanino, 2009). Therefore, the private farm wells make it possible to overcome these shortfalls, especially where the collective irrigation networks are absent, deactivated or not fully efficient (Fabiani, 2009), meaning that private farm wells are the main source of irrigation water for the region's agricultural sector. However, their overuse can lead to the progressive salinization of groundwater, with negative consequences on soil and crops and the related problem of desertification.

It is necessary to create favourable conditions to reduce the use of groundwater and increase the use of irrigation water from collective networks, in addition to promoting irrigation practices based on water-saving and reduction of the overall demand for water. In order to achieve these objectives, the regional collective networks require interventions for their enhancement, expansion and modernization, and against unauthorized withdrawals (ANBI, 2009). Implementation of these measures requires significant changes in regional water policy, but its importance for Apulian agriculture means that these changes could generate significant effects on management of production factors, on production function and on the technical efficiency of farms. This creates a need for studies assessing the economic impacts of changes in the availability of irrigation water from different sources, considering the general situation of water scarcity or allocative decisions unable to meet current needs. Knowledge of these aspects can help decision makers to formulate adequate water supply strategies for Apulian farms, in order to minimize the negative impacts on economic performance that at present characterize the region's agriculture (Petrillo and Sardaro, 2014; Acciani and Sardaro, 2014).

The aim of the work is to measure the technical efficiency of winegrowing farms in northern Apulia that use different irrigation water supply systems. The results highlight the extent to which different sources of irrigation water influence the management of production factors and inputs. This may suggest more efficient management strategies to farmers, and may provide decision makers with useful information for the formulation of policies to preserve both groundwater and the economic performance of farms.

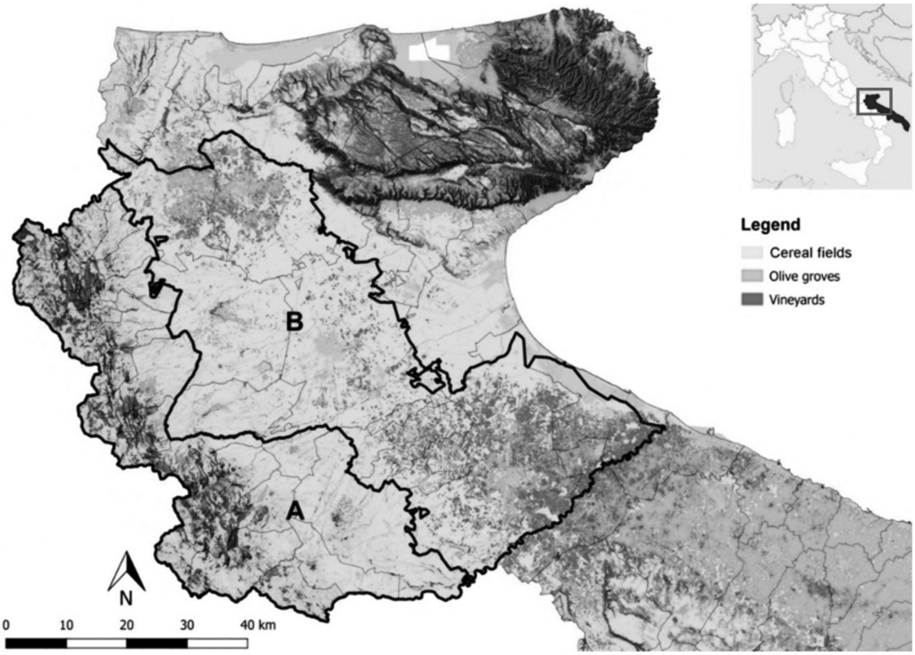
1. Materials and methods

1.1. *The study areas*

According to the classification of the 2014-2020 Rural Development Policy (based on the OECD method and reassessed through the National Strategic Plan for Rural Development), the regional municipal territories are classified into four types of area: rural areas with specialized intensive agriculture, intermediate rural areas, rural areas with overall development problems, and urban poles. This classification allows the territorialisation of rural development interventions in relation to the needs of each type of area, with their significant differences in terms of land characteristics, labour force, crops, technology and management of production factors. This study concerns rural areas with specialized intensive agriculture and rural areas with overall development problems (Figure 1), both in northern Apulia. The first area (A) includes 28 municipalities, has a UAA of 124,000 hectares, and coincides with the hilly territory of the province of Foggia, where the main crops are cereals (mainly durum wheat) (89% of the UAA), olives (4%) and grapes (3%) (Censimento nazionale sull'agricoltura, 2010). The second area (B) includes 13 municipalities, has a UAA of 211,000 hectares, and is mainly a flat territory corresponding to the Tavoliere plain in the Province of Foggia. Cereal crops account for 53% of the UAA, followed by olive groves (11%) and vineyards (14%). In general, Area A crops are managed using semi-extensive cultivation systems, i.e. based on a modest use of production factors and inputs (fertilizers, pesticides, irrigation water, etc.). On the contrary, farmers in Area B operate high-intensity production systems, i.e. based on a considerable use of factors and inputs.

The study focuses on the production of wine grapes using two different production systems, depending on the type of rural area. In particular, Area A uses the semi-extensive espalier production system, based on medium-low yields (9-16 t/hectare), local varieties, moderate use of inputs, and production of wines with the Protected Designation of Origin (PDO) or Protected Geographical Indication (PGI) marks. On the other hand, Area B mainly uses the intensive tendone production system, based on high yields (up to four/five times more compared to the semi-extensive system) obtained using more productive grape varieties, and requiring high levels of inputs; the grapes are mainly used to produce table wine.

Figure 1 - The study areas



Source: our elaboration through data from the Territorial Information System of the Apulia Region.

1.2. *The economic data*

Between October 2017 and December 2018, a survey form was used to collect economic data for the period 2014-2018 from 118 winegrowing farms in Area A and 126 in Area B. The cultivated varieties were Montepulciano, Uva di Troia, Bombino Bianco and Pampanuto for Area A, and Sangiovese, Lambrusco, Trebbiano and Garganega for Area B.

The survey form and variables for efficiency analysis were based on the economic balance, as defined by Serpieri (1929) and formalized by De Benedictis and Cosentino (1979). This approach compares the value of the final production with the related costs, so allowing the assessment of the income from the farm, the understanding of the economic mechanism generating income, and the investigation of how income is allocated among the subjects involved in the farm management (Idda *et al*., 2010).

Therefore, concerning the estimation of production function, output consists of the value of wine grapes produced, while the inputs are farm area, machinery value, number of working days, input quantities, and year

(Table 1). Based on the literature for this sector (Lawson *et al.*, 2004; Bozoğlu and Ceyhan, 2007; Sardaro *et al.*, 2018; Hansson and Öhlmér, 2008; Rahman, 2003; Tzouvelekas *et al.*, 2001; Tan *et al.*, 2010; Sardaro *et al.*, 2019) and on the specific characteristics of this study, we also considered some variables intended to explain the farm inefficiency. The input variables used for the production function are inversely related to technical inefficiency, and the age of the farmer negatively affects technical innovation, so as to be directly related to inefficiency. Access to credit increases farm's ability to spend money, encouraging technical innovations and making it possible to buy production factors and inputs, with positive effects on reducing inefficiency. The number of plots farmed indicates the level of land fragmentation and is directly related to travel and surveillance costs, and thus to inefficiency. The terrain slope has a negative influence on mechanized operations and the farm's technological level, and is thus also directly related to inefficiency. Finally, another variable is the water supply system, i.e. private farm wells, collective networks or a combination of both. Concerning this last aspect, it should be noted that the use of private wells often allows more flexible irrigation, in terms of watering frequency and volumes used. However, the use of private wells also entails various costs concerning: drilling of the well and its progressive depreciation during its technological life, which lasts an average of 25 years in the study areas; installation of electric pump; ordinary and extraordinary maintenance; use of irrigation water, which in Apulia requires paying for a five-year permit. Furthermore, and particularly in Apulia, the environmental impacts of overusing groundwater can cause wells to dry up and/or lead to the salinization of aquifers. Conversely, collective networks are less flexible because farmers must respect organized shifts for water use and also have to pay both a fixed fee for the ordinary maintenance of the network and a variable fee related to consumption. In addition, the collective networks may have problems concerning malfunctioning or leaks, illegal water withdrawals, and periods of low supply during dry years, meaning a consequent decrease in the water availability. Depending on crop and farming system, these aspects could affect farm efficiency.

The variables used in the production and efficiency functions were obtained via the survey form used during direct inspections of farms, except for the terrain slope, which was taken from the Territorial Information System of the Apulia Region (www.sit.puglia.it/). The monetary variables were inflation-adjusted.

Table 1 - Economic and efficiency variables

Variables		U.M.	Expected sign
Output			
Production	P	€/ha	
Inputs			
Farm area	L	ha	+
Machineries value	M	€/ha	+
Labour days	LD	N./ha	+
Fertilizers	Fe	kg/ha	+
Pesticides	Pe	kg/ha	+
Irrigation water	IW	m^3/ha	+
Year	Y	0-1	+/–
Determinants of the technical efficiency			
Farm area	L	ha	–
Machineries value	M	€/ha	–
Labour days	LD	N./ha	–
Fertilizers	Fe	kg/ha	–
Pesticides	Pe	kg/ha	–
Irrigation water	IW	m^3/ha	–
Farmer age	Age	Years	+
Dummy = 1: Credit access during the period 2014-2018	Credit	0-1	–
Number of plots	Plots	N.	+
Average land slope	Slope	%	+
Dummy = 1: groundwater through private well	Well	0-1	+/–
Dummy = 1: irrigation water through collective network	Network	0-1	+/–
Dummy = 1: irrigation water through well and collective network	Well/Network	0-1	+/–

Source: authors' elaborations through data from direct survey.

1.3. *The economic model*

The methodological approach concerns the production stochastic frontier (PSF) model applied to panel data (Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977; Coelli, 1996; Coelli *et al.*, 1998; Kumbhakar *et al.*, 1989), which allows estimation of the technical efficiency (TE) related to different irrigation water supply systems in the winegrowing farms of northern Apulia. In particular, TE is defined as the farm's aptitude to achieve the maximum output through specific input levels (Ali and Flinn, 1989). In this study, TE is output-oriented (Farrell, 1957), i.e. the ratio between the obtained output and the maximum possible output. In formal terms, the PSF can be expressed as:

$$P_{it} = f\left(x_{it};\beta\right) + v_{it} - u_{it} \tag{1}$$

where: P is the production obtained by the farm i in the year t (i = 1,2, …, N and t = 1,2, … T), x is the vector of production factors and inputs, and β is the J×1 vector of the production function parameters. Concerning error, it can be decomposed into two terms, i.e the symmetric v_{it}, which includes any measurement error or other factors beyond the farm control, and u_{it}, i.e. a non-negative asymmetric term relating to farm inefficiency. The first term is assumed independently and identically distributed (iid) with mean equal to zero and constant variance, so that $N(0, \sigma_v^2)$, while the second terms is also iid, but with half-normal distribution, so that $N^+(0, \sigma_u^2)$. The estimate of maximum likelihood (MLE) enables calculation of the vector of the parameters β, as well as the variance parameters, that is:

$$\begin{gathered}\sigma^2 = \sigma_v^2 + \sigma_u^2 \\ \textit{and} \\ \gamma = \sigma_u^2 / \sigma^2\end{gathered} \tag{2}$$

where γ is between zero (no technical inefficiency effect on the output variation) and one (the output variation is solely generated by the technical inefficiency) (Battese and Coelli, 1995). Hence, the level of TE for each farm can be calculated, according to Jondrow *et al.* (1982), as:

$$TE_{it} = \frac{P_{it}}{P^*} = \exp\left(-u_{it}\right) \tag{3}$$

where P^* is the output on the frontier. TE is between zero (no TE) and one (full TE) so that a value lower than one indicates that the present technological structure of the farm is inefficient, thus it is able to increase output without any variation of input. Finally, the inefficiency term u_{it} is defined as:

$$u_{it} = \delta_0 + \sum_m \delta_m z_{mit} + \omega_{it} \tag{4}$$

where z is the vector relating to the determinants of inefficiency, δ is the vector of the parameters to estimate, and ω is the unobservable random error that is assumed independently distributed with positive half-normal distribution, zero mean and variance σ^2. Noteworthy is the nonlinear relationship between $E(u_i)$ and the z variables, so that the slope coefficients are not marginal effects. Instead, these can be calculated as:

$$\frac{\partial E(u_i)}{\partial z_m} \tag{5}$$

Assuming a translog production function (Christensen *et al.*, 1973), which is more flexible than a Cobb-Douglas function about the constant elasticity of production and the unit elasticity of substitution (Wilson *et al.*, 1998), the PSF is defined as:

$$\ln P_{it} = \beta_0 + \sum_j \beta_j \ln x_{ijt} + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{ijt} \ln x_{ikt} + d_t + v_{it} - u_{it} \tag{6}$$

where, in addition to the previously defined components, d_t is the dummy variable referred to each year in which a variation of the production function could occur.

In order to integrate both the unobserved heterogeneity of farm production and the variation of inefficiency over time within the PSF model, Greene (2004, 2005) proposed the "True Random Effect" (TRE) model, which adds a stochastic iid term related to the farm i, namely w_i, so that:

$$\ln P_{it} = w_i + f\left(\ln x_{it}; \beta\right) + v_{it} - u_{it} \tag{7}$$

where the error component is defined as in the equation (1) and the parameters are estimated with the simulation of the maximum likelihood proposed by Greene (2005). The inefficiency term u_{it} is calculated so that $E\,[-u_{it} \mid w_i + \varepsilon_{it}]$, while the technical efficiency is assessed as in the equation (3).

The parameters of the production function and the inefficiency determinants were estimated simultaneously through the maximum likelihood (MLE) method according to Battese and Coelli (1993), and the analysis was carried out through FRONTIER 4.1 (Coelli 1996).

The fitting of the model was tested through the statistics γ (as previously defined), σ^2, which indicates the inefficiency of the farm output, and γ^* (Coelli *et al.*, 1998), which measures the differences between the inefficiency of the sampled farms and the inefficiency on the frontier. In addition, a number of hypotheses relating to some restrictions of the full models were verified:

i) H_0: $\beta_{ij} = 0$ (the translog function can be reduced to a Cobb-Douglas function);
ii) H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_m$ (there are no determinants of technical inefficiency, so the sampled farms are fully efficient);
iii) H_0: $\delta_1; \delta_2; \delta_3; \delta_4; \delta_5; \delta_6; \delta_7; \delta_8; \delta_9; \delta_{10}; \delta_{11}; \delta_{12}; \delta_{13}; \delta_{14}; \delta_{15}; \delta_{16} = 0$ (No effect on technical inefficiency by each determinant considered).

Checking used the Generalized likelihood-ratio test, which allowed the comparison between the implemented models and the restricted models based on the aforesaid hypotheses. The related statistic index is defined as:

$$-2\left[\ln L\left(H_0\right) - \ln L\left(H_1\right)\right] \tag{8}$$

where $L(H_0)$ and $L(H_1)$ are the likelihood values concerning the implemented model and the restricted models, respectively. The λ statistic can be approximated to a χ^2 distribution, with a number of degrees of freedom equal to the parameters affected by the restriction. Finally, the elasticity of production was calculated through the following equation:

$$\varepsilon_j = \frac{\partial \ln\left(P\right)}{\partial \ln\left(x_j\right)} = \beta_j + \sum_k \beta_{jk} \ln x_k \tag{9}$$

2. Results and discussions

2.1. *Characteristics of the sampled farms*

The descriptive statistics confirmed the differences between the two study areas relating to the outputs, the inputs and the inefficiency variables (Table 2). In particular, the farms in Area B had a higher income, mainly due to higher yields. The more intensive cultivation system required a use of inputs that was 19% to 47% higher than in Area A. Concerning the variables used to explain technical inefficiency, the vineyards in Area B were managed by younger farmers, who used more forms of credit in the period 2014-2018; these farms were smaller, more fragmented, located in flat areas and with greater access to private wells or mixed supply systems (both wells and collective networks). All differences in the considered variables between the two areas were at least 5% significant using the t-test (continuous variables) and the chi-square test (categorical variables).

Table 2 - Characteristics of the sampled farms, per study area (average values of the period 2014-2018)

Variables	Use of the variable[a]	U.M.	Winegrowing farms in area A (n = 118)				Winegrowing farms in area B (n = 126)				t-test
			Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	
P (.000 €)	O	€/ha	4.75	9.33	6.21	4.10	7.05	12.38	10.72	8.24	***
L	I/In	ha	1.18	22.82	5.39	11.63	0.88	18.54	4.71	9.06	**
M (.000 €)	I/In	€/ha	4.74	9.92	5.59	7.81	5.67	11.38	7.60	9.15	***
LD	I/In	N./ha	32.94	43.81	39.27	27.68	38.17	56.88	48.53	52.75	***
Fe	I/In	kg/ha	147.35	393.42	272.07	260.93	355.02	640.75	419.54	357.04	***
Pe	I/In	kg/ha	4.67	11.28	7.83	7.54	12.85	17.96	14.72	16.28	***
IW	I/In	m^3/ha	792.03	2,672.60	1,378.53	1,962.17	1,482.09	3,181.80	2,397.25	2,285.64	***
Y	I	0-1	0	1	0.50	0.71	0	1	0.50	0.71	–
Age	In	Years	18	64	49.33	35.21	18	62	46.95	37.04	**
Credit	In	0-1	0	1	0.28	0.14	0	1	0.47	0.39	***
Plots	In	N.	1	5	2.80	1.56	1	6	3.65	3.84	***
Slope	In	%	2.36	7.87	5.16	3.58	0	2.52	1.38	0.19	***
Well	In	0-1	0	1	0.11	0.17	0	1	0.53	0.58	***
Network	In	0-1	0	1	0.76	0.67	0	1	0.21	0.33	***
No irrigation	In	0-1	0	1	0.04	0.04	0	1	0.05	0.04	**
Well/ Network	In	0-1	0	1	0.09	0.12	0	1	0.21	0.36	***

* Sign. 10%; ** Sign. 5%; *** Sign. 1%.
[a] O = output variable of the production function; I = input variable of the production function; In = variable of the technical inefficiency.

Source: authors' elaborations through data from direct survey.

2.2. *The production frontier and technical efficiency*

The hypotheses relating to the restrictions of the models showed that (Table 3) i) the translog production function was the best functional form; ii) the use of determinants aimed at explaining technical inefficiency provided a sound analysis; iii) the determinants concerning farm inputs, farmer's age, credit access, land characteristics, and types of water supply were able to explain the technical inefficiency of the sampled farms. The only exception concerned the terrain slope of the farms in Area B, which had small values and standard deviation (Table 1), hence a scarce impact on technical inefficiency.

Table 3 - Hypotheses tests for some restriction of the PSF model

Restrictions	Area A				Area B			
	λ	**d.f.**	**$\chi^2_{0.95}$***	**Decision on H_0**	**λ**	**d.f.**	**$\chi^2_{0.95}$***	**Decision on H_0**
i) H_0: $\beta_{ij} = 0$	79.17	21	32.08	Rejected	85.02	21	32.08	Rejected
ii) H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_m$	41.05	16	25.69	Rejected	48.19	16	25.69	Rejected
iii) H_0: δ_1; δ_2; δ_3; δ_4; δ_5; δ_6; δ_7; δ_8; δ_9; δ_{10}; δ_{11}; δ_{12}; δ_{13}; δ_{14}; δ_{15}; $\delta_{16} = 0$	$11.76 < \lambda < 18.42$	1	2.71	Rejected	$13.26 < \lambda < 22.70$	1	2.71	Rejected, except for the land slope (λ=1.63)

* Critic values from Kodde and Palm (1986).

Source: authors' elaborations through data from direct survey.

Concerning the final models (Table 4), the variance parameters σ^2 and γ were significantly different from zero, indicating how technical inefficiency in Areas A and B affected output. In particular, parameter γ was close to one, suggesting that the outcome variations were mainly caused by changes in inefficiency, or, in other terms, that the differences in technical inefficiency among farms were important in explaining the output variation of the winegrowing farms in the study areas. Furthermore, γ^*, which best measures the effect of inefficiency on the total output variance, highlighted that 71% of the difference between the output of farms in Area A and the output assessed on the frontier was due to farm inefficiency. The same indicator for Area B was equal to 50%, also confirming the importance of technical inefficiency in influencing output of the intensive vineyards.

Since the output and the regressors were quantified in logarithmic form, the first-order coefficients were interpretable as elasticities of output. Thus, the results of the production frontier in both the areas confirmed that output is positively influenced by the considered factors and inputs. In particular, irrigation water generated the most decisive impact on output in both the areas, with an elasticity in Area B over double that of Area A, so that a 1% increase in the quantity of irrigation water generated an output increase of 0.78% and 1.72%, respectively in Areas A and B. These findings were due to the Mediterranean climate, the surface and underground hydrographic systems, and the characteristics of soil in Apulia, which created a higher demand for water to irrigate specific crops, such as grapes, tomatoes, etc., whose growth and harvest phases are in summer. In general, the incidence of the considered factors and inputs on output was significantly lower in Area A, where winegrowing mainly focused on grape quality. The sole exception was the labour factor, which had a greater impact due to the presence of obsolete and less varied machinery for cultivation practices. Furthermore, the quadratic forms of some factors and inputs showed that their excessive use reduced output in both areas. These factors/inputs were fertilizers, pesticides and irrigation water for Area A, and labour and pesticides for Area B. On the other hand, a significant increase in irrigation water in Area B helped to generate more output, due to the intensive cultivation system's ability to produce very high yields.

The interaction terms highlighted the importance of the relationships between factors/inputs and grape quality in Area A, and between factors/inputs and yields in Area B. In Area B there was a notably positive effect of each interaction term including irrigation water on output. The highest coefficient concerned joint use of irrigation water and fertilizers (0.37), although this interaction caused the greatest output reduction in Area A. This finding further confirms the opposing characteristics of the two cultivation systems in the investigated areas, and highlights the crucial role of irrigation water in combination with specific inputs, i.e. fertilizers, in affecting production.

Concerning inefficiency analysis (Table 4, Table 5), Area A farms achieved an efficiency of 73% with their current technology. Based on the output-oriented approach used in this study, these farms can achieve a 27% increase in output by using the current factors and inputs in a more efficient way. On the other hand, Area B farms are more efficient (86%), and can increase their output by 14% using their current technology. Specifically, technical inefficiency in Area A can be reduced by an increase in land area in order to exploit returns to scale, and by an increase in the value of machinery, both in terms of modernization and diversification of equipment. Inefficiency in Area A can also be reduced by increasing the number of working days, which is a problem in the semi-extensive area for the high age of farmers and the lack of generational turnover. In addition, the use of fertilizers, pesticides and irrigation water should be increased and improved without compromising grape quality (sugar content, total acidity, residues from fertilizers and pesticides, etc.). There is also a need for the average age of farmers (generational turnover) to come down, which would favour the implementation of innovative management strategies, while easier credit access would enable investments in innovations, such as innovative cultivation practices mainly related to mechanization to reduce the inefficiencies due to the terrain slope. Similar trends also affected Area B farms, although with some differences. These include the irrelevance of farmer age, which is on average lower compared to the area A; the importance of the number of plots, positively related to technical inefficiency since strongly connected to organizational and managerial difficulties (increased surveillance time and travel costs, need for different cultivation strategies according to the soil and climatic characteristics of each plot, etc.); the terrain slope, which was not analysed due to the restrictions imposed on the model.

The considered water supply systems generated different impacts in the two areas (Table 5). In particular, the collective network was the only system able to reduce inefficiency in Area A, while in Area B all the systems considered contributed to this result. The most efficient source was private well, followed by the simultaneous presence of well and collective network, and lastly by the network alone. However, as water use increased, the efficiency of the three water sources was similar in the two areas. In particular, the greatest efficiency was achieved with the use of well, followed by the combination of well and collective network, while the presence of collective network alone increased inefficiency in both areas. In any case, well and mixed supply system were more effective in reducing inefficiency in Area B, while the collective network increased inefficiency more in Area A.

Overall, irrigation water was the most important input for winegrowing farms in both areas (highest coefficients in the PSF model); if combined with fertilizers, it allowed a significant increase in output in Area B, but a decrease in Area A. Moreover, the supply systems of this resource strongly affected efficiency, which was greater in presence of wells in Area B, and also in Area A as the quantity of water used increased. Conversely, the collective network was the most efficient supply system in Area A only during years of sufficient rainfall, but was always the least efficient system in Area B.

Table 4 - Estimate of the PSF and TE parameters

Variables	Param.	Area A Coeff.	Area A S.E.		Area B Coeff.	Area B S.E.		Sig. z-test
PSF model								
Constant	β_0	0.379	0.113	***	0.231	0.060	***	°°
ln(L)	β_1	0.661	0.230	**	1.147	0.242	***	°°°
ln(M)	β_2	0.452	0.143	***	0.910	0.256	***	°°°
ln(LD)	β_3	0.318	0.071	***	0.481	0.145	***	°°
ln(Fe)	β_4	0.536	0.092	***	1.495	0.257	***	°°°
ln(Pe)	β_5	0.502	0.181	**	0.513	0.189	**	
ln(IW)	β_6	0.781	0.165	***	1.725	0.249	***	°°°
ln(Y)	β_7	0.439	0.152	**	0.208	0.087	**	°°°
$[\ln(L)]^2$	β_{11}	0.060	0.025	**	0.101	0.027	***	°°°
$[\ln(M)]^2$	β_{22}	0.050	0.019	**	0.073	0.019	***	°°
$[\ln(LD)]^2$	β_{33}	0.032	0.007	***	–0.048	0.013	***	°°
$[\ln(Fe)]^2$	β_{44}	–0.084	0.020	***	0.156	0.037	***	°°°
$[\ln(Pe)]^2$	β_{55}	–0.055	0.009	***	–0.079	0.021	***	°°
$[\ln(IW)]^2$	β_{66}	–0.151	0.041	***	0.291	0.080	***	°°°
$[\ln(Y)]^2$	β_{77}	0.018	0.007	**	0.006	0.001	***	°°°
ln(L) × ln(M)	β_{12}	0.063	0.052		0.185	0.052	***	°°°
ln(L) × ln(LD)	β_{13}	–0.051	0.019	**	0.026	0.025		°°°
ln(L) × ln(Fe)	β_{14}	–0.027	0.011	**	0.278	0.064	***	°°°
ln(L) × ln(Pe)	β_{15}	–0.050	0.045		0.059	0.044		
ln(L) × ln(IW)	β_{16}	–0.076	0.059		0.094	0.025	***	°°°
ln(L) × ln(Y)	β_{17}	–0.018	0.015		–0.023	0.016		°°
ln(M) × ln(LD)	β_{23}	0.062	0.025	**	–0.056	0.016	***	°
ln(M) × ln(Fe)	β_{24}	0.047	0.018	**	0.178	0.048	***	°°°
ln(M) × ln(Pe)	β_{25}	–0.039	0.032		0.065	0.039		°°°
ln(M) × ln(IW)	β_{26}	0.028	0.011	**	0.113	0.029	***	°°°
ln(M) × ln(Y)	β_{27}	0.024	0.009	**	0.059	0.020	***	°°°
ln(LD) × ln(Fe)	β_{34}	0.069	0.016	***	0.041	0.018	**	°°
ln(LD) × ln(Pe)	β_{35}	0.031	0.025		–0.022	0.013		°°
ln(LD) × ln(IW)	β_{36}	0.078	0.015	***	0.119	0.028	***	°°°
ln(LD) × ln(Y)	β_{37}	0.020	0.014		0.013	0.009		°°
ln(Fe) × ln(Pe)	β_{45}	0.044	0.017	**	0.085	0.034	**	°°°
ln(Fe) × ln(IW)	β_{46}	–0.107	0.029	***	0.369	0.090	***	°°°
ln(Fe) × ln(Y)	β_{47}	0.024	0.020		0.051	0.033		°°°

Table 4 - continued

Variables	Param.	Area A			Area B			Sig. z-test
ln(Pe) × ln(IW)	β_{56}	–0.083	0.055		0.117	0.028	***	°°
ln(Pe) × ln(Y)	β_{57}	0.015	0.010		0.034	0.021		°°°
Inefficiency model								
Constant	δ_0	0.325	0.068	***	0.142	0.035	***	°°°
L	δ_1	–0.327	–0.149	**	–0.601	0.178	***	°°°
M	δ_2	–0.268	0.107	**	–0.533	0.124	***	°°°
LD	δ_3	–0.671	0.137	***	–0.264	0.098	**	°°°
Fe	δ_4	–0.320	0.120	**	–0.716	0.185	***	°°°
Pe	δ_5	–0.055	0.023	**	–0.051	0.020	**	
IW	δ_6	–0.163	0.038	***	–0.858	0.177	***	°°°
Age	δ_7	0.022	0.009	**	0.062	0.044		°°°
Credit	δ_8	–0.039	0.012	***	–0.044	0.017	**	°
Plots	δ_9	0.083	0.068		0.057	0.013	***	°°
Slope	δ_{10}	0.095	0.022	***	–	–		–
Well	δ_{11}	0.467	0.336		–0.835	0.233	***	°°°
Network	δ_{12}	–0.771	0.173	***	–0.324	0.102	***	°°°
Well/Network	δ_{13}	0.149	0.134		–0.776	0.211	***	°°°
Well × IW	δ_{14}	–0.635	0.135	***	–1.472	0.308	***	°°°
Network × IW	δ_{15}	0.403	0.165	**	0.272	0.084	***	°°°
Well/Network × IW	δ_{16}	–0.588	0.154	***	–0.941	0.166	***	°°°
Variance parameters								
σ_u^2		0.159			0.101			
σ_v^2		0.024			0.036			
$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.183	0.044	***	0.137	0.035	***	
$\gamma = \sigma_u^2 / \sigma^2$		0.869	0.153	***	0.737	0.175	***	
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\pi/(\pi-2)\right]$		0.706			0.505			
Log-likelihood		–248.77			–295.30			
Farms		118			126			
Obs.		572			615			
Technical efficiency								
Mean		0.724			0.859			
Min.		0.431			0.654			

Table 4 - continued

Variables	**Param.**	**Area A**	**Area B**	**Sig. z-test**
Max.		0.985	0.992	
S.D.		0.284	0.315	

***: sign. 1%; **: sign. 5%; *: sign. 10%.

°°°: sign. 1%; °°: sign. 5%; °: sign. 10% from the z-test $\left(Z = b_1 - b_2 \Big/ \sqrt{SE_{b_1}^2 + SE_{b_2}^2}\right)$

Source: authors' elaborations through data from direct survey.

Table 5 - Marginal effects of the exogenous factors

Determinants of inefficiency		**Marginal effect on E(u$_i$)**			
		Area A		**Area B**	
L	δ_1	–0.232	**	–0.451	***
M	δ_2	–0.201	**	–0.378	***
LD	δ_3	–0.476	***	–0.187	**
Fe	δ_4	–0.227	**	–0.551	***
Pe	δ_5	–0.036	**	–0.038	**
IW	δ_6	–0.098	***	–0.704	***
Age	δ_7	0.016	**	0.047	
Credit	δ_8	–0.029	***	–0.031	**
Plots	δ_9	0.064		0.044	***
Slope	δ_{10}	0.072	***	–	
Well	δ_{11}	0.304		–0.710	***
Network	δ_{12}	–0.609	***	–0.224	***
Well/Network	δ_{13}	0.106		–0.629	***
Well × IW	δ_{14}	–0.495	***	–1.178	***
Network × IW	δ_{15}	0.282	**	0.182	***
Well/Network × IW	δ_{16}	–0.429	***	–0.772	***

Source: authors' elaborations through data from direct survey.

Finally, regarding the elasticities of production (Table 6), the estimates indicated that the most important inputs in Area A were labour and machinery, so that an increase in output can be obtained mostly by levering on these factors. In particular, ceteris paribus, a 1% increase in annual days of work and in machinery value generated a 0.37% and 0.28% increase in output, respectively. Therefore, Area A winegrowing was rather elastic regarding these factors, thus allowing farmers to achieve significant improvements in management performance. Irrigation water, however, was characterized by an elasticity of production of 17%, thus affecting output to the extent to which this input can contribute to maintaining grape quality. On the other hand, in Area B, land and irrigation water mainly affected economic performance so that, ceteris paribus, a 1% increase in these factors gave a 0.33% and 0.30% rise in output, respectively. The elasticity of production for irrigation water in Area B was 47% greater than for Area A, thus providing a further impact measure of this input on income in the considered areas. Finally, the returns to scale showed that farms in Area A and Area B can increase their production by an average of 26% and 17% respectively by efficient use of their available resources.

Table 6 - Elasticity and returns to scale

Inputs	**Area A**		**Area B**	
	Elasticity	**S.D.**	**Elasticity**	**S.D.**
L	0.201	0.192	0.328	0.297
M	0.283	0.214	0.171	0.174
LD	0.369	0.281	0.134	0.136
Fe	0.142	0.101	0.176	0.124
Pe	0.095	0.115	0.052	0.038
IW	0.167	0.137	0.305	0.295
Returns to scale	**1.257**	**0.936**	**1.166**	**1.200**

Source: authors' elaborations through data from direct survey.

2.3. *The irrigation system of the Capitanata Consortium*

The inefficiency results concerning the use of irrigation water by winegrowing farms in northern Apulia highlighted the weaknesses of the current water management in a wide share of the administrative area of the Capitanata Consortium. The analysis indicated the great importance of private wells, despite the serious environmental problems caused by exploitation of groundwater. Its use is almost free (except for a small fixed fee paid every five years), and allows farmers to meet rapidly the water demand of their crops in summer. On the other hand, irrigation water from the collective network is more expensive (a fixed fee for ordinary network maintenance in addition to approximately 0.40 € m^{-3} for the water use) though water demand is not always satisfied.

The inefficiency related to the irrigation water management can be enhanced through the findings of recent studies concerning the Capitanata Consortium or the region as a whole. In particular, Giannoccaro *et al.* (2019) investigated the economic impacts of reduced irrigation water availability over 16 years in the Capitanata Consortium. The results showed that in comparison with years of sufficient rainfall, dry years caused an economic loss of 30% in terms of gross product reduction and increased irrigation costs, suggesting the need for a broader drought management plan to minimize the economic impacts of irrigation water shortages. Benedetti *et al.* (2019) measured the technical efficiency of several irrigated crops and production techniques using a stochastic frontier production method, in order to develop efficient management options to reduce water consumption and waste in the Capitanata Consortium. The results highlighted that processing tomato was the most efficient crop production system, that organic farms had lower efficiency levels than conventional ones, and that a fertigation system was able to increase technical efficiency. Finally, Arborea *et al.* (2017) carried out an economic analysis of the costs and benefits of wastewater treatment and reuse by focusing on wastewater project plants in Apulia. In particular, the study focused on the use of wastewater by newly irrigated farms and already irrigated farms, which could use wastewater as an alternative to groundwater. The results showed that urban wastewater could increase regional irrigation water availability by an additional 10% of overall demand. In addition, while treatment costs depended on effluent quality and plant size, the benefits were stable. These outcomes highlighted the divergent trends between the demand and supply of irrigation water in the Capitanata Consortium, and indicated the need to provide a suitable water management plan to meet the demand for irrigation water, including the use of supplementary resources, i.e. wastewater. Indeed, the collective network of the Capitanata Consortium, included in the Southern Apennines Hydrographic District, currently has the second largest irrigation network in Italy (4,000 km) after the Padano District in northern Italy (over 11,000 km). The Consortium is subject to frequent water supply crises, which are not always caused by the extreme climatic events (drought) typical of the Mediterranean area. Water deficits are often due to the structural and technological obsolescence of the collective network, which cause the loss of significant volumes of water, and to poor network maintenance. Other factors are inadequate storage systems, poor water quality due to illegal dumping, and unauthorized withdrawals (Zucaro *et al.*, 2011). In addition, the irrigated area of the district amounts to 47% of the equipped area (against a national average of 71%) and to 4% of the administrative area, while the equipped area is 8% of the administrative area. Therefore, irrigation water from private wells, which is often uncontrolled and unauthorized, is the sole resource for ensuring constant satisfaction of the yearly water demand, although its use can cause irreversible environmental damage, such as lowering the piezometric level of the aquifer, seawater intrusion into coastal aquifers, and a general deterioration in soil quality. A further problem related to the management of water in the study areas is that many users do not actually pay for the water they consume, and this generates critical issues in planning water use. However, one positive aspect concerns the diffusion of high-efficiency irrigation systems, such as localized irrigation (48%) and sprinkler irrigation (44%), also because of environmental objectives promoted by the EU and by national policies. In this regard, water demand has increased in recent decades (also due to climate change), thus creating notable supply problems for different water uses in the civil, industrial and agricultural sectors. Thus, planning of water supply has been based on a territorial and intersectoral perspective, giving priority to civil and agricultural uses, also in compliance with environmental objectives (Zucaro *et al.*, 2011). Consequently, there has been a reduction in the irrigated UAA, and expansion of this area is now possible only if more efficient irrigation systems are planned. The problems concerning management of the collective networks in the study areas can be summarized by the relationship between annual contribution in the respective district and the related equipped area. This ratio is equal to about 105 €/hectare in the Southern Apennine District and to about 50 €/hectare in the Padano District, whose network is 2.75 times larger (Zucaro *et al.*, 2011). Although these values are not fully comparable, since the two districts have additional and different services besides the management of irrigation water, the significant discrepancy can still be used to consider the economic consequences of the structural and management inefficiencies of the collective irrigation networks in the study areas.

These aspects summarize the dynamics that compel farmers to use groundwater from private wells rather than irrigation water from collective networks. However, a correct water policy should focus on the preservation of groundwater via a partial or total ban on farmers using this resource, and should provide for interventions to make the collective networks more effective and efficient. The use of private wells ensures a higher level of farm efficiency, but this could be greatly reduced by restrictions on the use of groundwater. If this reduction is not adequately compensated by a suitable improvement in the collective networks, which this study has shown to be highly inefficient, the winegrowing sector could suffer significant damage. Obviously, similar trends could affect other crops with considerable water requirements in summer, including, peaches, nectarines, tomatoes and melons.

The setting of a water management policy able to promote a decreasing use of private wells together with enhanced efficiency of the collective networks is crucial. In addition, there is a need to promote efficient irrigation practices and systems for water saving. The advantages would benefit not only the agricultural sector, but the entire community, since irrigation provided by collective networks has multifunctional characteristics, especially in the study areas. In particular, it is based on reservoirs, i.e. infrastructures for irrigation that have also acquired environmental and recreational functions over the years, generating externalities that are more or less compensated (Sardaro *et al.*, 2018). These are related to aquifer recharge, the conservation of biodiversity and protected migratory species, the preservation of irrigation agroecosystems and the historical agricultural landscape, the creation of wetlands, the management of supply chains based on irrigated crops, and general improvements in production quality.

3. Conclusions

The study investigated important management aspects in the light of Directive 2000/60/EC, related to the formulation of policies to improve the qualitative and quantitative conditions of groundwater, to increase the efficiency of the collective irrigation networks and to strengthen the related positive externalities, and to improve the economic performances of regional winegrowing farms. Analysis of technical inefficiency enables understanding of the mechanisms by which output is obtained through the management and interaction of the production factors and inputs. Focusing on different water supply systems makes it possible to classify them in terms of technical inefficiency and to understand their impacts on farm output. Consequently, farmers can be informed and directed towards more sustainable approaches, while policy makers can be supported in formulation of suitable water management policies that also take account of their effects on farms' economic performance.

References

Acciani, C. & Sardaro, R. (2014). Percezione del rischio da campi elettromagnetici in presenza di servitù di elettrodotto: incidenza sul valore dei fondi agricoli. *Aestimum*, 64, 39-55, doi: 10.13128/Aestimum-14708.

Aigner, D.J., Lovell, C.A.K. & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6, 21-37, doi: 10.1016/0304-4076(77)90052-5.

Ali, M. & Flinn, J.C. (1989). Profit efficiency among Basmati rice producers in Pakistan Punjab. *American Journal of Agricultural Economics*, 71, 303-310, doi: 10.2307/1241587.

ANBI (2009), Relazione annuale. www.adb.basilicata.it/adb/Pstralcio/pianoacque/basilicata/Allegato%205%20-%20Uso%20irriguo%20nel%20distretto%20-%20Regione%20BASILICATA.pdf.

Arborea, S., Giannoccaro, G., de Gennaro, B.C., Iacobellis, V. & Piccinni, A.F. (2017). Cost–Benefit Analysis of Wastewater Reuse in Puglia, Southern Italy. *Water*, 9, 175, doi: 10.3390/w9030175.

Battese, G.E. & Coelli, T.J. (1993). A stochastic frontier production function incorporating a model for technical inefficiency effects. Working Paper 93/05. Department of Econometrics, University of New England, Armidale, Australia.

Battese, G.E. & Coelli, T.J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20, 325-332, doi: 10.1007/BF01205442.

Benedetti, I., Branca, G., Zucaro, R. (2019). Evaluating input use efficiency in agriculture through a stochastic frontier production: An application on a case study in Apulia (Italy). *Journal of Cleaner Production*, 236, 117609, doi: 10.1016/j.jclepro.2019.117609.

Berbel, J., Borrego, M.M., Expósito, A., Giannoccaro, G., Montilla-López, N.M. & Roseta-Palma, C. (2019). Analysis of irrigation water tariffs and taxes in Europe. *Water Policy*, 21, 806-825, doi: 10.2166/wp.2019.197.

Bozoğlu, M. & Ceyhan, V. (2007). Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey. *Agricultural Systems*, 94, 649-656, doi: 10.1016/j.agsy.2007.01.007.

Coelli, T.J. (1996). A guide to FRONTIER Version 4.1: a computer program for stochastic frontier production and cost function estimation. Working Paper. Centre for Efficiency and Productivity Analysis, University of New England, Armidale.

Coelli, T.J., Rao, D.S.P. & Battese, G.E. (1998). *An introduction to efficiency and productivity analysis*. Boston: Kluwer Academic Publishers, doi: 10.1007/978-1-4615-5493-6.

Christensen, L., Jorgensen, D. & Lau, L. (1973). Transcendental Logarithmic Production Frontier. *Review of Economics and Statistics*, 55, 28-45, doi: 10.2307/1927992.

De Benedictis, M. & Cosentino, V. (1979). *Economia dell'azienda agraria*. Bologna: il Mulino.

Distretto Idrografico dell'Appennino Meridionale (2010). Piano di Gestione Acque (Direttiva Comunitaria 2000/60/CE, D.Lvo. 152/06, L. 13/09).

Fabiani, S. (a cura di) (2009). *Aspetti economici dell'agricoltura irrigua in Puglia*. Roma: Istituto Nazionale di Economia Agraria.

Farrell, M.J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, 120, 253-281, doi: 10.2307/2343100.

Giannoccaro, G., Casieri, A., de Vito, R., Zingaro, D. & Portoghese, I. (2019). Impatti economici dell'interruzione del servizio irriguo consortile nell'area della Capitanata (Puglia). Stima empirica per il pomodoro da industria nel periodo 2001-2016. *Aestimum*, 74, 101-114, doi: 10.13128/aestim-7382.

Greene, W. (2004). Distinguishing between heterogeneity and inefficiency: stochastic frontier analysis of the World Health Organization's panel data on national health care systems. *Health Economics*, 13, 959-980, doi: 10.1002/hec.938.

Greene, W. (2005). Reconsidering heterogeneity in panel data estimators of the stochastic frontier model. *Journal of Econometrics*, 126, 269-303, doi: 10.1016/j.jeconom.2004.05.003

Hansson, H. & Öhlmér, B. (2008). The effect of operational managerial practices on economic, technical and allocative efficiency at Swedish dairy farms. *Livestock Science*, 118, 34-43, doi: 10.1016/j.livsci.2008.01.013.

Idda, L., Furesi, R. & Pulina, P. (2010). *Economia dell'allevamento ovino da latte. Produzione, trasformazione, mercato*. Milano: FrancoAngeli.

Istat (2010), 6° Censimento Generale dell'Agricoltura, http://dati-censimentoagricoltura.istat.it/Index.aspx.

Jondrow, J., Lovell, K., Materov, L. & Schmidt, P. (1982). On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics*, 19, 233-238, doi: 10.1016/0304-4076(82)90004-5.

Kumbhakar, S.C., Biswas, B. & Bailey, D.V. (1989). A study of economic efficiency of Utah dairy farmers: a systems approach. *Review of Economics and Statistics*, 71, 595-604, doi: 10.2307/1928101.

Lawson, G.L., Agger, J.F., Lund, M. & Coelli, T. (2004). Lameness, metabolic and digestive disorders, and technical efficiency in Danish dairy herds: a stochastic frontier production function approach. *Livestock Production Science*, 91, 157-172, doi: 10.1016/j.livprodsci.2004.07.016.

Meeusen, W. & van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*, 18, 435-444, doi: 10.2307/2525757.

Nino, P. & Vanino, S. (a cura di) (2009). *Uso del suolo e stima dei fabbisogni irrigui nelle aree non servite da reti collettive dei consorzi di bonifica nelle regioni meridionali*. Roma: Istituto Nazionale di Economia Agraria.

Rahman, S. (2003). Profit efficiency among Bangladeshi rice farmers. *Food Policy*, 28, 487-503, doi: 10.1016/j.foodpol.2003.10.001.

Petrillo, F. & Sardaro, R. (2014). Urbanizzazione in chiave neoliberale e progetti di sviluppo a grande scala. *Scienze Regionali*, 13, 125-134, doi: 10.3280/SCRE2014-002010.

Sardaro, R., Bozzo, F. & Fucilli, V. (2018). High-voltage overhead transmission lines and farmland value: evidences from the real estate market in Apulia, southern Italy. *Energy Policy*, 119, 449-457, doi: 10.1016/j.enpol.2018.05.005.

Sardaro, R., Grittani, R., Scrascia, M., Pazzani, C., Russo, V., Garganese, F., Porfido, C., Diana, L. & Porcelli, F. (2018). The Red Palm Weevil in the City of Bari: A First Damage Assessment. *Forests*, 9, 452, doi: 10.3390/f9080452.

Sardaro, R., Faccilongo, N. & Roselli, L. (2019). Wind farms, farmland occupation and compensation: Evidences from landowners' preferences through a stated choice survey in Italy. *Energy Policy*, 133, 110885, doi: 10.1016/j.enpol.2019.110885.

Serpieri, A. (1929). *Guida a ricerche di Economia Agraria*. Ristampa del 1960. Bologna: Edagricole.

Tan, S., Heerink, N., Kuyvenhoven, A. & Qu F. (2010). Impact of land fragmentation on rice producers' technical efficiency in South-East China. *NJAS-Wageningen Journal of Life Sciences*, 57, 117-123, doi: 10.1016/j.njas.2010.02.001.
Tzouvelekas, V., Pantzios, C.J. & Fotopoulos C. (2001). Technical efficiency of alternative farming systems: the case of Greek organic and conventional olive-growing farms. *Food Policy*, 26, 549-569, doi: 10.1016/S0306-9192(01)00007-0.
Wilson, P., Hadley, D., Ramsden, S. & Kaltsas, L. (1998). Measuring and explaining technical efficiency in UK potato production. *Journal of Agricultural Economics*, 48, 294-305, doi: 10.1111/j.1477-9552.1998.tb01273.x.
Zucaro, R., Pontrandolfi, A., Dodaro, G.M., Gallinoni, C., Pacicco, C.L. & Vollaro, M. (2011). *Atlante nazionale dell'irrigazione*. INEA.
Zucaro, R. (a cura di) 2014. *Condizionalità ex-ante per le risorse idriche: opportunità e vincoli per il mondo agricolo*. Rapporto INEA.

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