Efficiency concept under stochastic consideration of water value in irrigated agricultural land in Crete, Greece

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ABSTRACT

Water is an increasingly scarce and valuable resource. It is generally accepted that there is a finite supply of water. As economies grow there is an increasing demand for water. The application of water to agricultural lands for irrigation is one of the essential uses of this natural resource in many areas. There is competition among agriculture, industry, and human consumption for the limited supplies of water. Efficiency studies are necessary, especially in areas where there is a shortage of factors of production such as water. Panel data for viticulture products, citrus products and olive oil for the time period 2002–2012, in the area of Iraklio, Crete, were used for the estimation of production models. The results indicate that the production process for the three crops cannot be represented by a single production function having a single set of coefficients. Different methods yield different efficiency measures. The stochastic frontier yields higher efficiency measures. Farmers are less efficient in the use of irrigation water than in the use of water and fertilizer together. The value of water is found to be equal to 0.73 euros/m^3.

Key words | efficiency concept, irrigation water, production functions, stochastic modeling

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INTRODUCTION

The Iraklio prefecture economy is basically dependent on agricultural practice. Therefore, water has immense significance in the economic cycle. Recently, the common crops of the prefecture like olives and grapes have been taken into consideration in all irrigation plans designed in Iraklio (Dedian *et al.* 2000; Tsagarakis *et al.* 2004). Commonly, to increase the production of crops, adequate irrigation and tolerable fertilization are among the limiting factors that need to be considered, especially for traditional products like wine production using American rootstock planting techniques (Angelakis *et al.* 2005; Karagiannis & Soldatos 2007).

Irrigation schemes play an important role in crop production. Thus, low rainfall periods in spring and prolonged drought periods in summer besides the heavy irrigational practice adopted recently have led to an intensification of the water shortage problem (Lazarova *et al.* 2001; Iglesias *et al.* 2007). Moreover, such circumstances put the underground water under pressure to satisfy irrigational purposes (Maliarakis 1991). Based on the latter scholarly work, the prefecture is in danger of groundwater overexploitation due to illegal wells and unlicensed drilling.

According to another point of view made by Monopolis (1993) there is not a lack of water but rather a lack of good management of water. Most of the underground water ends up in the sea without being used because of lack of good management by the responsible agency in the prefecture. To support this view, Monopolis (1993) estimated that the renewable underground reserves of water for the whole island of Crete are approximately 3 billion m^3 per year, while the annual total consumption cannot be more than 450 million m^3. Therefore, about 15% of the underground water that flows in the island every year is consumed.

According to Førsund *et al.* (1980), a production frontier sets a range of all possible observations and gives the maximal product that can be attained from a group of input quantities. All possible points lie below the frontier and

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none can be above it. It is the locus of maximum possible outputs for each level of input use (Kumbhakar 1994).

Aigner & Chu (1968) in their definition of production frontier explain that it sets the limit on the highest possible output that a firm can realize under a certain combination of factors at a given state of technical knowledge during the production period. Production frontiers can be either deterministic or stochastic.

Principally, Farrell (1957) assumed constant returns to scale and constructed a unit isoquant as a frontier. This isoquant is estimated from a subset of observations from the sample. The rest of the observations lie above the isoquant. Aigner & Chu (1968) proposed a homogeneous Cobb–Douglas production frontier. Afriat (1972) proposed this model first and suggested that it be estimated by the maximum likelihood (ML) method. He also proposed a two-parameter beta distribution.

Schmidt (1976) showed that the estimates of Aigner and Chu are ML estimates under certain assumptions for the distribution of the disturbance term. The main disadvantage of a deterministic frontier is that it ignores the possibility that a firm's performance may be affected by factors such as bad weather which are entirely outside its control, as well as by factors like inefficiency which are under its control.

The production frontier models have one-sided error terms that are used as a measure of technical efficiency because they show production below the frontier (Førsund *et al.* 1980). To estimate efficiency many methods have been developed, including economic–engineering analysis, average factor productivity, efficiency indices and parametric and non-parametric frontier functions (Bravo-Ureta 1986; Antonelli & Ruini 2015).

The aim of the current research is to envisage the efficient use and proper management of the water in the prefecture taking into consideration the production functions under the concept of efficiency.

METHODOLOGICAL FRAMEWORK

Study area

Iraklio prefecture is the largest prefecture of the island of Crete. It is located at 35° 18′ 0″ N, 25° 13′ 0″ E, with a total area close to 2,700 km^2 (Figure 1). The prefecture is characterized by a mountainous region with two major plains: Iraklio and Messara plains. The main mountains are called the Yuhtas (height 837 m), the Afentis (1,592 m) and the Kofinas (1,250 m). The main rivers are the Yofiros and the Geropotamos. The climate is the typical climate of the Mediterranean islands. The annual average rainfall during the period from 1909 to 1987 was recorded to be around 500 mm. Furthermore, the major precipitation takes place during the winter season (250 mm), followed by autumn precipitation (140 mm), spring precipitation close to 100 mm, then finally an almost dry summer with precipitation recorded around 5 mm (Maheras & Koliva-Mahera 1989). Two moist periods were observed from the archive precipitation date; a long moist period of 16 years started in 1917 and another shorter moist period started in 1961 and lasted for 8 years. One long drought period of 23 years starting in 1938 was also observed. Monthly values of air temperature and precipitation were used in a study to calculate monthly, seasonal and annual values of potential evapotranspiration, actual evapotranspiration, and water surplus and water deficit for Iraklio. The annual values of deficit show a tendency to decrease from 1951 to 1987. After that period, they begin to increase and that continues until the end of the examined period. The water deficit reached its minimum value (143.3 mm) in the year 1987 and its maximum (744.8 mm) in the year 1956. For surplus, it was noticed that during the decade of the 1960s it showed quite high values. In the years 1963, 1990 and 1994 the surplus had zero values. It increased slowly from the year 1991 until 2002 and then it started to decrease (Elhag & Bahrawi 2016).

Description of data

The main source of information is the Rural Agronomic Development Administration of Crete and the Hellenic Ministry for Agriculture (2002). Panel data for viticulture products, citrus products, and olive oil for the time period 2002–2012, in the area of Iraklio, were used for the estimation of the model.

Viticulture products consist of sultana viticulture production for dry raisins, for consumption and for wine making, desert viticulture production for consumption and for wine making, wine viticulture production for wine making and for consumption, and the vine leaves. Citrus production consists of oranges, mandarins, sour oranges, grapefruits, and citrons.

Figure 1 | Location of the designated study area.

Fertilizers and water are the two inputs that are used as independent variables in the model. The recommended quantities of fertilizer are 24.5 kg/acre for viticulture products, 13.5 kg/acre for olive oil and 15 kg/acre for citrus products (1 acre = 4,046.86 m^2).

The water input was approximated in a similar way by considering the percentages of cultivated area per crop that are irrigated each year, and the recommended quantities of water per acre. The recommended quantities of water are 100 m^3/acre for viticulture products, 100 m^3/acre for olive oil and 125 m^3/acre for citrus products.

The production quantities and the fertilizer of the three crops for each year are measured in euros. Water is measured in m^3. All values, in money terms, are deflated using 2002 as the base year.

Stochastic frontier

The stochastic frontier uses a mixture of one-sided and two-sided errors. The maximal output that is produced, given some inputs, is random and not exact and that is due to the unbounded effects of some of the inputs (e.g. weather). This type of frontier expresses maximal output, given some inputs, as a normal distribution and not as a point. The sub-optimal values of certain inputs cause the one-sided error (Førsund *et al.* 1980). According to Aigner *et al.* (1977) a stochastic production frontier is written as:

$$y_i = f(x_i, \beta) + \varepsilon_i \quad (1)$$

where $\varepsilon_i = v_i + u_i$, and $i = 1 - N$, and where

y_i = maximum output produced
x_i = vector of inputs
β = vector of unknown parameters to be estimated, and
ε = error term and $\varepsilon - N(0, \sigma_v^2)$.

The error term is composed of two parts: v_i is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and u_i is assumed to be distributed independently of v_i. The condition $u \leq 0$ must be satisfied to ensure that each dataset output will lie on or below its frontier $[f(x_i, \beta) + v_i]$. Such deviations mean that all results are under the control boundaries of each dataset. The term v_i is a random disturbance, which can be equal, greater than or less than zero, and it is the result of factors and errors of measurement on y.

Efficiency concept

The study of frontiers is necessary for the estimation of efficiency. Førsund *et al.* (1980) state that inefficiency is the amount by which a target dataset lies below its production and profit frontier and the amount by which it lies above its cost frontier. It can be separated into technical, allocative and economic efficiency (Aldaya *et al.* 2010).

Consider a stochastic production frontier as in Equation (1): v_i permits random variation in output due to factors outside the control of the designated dataset (Dawson 1990) and u_i reflects the technical efficiency. Aigner *et al.* (1977) and Meeusen & van den Broeck (1977) assume that v is normal, that is $v - \mathrm{N}(0, \sigma_v^2)$ and u is half normal, that is u distributes as the absolute value of a normal distribution $|\mathrm{N}(0, \sigma_v^2)|$, and

$$f(v) = \frac{1}{\sigma_v (2\pi)^{1/2}} \exp\left(\frac{v^2}{2\sigma_v^2}\right) \tag{2}$$

$$f(u) = \frac{1}{\sigma_u (2\pi)^{1/2}} \exp\left(\frac{u^2}{2\sigma_u^2}\right), \quad u \geq 0 \tag{3}$$

The derivation of the density function of ε according to Aigner *et al.* (1977) is:

$$f(\varepsilon) = \frac{2}{\sigma} f^*\left(\frac{\varepsilon}{\sigma}\right)[1 - F^*(\varepsilon\lambda\sigma^{-1})], \quad -\infty \leq \varepsilon \leq +\infty \tag{4}$$

where the variance of $\varepsilon(\sigma)^2$ is equal to $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \sigma_u/\sigma_v$, $f^*(.)$ is the standard normal density function, and λ is an indicator of the relative variability of the two sources of random error that distinguish firms from one another. The function $f(\varepsilon)$ is asymmetric around zero, with its mean and variance presented by:

$$E(\varepsilon) = E(u) = -\frac{\sqrt{2}}{\sqrt{\pi}} \sigma_u$$

$$V(\varepsilon) = V(u) + V(v) = \left(\frac{\pi - 2}{\pi}\right)\sigma_u^2 + \sigma_v^2 \tag{5}$$

The estimation problem is posed if the random sample of N observations is available and then forming the relevant log-likelihood function:

$$\ln L(y|\beta, \lambda, \sigma^2) = N \ln\frac{\sqrt{2}}{\sqrt{\pi}} + N \ln \sigma^{-1} + \sum_{i=1}^{N} \ln[1 - F^*(\varepsilon_i \lambda \sigma^{-1})] - \frac{1}{2\sigma^2} \sum_{i=1}^{N} \varepsilon_i^2 \tag{6}$$

This form of likelihood function was also considered by Amemiya (1973). By taking the partial derivatives of the logarithm of the likelihood function, equating them to zero, and solving them, we obtain the ML estimates for $\beta, \lambda,$ and σ^2. The partial derivatives are:

$$\frac{\partial \ln L}{\partial \sigma^2} = -\frac{N}{2\sigma^2} + \frac{1}{2\sigma^4} \sum_{i=1}^{N} (y_i - \beta' x_i)^2 + \frac{\lambda}{2\sigma^3} \sum_{i=1}^{N} \frac{f_i^*}{(1 - F^*)} (y_i - \beta' x_i) = 0 \tag{7}$$

$$\frac{\partial \ln L}{\partial \lambda} = \frac{1}{\sigma} \sum_{i=1}^{N} \frac{f_i^*}{(1 - F^*)} (y_i - \beta' x_i) = 0 \tag{8}$$

$$\frac{\partial \ln L}{\partial \beta} = \frac{1}{\sigma^2} \sum_{i=1}^{N} (y_i - \beta' x_i) x_i + \frac{\lambda}{\sigma} \sum_{i=1}^{N} \frac{f_i^*}{(1 - F^*)} x_i = 0 \tag{9}$$

Combining the first two equations we get the ML estimator for σ^2, as follows:

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (y_i - \beta' x_i)^2 \tag{10}$$

By pre-multiplying $(-\lambda)$ into Equation (8) and adding to this Equation (9) pre-multiplied by β' and simplifying it as follows:

$$\frac{1}{\sigma^2} \sum_{i=1}^{N} (y_i - \beta' x_i) \beta' x_i + \frac{\lambda}{\sigma} \sum_{i=1}^{N} \frac{f_i^*}{(1 - F^*)} y_i = 0 \tag{11}$$

in conjunction with (9) gives a system of $(k+1)$ equations, where k is the number of inputs.

Aigner *et al.* (1977) claim all the usual ML properties for the values β, λ and σ^2 which simultaneously equate (7), (8) and (9) to zero, since this density function is continuous in the range of ε.

The technical efficiency relative to the stochastic production frontier is captured by the one-sided error component u_i, ≥ 0 (Huang & Bagi 1984). The population average technical efficiency is:

$$E(e^{-u_i}) = 2e^{\sigma_u^2/2}(1 - F^*(\sigma_u)) \tag{12}$$

where F^* is the standard normal distribution function. The estimated stochastic frontier and the variances σ_u^2 and σ_v^2 can be used to measure population average technical efficiency. The measurement of the individual technical efficiency e^{-u_i} requires the estimation of the non-negative error u_i.

Jondrow *et al.* (1982) have shown that individual firm measures of technical efficiency can be calculated from:

$$E[u_i|\varepsilon_i] = \frac{\sigma_u \sigma_v}{\sigma}\left[\frac{f^*(\varepsilon_i\lambda/\sigma)}{1 - F^*(\varepsilon_i\lambda/\sigma)} - \frac{\varepsilon_i\lambda}{\sigma}\right] \tag{13}$$

where $i = 1 \ldots n$ number of firms and $f^*(.)$ and $F^*(.)$ are respectively the values of the standard normal density function and the standard normal distribution function evaluated at $(\varepsilon_i\lambda/\sigma)$. The standard normal density and distribution functions (Chow 1983) are respectively:

$$f^*(x) = \frac{1}{(2\pi)^{1/2}} e^{-x^2/2} \tag{14}$$

$$F^*(x) = \int_{-\infty}^{x} \frac{1}{(2\pi)^{1/2}} e^{-x^2/2} ds \tag{15}$$

The estimates of ε, λ and σ are used to evaluate $f^*(.)$ and $F^*(.)$ at $(\varepsilon_i\lambda/\sigma)$ by substituting x in Equations (14) and (15):

$$f^*\left(\frac{\varepsilon_i\lambda}{\sigma}\right) = \frac{1}{(2\pi)^{1/2}} e^{-(\varepsilon_i\lambda/\sigma)^2/2} \tag{16}$$

$$F^*(\varepsilon_i\lambda/\sigma) = \int_{-\infty}^{(\varepsilon_i\lambda/\sigma)} \frac{1}{(2\pi)^{1/2}} e^{-(\varepsilon_i\lambda/\sigma)^2/2} ds \tag{17}$$

Finally, measures of technical efficiency can then be calculated according to Dawson (1990) as follows:

$$TE = \exp(-E[u_i|\varepsilon_i]), \; 0 \leq TE \leq 1 \tag{18}$$

Battese & Corra (1977) define $\gamma = \sigma_u^2/\sigma^2$, $0 \leq \gamma \leq 1$. This represents the total variation in output from the frontier attributed to technical efficiency.

RESULTS AND DISCUSSION

Crop-fertilizers/water production model

The stochastic frontier was estimated using the results of the fixed effects model and an average intercept for the three crops. It was found that $\gamma = 0.94$. This implies that 94% of the discrepancy between the observed values of the output and the frontier output is due to technical inefficiency. The term u_i dominates v_i and the shortfall of the realized output from the frontier is due primarily to factors that are within the control of the farmer (Chenoweth *et al.* 2014). The ratio of the two standard errors is defined as $\lambda = 4.006$. The frontier was estimated by applying the ML method (Kumbhakar 1994). The maximized value of the logarithm of the likelihood function is −21.82. Meanwhile, the constant term has decreased also. Fertilizer is a more important factor than water (Elhag & Bahrawi 2016). The estimates are given in Table 1.

The results of the estimated stochastic production frontier were used to calculate the technical efficiency of the Iraklio prefecture farmers in the production of viticulture products, olive oil and citrus products during the period 2002–2012. The estimates are presented in Table 2 and Figure 2.

The technical efficiency for each crop each year is calculated by estimating the conditional expectation of the error term u_i given ε_i from Equation (18). The level of technical efficiency in Iraklio appears to be high for the three crops. On

Table 1 | Estimates of the crop-fertilizers/water stochastic frontier

Constant α	Fertilizer α_1	Water α_2	σ_u^2	σ_v^2	Log-likelihood
5.699	0.894	0.103	0.621	0.308	−21.82
(3.338)	(2.633)	(1.137)			

Table 2 | Year-specific technical efficiency indices for the three crops (stochastic frontier analysis, two outputs)

Year	Viticulture products (%)	Olive oil (%)	Citrus products (%)
2002	60.77	91.94	74.78
2003	88.02	51.33	87.38
2004	88.71	93.92	75.54
2005	86.87	38.65	70.70
2006	87.47	89.42	89.35
2007	92.21	93.48	88.88
2008	79.63	90.88	86.96
2009	86.98	91.08	90.87
2010	89.74	91.32	89.96
2011	91.61	75.18	89.96
2012	67.63	79.30	87.35
Average	83.60	80.59	84.37
Minimum	60.77	38.65	70.70
Maximum	92.21	93.48	90.87

average, the producers of viticulture products realized about 83.6% of their technical efficiency and the producers of olive oil 80.59% of their technical efficiency during the period 2002–2012. The producers of citrus products realized about 84.37% of their technical efficiency during the same period.

The stochastic model provided crop efficiency estimates with low variability. Efficiency ranges from 60.77% to 92.21% for farmers of viticulture products, and from 70.70% to 90.87% for farmers producing citrus. Only in the case of olive oil is there still a wide variation during the period 2002–2006, which in comparison to the corresponding variation in the deterministic frontier can be considered low (Zeng *et al.* 2014). During the period 2006–2012, the technical efficiency of the farmers tends to be stable over time, as is shown in Figure 2. No farms are perfectly efficient (100%). This is because in the stochastic frontier a portion of the total error is attributable to random behavior (Huang *et al.* 2012; Elhag 2016). The farmers of viticulture products achieved their maximum technical efficiency in 2007, the farmers of olive oil in 2004 and the farmers of citrus products in 2009 as demonstrated in Table 2.

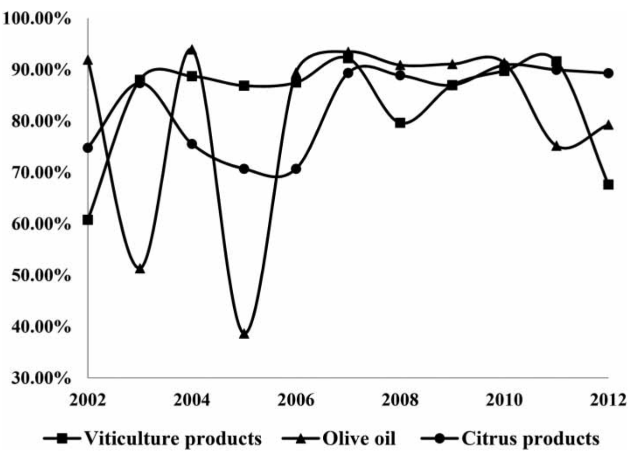

Figure 2 | Year-specific technical efficiency indices for the three crops using the stochastic method with two inputs.

Crop–water production model

The results of the crop–water stochastic production frontier are shown in Table 3. Both the constant term and the water coefficient are highly significant. These estimates were used to measure crop technical efficiency of the use of irrigation water.

The value $\gamma = 0.97$ means that 97% of the discrepancy between the observed values of output and the frontier output is due to technical inefficiency (Huang & Bagi 1984). The ratio of the two standard errors is $\lambda = 6.174$. The maximized value of the logarithm of the likelihood function is -27.1667. The year-specific technical efficiency indices for the three crops are presented in Table 4 and in Figure 3.

There is a variation in the level of technical efficiency of the use of irrigation water. Efficiency ranges from 61.16% to 90.54% for viticulture products, from 35.35% to 95.17% for olive oil and from 52.94% to 96.24% for citrus products but this variation is lower than the variation that appears in the deterministic production frontier. The average technical efficiencies of the use of irrigation water, which are 82.07% for viticulture products, 77.15% for olive oil and 81.03% for citrus products, indicate that farmers of olive oil have the lowest average technical efficiency. It is obvious that in the

Table 3 | Estimates of the crop–water stochastic frontier

Constant α	Water α_2	σ_u^2	σ_v^2	Log-likelihood
9.846	2.021	0.98	0.025	−27.166
(13.826)	(11.375)			

Table 4 | Year-specific technical efficiency indices for the three crops (SFA, one output)

Year	Viticulture products (%)	Olive oil (%)	Citrus products (%)
2002	68.37	94.48	66.72
2003	80.49	35.35	65.73
2004	82.73	92.04	52.94
2005	90.54	40.63	78.01
2006	87.56	87.19	86.67
2007	89.91	93.45	90.61
2008	89.43	95.17	94.95
2009	86.01	82.91	92.12
2010	77.15	94.02	96.24
2011	89.42	64.77	96.25
2012	61.16	68.68	91.65
Average	82.07	77.15	81.03
Minimum	61.16	35.35	52.94
Maximum	90.54	95.17	96.24

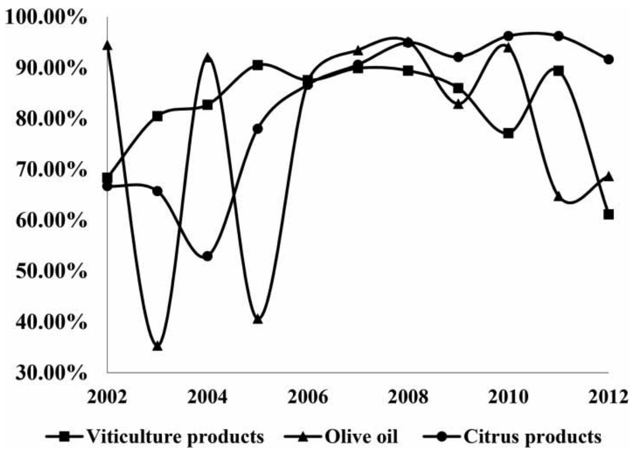

Figure 3 | Year-specific technical efficiency indices for the three crops using the stochastic method with one input.

case of the crop–water production frontier, the comparison of the results does not help to decide which crop farmers have the highest technical efficiency in the use of irrigation water (Bekri & Yannopoulos 2012). Each method indicates a different crop.

Different methods yield different efficiency estimates which prove that the efficiency of the irrigation water use is lower than the efficiency of the use of both water and fertilizer inputs together (Podimata & Yannopoulos 2013; Bekri *et al.* 2015).

CONCLUSIONS

The estimates indicate that viticulture, olive oil and citrus crops cannot be modeled with a single production function. Each crop has its specific production function characterized by common slope coefficients for all three crops and an intercept that varies over crops. Technical efficiency varies from one crop to another. In the case of two inputs, farmers are most efficient in the production of citrus products and least efficient in the production of olive oil. The farmers of viticulture products achieved their maximum technical efficiency in 2007, the farmers of olive oil in 2004 and the farmers of citrus in 2009. Using stochastic frontiers, it was found that farmers are more efficient in the use of all inputs than in the use of irrigation water. Using the stochastic frontiers, the average technical efficiency of all input use ranges from 80.59% for olive oil to 84.37% for citrus products and the average technical efficiency of water irrigation use ranges from 77.15% for olive oil to 82.07% for viticulture products. Therefore, the efficiency of irrigation water has to be increased by better irrigation management and using the stochastic frontiers it was found that on the average farmers are highly technically efficient in the production of these three crops. The marginal product value of water is equal to 0.73 euros/m^3. It is higher than the price that the responsible agency of the prefecture charges the farmers for each m^3 they use (approximately 0.16 euros/m^3, 2012 price). This indicates that water has a high value.

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