Direct Subsidies and Technical Efficiency in Greek Agriculture

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IN GREEK AGRICULTURE

By

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DIRECT SUBSIDIES AND TECHNICAL EFFICIENCY IN GREEK AGRICULTURE

In this paper we apply the technical inefficiency effect model to a set of eight different crop products (i.e., wheat, mixed arable crops, tobacco, cotton, olive oil, fruits, vegetables, and greenhouse horticulture) in Greek agriculture. For each product, a panel data set covering the period 1991-1995 is used and separate econometric results are obtained for each product. A particular set of socioeconomic and demographic variables is used to explain technical efficiency differentials among Greek farmers, including the direct subsidies given to each farmer, and the concordance of these efficiency determinants is discussed across the eight different crop products considered.

Keywords: Direct subsidies, technical efficiency, Greek agriculture

1. Introduction

The McSharry reforms in the CAP in 1992 introduced a shift in the method of support for agricultural products in the EU. In particular the former method, which relied on price supports was substituted by a method based on direct subsidies. This method of support, has expanded considerably in the EU since 1992, and currently constitutes the major form of support to EU farmers. It is therefore, interesting to inquire whether this method of support has contributed to improving technical efficiency among EU farmers. There are reasons to hypothesize that this new method of support, by making more apparent the payments to farmers, and also by delinking them to some extent from current individual farmer production, can contribute to making farmers more complacent about their production and hence less technically efficient. This is a hypothesis that can be put to test by utilizing micro production data and testing whether technical inefficiency is in any way explained by direct subsidies. The purpose of this paper is to do exactly that, by utilizing data from the Farm Accounancy Data Network (FADN) for Greek agriculture.

The method of doing this is by estimating the degree of technical inefficiency, and simultaneously the sources of these efficiency differentials among farms. That is, given the difference in efficiency levels among farmers, it is appropriate to question why some producers can achieve relatively high efficiency whilst others are technically less efficient. Variation in farmers' degree of technical efficiency may arise from some characteristics that affect their ability to adequately use the existing production technology

Among the alternatives available in the literature, the two-stage approach for explaining efficiency differentials has gained considerable popularity in empirical studies. The two-stage approach proceeds as follows. The first stage involves the specification and estimation of a stochastic production frontier function and prediction of output-oriented technical efficiency under the assumption of identically distributed one-side error term. On the other hand, the second stage involves the specification of a regression model for explaining the predicted output-oriented technical inefficiency using a set of exogenous variables (i.e., socioeconomic, demographic and managerial characteristics) that are assumed to affect farmers' performance. Some other authors (e.g., Audibert, 1997; Tian and Wan, 2000) have also included biological factors, economic conditions, social environment and health status in the set of exogenous variables.

There are however two serious econometric problems associated with the two-stage approach to the extent that Kumbhakar and Lovell (2000, p. 264) concluded "it is questionable that even a successful second-stage regression contributes anything to our understanding of the determinants of efficiency variation". *First*, technical efficiency is assumed to be identically and independently distributed across observations in the first-stage, an assumption which is violated in the second-stage where it is assumed to have a particular (linear) functional relationship with the factors presumed to affect farm performance. *Second*, the variables used in the second-stage are assumed to be uncorrelated with the regressors (input quantities) in the first-stage. If, however, they are not then the maximum likelihood estimates of the stochastic production frontier model are biased estimates of the true values.

The above criticism applies to a great extent to maximum likelihood models. It also applies, but to a lesser extent, to random effect models as the assumption of uncorrelatedness of the regressors used in the two stages is violated. However, it does not apply to fixed effect models as neither of the aforementioned assumptions is required at the outset; nevertheless, its appropriate use relies on having access to data for the whole population rather for a sample of firms. On the other hand, the two-stages approach can also consistently be applied whenever Data Envelopment Analysis (DEA) is used to estimate technical efficiency at the first stage.

Several authors attempted to overcome the above criticism by suggesting the estimation of the stochastic production frontier and the relationship aimed to explain technical efficiency differentials (inefficiency effects models) in a single-stage (see Reifschneider and Stevenson, 1991; Kumbhakar, Ghosh and McGuckin, 1991; Battese and Coelli, 1995). Specifically, the one-sided error term in the stochastic production frontier model is replaced by a linear function of exogenous variables assumed to affect individual technical efficiency levels. In that way consistent information on the factors explaining only technical efficiency differentials are obtained.

In this paper we apply this simultaneous technical inefficiency effect model to a set of eight different crop products (i.e., wheat, mixed arable crops, tobacco, cotton, olive oil, fruits, vegetables, and greenhouse horticulture) in Greek agriculture. For each product, a panel data set covering the period 1991-1995 is used and separate econometric results are obtained for each product. A particular set of socioeconomic and demographic variables is used to explain technical efficiency differentials among Greek farmers, including the direct subsidies given to each farmer, and the concordance of these efficiency determinants is discussed across the eight different crop products considered. The necessary data are taken from the FADN.

2. Empirical Model

Consider the following general stochastic production frontier function:

$$y_{it} = f(x_{it};\beta)\exp(v_{it} - u_{it}), \qquad (1)$$

where $f(\bullet)$ is approximated by a translog function, i.e.,

$$y_{it} = \beta_0 + \beta_T t + \frac{1}{2}\beta_{TT}t^2 + \sum_{j=1}^{n}\beta_j x_{jit} + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{l}\beta_{jk}x_{jit}x_{kit} + \sum_{j=1}^{n}\beta_{jt}x_{jit}t + e_{it}, \qquad (2)$$

y_{it} is the logarithm of the observed output produced by the ith farm at year t, x_{jit} is the logarithm of the quantity of the jth input used by the ith farm at year t, β is a vector of parameters to be estimated, and $e_{it} = v_{it} - u_{it}$ is a stochastic composite error term. The v_{it} depicts a symmetric and normally distributed error term (i.e., statistical noise), which represents those factors that cannot be controlled by farms, such as access to raw material, labor market conflicts, measurement errors in the dependent variable, and left-out explanatory variables. The u_{it} is a one-side, non-negative, error term representing the stochastic shortfall of the ith farm output from its production frontier, due to the existence of technical inefficiency. Thus, u_{it} accounts for the ith farm degree of technical inefficiency. It is further assumed that v_{it} and u_{it} are independently distributed from each other.

Battese and Coelli (1995) suggested that the technical inefficiency effects, u_{it}, in (1) could be replaced by a linear function of explanatory variables reflecting farm-specific characteristics. The technical inefficiency effects are assumed to be independent and non-negative truncations (at zero) of normal distributions with unknown variance and mean. Specifically,

$$\mathrm{u}_{\mathrm{it}} = \delta_o + \sum_{m=1}^{M}\delta_m z_{mi} + \omega_{it}, \qquad (3)$$

where z_{ml} are farm and time specific explanatory variables associated with technical inefficiencies; δ_0 and δ_m are parameters to be estimated;[1] and ω_i is a random variable with zero mean and finite variance σ_ω^2, defined by the truncation of the normal distribution such that $\omega_{it} \geq -\left(\delta_0 + \sum \delta_m z_{mi}\right)$. This implies that the means, $\mu_{it} = \delta_0 + \sum \delta_m z_{ml}$, of the u_{it} are different for different farms but the variance, σ_ω^2, is assumed to be the same.

The above formulation of inefficiency effects has three advantages. *First*, it permits the prediction and explanation of technical inefficiency by using a single-stage estimation procedure, as long as the inefficiency effects in (3) are stochastic. The two-stage estimation procedure, often used in previous empirical applications, has been recognized as one that is inconsistent with the assumption of identically distributed inefficiency effects in the stochastic frontier. *Second*, it allows separating time-varying technical efficiency from technical change by using a single-stage estimation procedure, as long as that inefficiency effects are stochastic and follow a particular (i.e., truncated half-normal) distribution. *Third*, even though inefficiency effects follow a truncated half-normal distribution, the truncation point is farm-specific determined by the z-variables. As a result, inefficiency effects are farm-specific.

After substituting (2) and (3) into (1) the resulting model is estimated by a single-equation estimation procedure using the maximum likelihood method and the FRONTIER (version 4.1c) computer program developed by Coelli (1992). The variance parameters of the likelihood function are estimated in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$, where the γ-parameter has a value between zero and one. The closer the estimated value of the γ-parameter to one is, the higher the probability that the technical inefficiency effect is significant in the stochastic frontier model, and in such a case the average response production function is not an adequate representation of the farms' technology.

Several hypotheses can be tested by using the generalized likelihood-ratio statistic, $\lambda = -2\{\ln L(H_0) - \ln L(H_1)\}$, where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null (H_0) and the alternative (H_1) hypothesis, respectively.[2] *First*, if $\gamma = 0$ technical inefficiency effects are non-stochastic and (1) reduces to the average response function in which the explanatory variables in the technical inefficiency model are also included in the production function.[3] *Second*, if $\gamma = \delta_0 = \delta_m = 0$ for all *m*, the inefficiency effects are not present. Consequently, each farm in the sample is operating on the frontier and thus, the systematic and random technical inefficiency effects are zero. *Third*, if $\delta_m = 0$ for all *m*, the explanatory variables in the model for the technical inefficiency effects have zero coefficients. In this case, farm-specific factors do not influence technical inefficiency and (1) reduces to Stevenson's (1980) specification, where u_{it} follow a truncated normal distribution. *Fourth*, if $\delta_0 = \delta_m = 0$ the original Aigner, Lovell and Schmidt (1977) specification is obtained, where u_{it} follow a half-normal distribution.

Farm-specific estimates of the output-oriented measure of technical efficiency are obtained directly from the estimated mean and variance of u_{it}. Specifically,

$$TE_{it}^{O} = \exp(-u_{it}) = \exp\left(-\delta_0 - \sum_{m=1}^{M}\delta_m z_{mi} - \omega_{it}\right). \quad (4)$$

Thus, the output-oriented measure of technical efficiency is inversely related to the inefficiency effects. Following Battese and Coelli (1988), TE_{it}^{O} is predicted using the conditional expectation of $\exp(-u_{it})$ given ω_{it}:

$$TE_{it}^{O} = E\{\exp(-u_{it}|\omega_{it})\} = \exp(-\mu_{it}^{0} + 0.5\sigma_o^2)\left\{\frac{\Phi\left[\left(\frac{\mu_{it}^{0}}{\sigma_o}\right) - \sigma_o\right]}{\Phi\left[\frac{\mu_{it}^{0}}{\sigma_o}\right]}\right\}, \quad (5)$$

where $\mu_{it}^{0} = \frac{\sigma_v^2\left(\delta_0 + \sum\delta_m z_{mi}\right) - \sigma_u^2\omega_{it}}{\sigma_v^2 + \sigma_u^2}$, $\sigma_o^2 = \frac{\sigma_u^2\sigma_v^2}{\sigma_u^2 + \sigma_v^2}$, $\Phi[\bullet]$ represents the cumulative density function of the standard normal random variable, and E is the expectation operator.

Several socioeconomic and demographic variables have been employed in the technical inefficiency effect model and alternative associated hypotheses can be stated and tested econometrically. *First*, the age of the farmer, measured in years, is used as a proxy of entrepreneurial skills, experience and learning-by-doing. There have been two alternative and mutually exclusive hypotheses concerning the impact of farmer age on technical efficiency. On the one hand, it has been argued (e.g., Coelli and Battese, 1996) that older farmers are likely to have more farming experience and hence be less technically inefficient. On the other hand, older farmers are likely more conservative and thus less willing to adopt new practices, thereby perhaps having greater technical inefficiencies. In contrast, younger farmers are more aware of current technology and tend to acquire more easily knowledge about technical advances (Weersink, Turvey and Godah, 1990). If young farmers did not become more relatively efficient with age they would not be able to compete and would forced out of business.

It has also been argued (Makary and Rees, 1981; Tauer, 1995) that young farmers are becoming relatively more efficient over time by improving learning-by-doing, but this would continue until the relationship leveled off and it is expected to decline as farmer approaches the retirement age. In this case, the effect of age on technical efficiency should be modeled through a quadratic specification, where the (expected) positive sign of the squared term supports the hypothesis of decreasing returns to experience or human capital. This quadratic specification has been adopted in the empirical model.

Second, the effect of farm size (measured in terms of European Size Units or ESU) on technical efficiency is also highly debatable. On the one hand, it has been argued (e.g., Hallam and

Machado, 1996) that larger farms by exploring scale economies tend to be more technically efficient than smaller farms. In contrast, Amara et al. (1999) suggested that increased farm size diminishes the timeliness of input use. As a result it becomes more difficult for larger farms to conduct their operations at the optimal time and thus, inputs are used less efficiently. On the other hand, farmers with smaller operations may have alternative income sources, which are more important and hence put less effort into farming compared with the larger farmers (Coelli and Battese, 1996).

Third, the existing literature is much more clear regarding the effect of the extent of own land on technical efficiency. Specifically, it is expected that there is a positive relationship between the percentage of cultivated land that is owned and the degree of technical efficiency. Following Llewelyn and Williams (1996), technical efficiency may be higher for farmers who own their land because of greater incentives for efficiency and better resource management practices relative to those who are renting.

Fourth, the portion of family labor in total utilized labor is expected to affect positively technical efficiency due to stronger incentives for efficient production as well as absence of monitoring and screening effort associated with hired labor.

Fifth, irrigation is expected to have a positive effect on technical efficiency of crop production. Irrigation, as a risk-reducing input, tend to increase mean yield and at the same time decrease its variability when rainfall is inadequate. This is certainty the case with high yielding varieties where the adequate and timely application of both water and fertilizer are necessary, ceteris paribus, for greater production. Thus it is expected that the degree of technical efficiency in crop production is positively associated the percentage of irrigated land.

Sixth, the impact of direct subsidies (independent of output level) on the degree of technical efficiency has not been examined before. In the context of CAP, direct income transfers have being in order since 1992 by means of compensation for both land set aside, as well as as compensation for official price declines. Intuitively, as the magnitude as well as the relative importance of these direct income transfers increases, farmers tend to put less effort into their farming activities than otherwise. Thus, a negative relationship is hypothesized between direct subsidies (measured in thousands drs) and technical efficiency.

Seventh, two hypotheses have been stated about the effect that farm debt (measured in thousands drs) may have on technical efficiency. On the one hand, Jensen's (1986) free cash flow hypothesis suggests that greater reliance on current debt to finance the farm operation stimulates considerable effort by farmers to improve their performance in order to meet these obligations. On the other hand, the level of debt may affect the ability of the farm management to obtain the necessary inputs at the critically important periods of planting and harvesting (Sotnikov, 1998). Current large debts decrease the possibility for more bank loans and thus the ability to timely purchase intermediate inputs.

Eight, farmers who produce only one crop may be more efficient than those who are more diversified (Llewelyn and Williams, 1996). The relatively high skill level associated with specialization and the increased farm reliance on the fortunes of a single product could be among the rationales behind the superior performance of highly specialized farms. On the other hand, specialization may decrease technical efficiency in the presence of significant scope economies (Featherstone, Langemeier and Ismet, 1997). Specialization here is measured using the *Herfindhal* index defined as $D = \sum_m \left(s_m^S\right)^2$, where s_m^S is the share of m^{th} output in total farm production. A value of D close to unity indicates specialization, whereas smaller value reflect increased diversification.

3. Data Description

The data for the present study is taken from FADN and cover the period 1991-1995. Eight different crops are considered, namely wheat, mixed arable crops, tobacco, cotton, olive oil, fruits, vegetables and greenhouse horticulture. Farms are classified by commodity according to their source of revenue. That is, a farm is classified as producing a particular commodity as long as two thirds of its revenues come form the production of this particular good. Farms are included in FADN annual survey in a rotating manner and according to their standard gross margin; farms with less than 2 ESU are excluded in the Greek FADN.

For each crop, output is measured in terms of total revenue. Four inputs are included in the production frontier function, namely land measured in hectares, labor measured in annual working hours, intermediate inputs (fertilizer, pesticides, repairing cost, seeds, electricity, etc) measured in thousands drs, and capital stock (including machinery, building and occasionally tress) also measured in thousands drs. Also a time trend is included to account for technical change. On the other hand, in the inefficiency effect model, except for the variables mentioned already in the previous section, we have also included four regional dummies, two location dummies referring to less favored and mountain areas respectively, and two altitude dummies for farms located between 300-600 and more than 600 meters. Finally a time trend is included to account for time-varying technical efficiency.

4. Empirical Results

For all crops considered, the null hypotheses that $\gamma = 0$ and that $\gamma = \delta_0 = \delta_m = 0$ are both rejected at 5% level of significance indicating respectively that the technical inefficiency effects are in fact stochastic and present in the model.[4] Thus, farms in each sample operate below the technically efficient frontier and a significant part of output variability among farms is explained by the existing differences in the degree of technical efficiency. Consequently, the traditional average production does not represent adequately the production structure.

As far as the distribution of the technical inefficiency effects is concerned, (1) cannot be reduced to Aigner, Lovell and Schmidt's (1977) specification (in which the technical inefficiency effects have a half-normal distribution) as the null hypothesis of $\delta_0 = \delta_m = 0 \;\; \forall m$ is rejected for all crops considered at 5% level of significance. Furthermore, (1) cannot be reduced to Stevenson's (1980) specification (in which the technical inefficiency effects have the same truncated-normal distribution with mean equal to δ_0) as the null hypothesis of $\delta_m = 0$ is rejected for all crops considered at 5% level of significance. The latter also implies that the explanatory variables included in (3) contribute significantly to the explanation of technical inefficiency.

On the other hand, there are some difference among crops considered in this study as far as the structure of production technology is concerned. Specifically, wheat production is better described by a Cobb-Douglas frontier function with Hicks neutral technical change. In addition, the hypothesis of Hicks neutral technical change cannot be rejected in the cases of vegetables and greenhouse horticulture production even though in both cases the frontier function is better described by the translog specification (2). For all other crops, the translog specification with biased technical change cannot be rejected.

The estimated mean technical efficiency scores by crop and year are presented in Table 1. It can be seen that there are significant differences among crops. On average over the period under consideration, wheat farmers exhibited the lowest degree of technical efficiency, while fruits growers the highest. Relative low also is the degree of technical efficiency in the production of tobacco and mixed arable crops. Technical efficiency scores remain almost stable for olive oil and greenhouse horticulture and decrease for wheat. For the rest of crops considered there is no a clear temporal pattern.

The qualitative results concerning the determinants of efficiency differentials are presented in Table 2. A positive (negative) sign indicates a positive (negative) relationship between the corresponding explanatory variable and technical efficiency. Statistically insignificant relations are indicated by a zero. In general, the qualitative results are mixed for most of the explanatory variables, with the exception of farm debt, irrigation and direct subsidies.

In particular, the age of farmers does not seem to have a statistically significant effect on technical efficiency in the production of wheat, tobacco, vegetables, and greenhouse horticulture. For mixed arable crops, cotton and olive oil, older farmers to tend to be more efficient. For these crops, the estimated coefficient of the term corresponding to $(\text{age})^2$ is positive, supporting the hypothesis of decreasing returns to human capital. However, in the case of fruits, it was found that younger farmers tend to be more efficient.

Farm size is not a statistically important factor in explaining technical efficiency differentials among tobacco, fruits and greenhouse horticulture growers in Greece. In contrast, a positive relationship was found between farm size and technical efficiency for wheat, mixed arable crops, cotton, olive oil and vegetables production. This implies that either larger farms by exploring scale economies tend to be more technically efficient than smaller farms or farmers with smaller operations may have alternative income sources, which are more important and hence put less effort into farming compared with the larger farmers. In the case of Greek agriculture the latter is more likely the case.

Much more mixed are our empirical findings with respect to the effect of own land and family labor. It seems that the percentage of own land does not affect the degree of technical efficiency in the production of tobacco, cotton, fruits and greenhouse horticulture. It is found to be positive in the cases of wheat and mixed arable crops, while it is negative in the cases of olive oil and vegetables production. On the other hand and in contrast to what was expected, the percentage of family labor is negatively associated with the degree of technical efficiency in the production of wheat, mixed arable crops, tobacco, cotton, olive oil and vegetables. More likely this implies a surplus of family labor.

Complete concordance was found with respect to the effect irrigation may have on the degree of technical efficiency. Farmers with relatively large percentage of irrigated land tend to achieve higher technical efficiency scores. This is a rather expected results as we are dealing with highly water intensive crops, perhaps with the exception of olive oil production.

Remarkable consistency was also found with respect to the effect of direct subsidies on the degree of technical efficiency. It was negative for all crops except vegetables and greenhouse horticulture, where however the magnitude as well as the share of direct income transfers in total revenue is almost negligible (see Table 3). By combining the results of Tables 1 and 3 it can be seen that since the last reform of the CAP, when the magnitude of direct income transfers increased substantially for wheat and mixed arable crops, there is clear negative relationship between the pattern of technical efficiency and the magnitude of direct subsidies. The same is apparently true for tobacco, but it relative terms. The opposite occurred in cotton production where the decrease in direct subsidies led to an increase in technical efficiency.

The empirical findings with respect to farm debt are in contrast to Jensen’s (1986) hypothesis that greater reliance on current debt to finance the farm operation stimulates considerable effort by farmers to improve their performance in order to meet these obligations. Farm debt here is found to have a negative effect with the exception of olive oil production.

We found mixed empirical results with respect to the effect of specialization on technical efficiency. Specialization tend to increase technical efficiency in the production of tobacco, cotton, fruits and vegetables, while tend to decrease technical efficiency in the cases of wheat, olive oil and greenhouse horticulture. Specialization seems to have no impact on technical efficiency in mixed arable crops production.

5. Concluding Remarks

In this paper we consider the determinants of technical efficiency differentials among Greek farmers for wide range of crop products, namely wheat, mixed arable crops, tobacco, cotton, olive oil, fruits, vegetables and greenhouse horticulture. Within this framework, we provide for first time some empirical results concerning the impact of the CAP reform of 1992 on the productive performance of farmers. Even though these results are restricted to Greek agriculture, they show that direct income transfers through both the land set aside program, as well as compensation for pofficial price declines have tend to decrease technical efficiency and consequently, squeezed competitiveness. The main reason for the result may be that farmers tend to put less effort on farming activities as a larger part of their income is guaranteed through direct subsidies, which are designed to substitute for market income. Further research is needed in this direction by means of analyzing the experience of other EU countries in order to conform the results of the present study or conclude that these are country specific.

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Table 1: Mean Technical Efficiency Scores by Crop, 1991-1995

	1991	1992	1993	1994	1995
Wheat	69.6	56.3	53.8	53.9	47.1
Mixed arable crops	73.4	63.3	58.3	62.1	70.9
Tobacco	71.1	67.6	64.7	66.4	76.2
Cotton	67.5	59.6	71.4	79.6	86.0
Olive oil	72.5	69.1	67.9	70.1	72.5
Fruits	77.7	70.3	69.9	81.0	88.9
Vegetables	78.5	74.1	69.7	70.8	59.7
Greenhouse hortic.	74.1	74.0	74.3	72.8	70.5

Source. Authors’ analysis

Table 2: Technical Inefficiency Effects by Crop Type

	Farmer Age	Farm Size	% of Own Land	% of Family Labor	% of Irrigated Land	Direct subsidies	Farm Loans	Degree of Specialization
Wheat	0	+	+	-	+	-	-	-
Mixed arable crops	+	+	+	-	+	-	-	0
Tobacco	0	0	0	-	+	-	-	+
Cotton	+	+	0	-	+	-	-	+
Olive oil	+	+	-	-	+	-	0	-
Fruits	-	0	0	+	+	-	-	+
Vegetables	0	+	-	-	+	0	-	+
Greenhouse hortic.	0	0	0	0	+	0	-	-

Source. Authors' analysis

Table 3: Direct Subsidies by Crop: Greek Agriculture, 1991-1995

	1991	1992	1993	1994	1995
	Direct subsidies (thousands drs)				
Wheat	636	719	1,514	1,958	2,395
Mixed arable crops	363	327	538	729	978
Tobacco	60	84	185	232	285
Cotton	701	852	276	276	307
Olive oil	505	608	799	1,239	1,116
Fruits	80	78	95	131	123
Vegetables	121	87	135	247	201
Greenhouse hortic.	225	192	326	364	302
	Direct subsidies/Revenue (%)				
Wheat	13	16	33	39	56
Mixed arable crops	7	6	10	11	14
Tobacco	1	2	5	7	9
Cotton	10	13	3	3	4
Olive oil	22	21	26	38	32
Fruits	2	2	2	2	3
Vegetables	2	2	3	4	3
Greenhouse hortic.	4	3	5	7	6

Source. Author's analysis

Endnotes

[1] Biased estimates of δ_m parameters may be obtained by not including an intercept parameter δ_0 in the mean, μ_{it}, and in such a case the shape of the distribution of the inefficiency effects is unnecessarily restricted (Battese and Coelli, 1995).

Supprimé : 2

[2] If the given null hypothesis is true, the generalized likelihood-ratio statistic has approximately a χ^2 distribution, except the case where the null hypothesis involves also $\gamma = 0$. In this case, the assumptotic distribution of λ is a mixed χ^2 (Coelli, 1995) and the appropriate critical values are obtained from Kodde and Palm (1986).

[3] In this case, three parameters (γ, δ_o, δ_T) can not been identified and thus, the critical value to test the null hypothesis is obtained from the χ_3^2 distribution.

[4] The estimated parameters of the translog production frontier function for the eight crops considered in this study are not presented here to save space but they are available upon request.