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TECHNICAL EFFICIENCY AND PRODUCTIVITY GROWTH IN THE FARMING SYSTEM OF THE DOURO REGION: A STOCHASTIC FRONTIER APPROACH

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ABSTRACT

The objective of this paper is to study the changes on the productive performance of the Douro farming system during 1988-98. We analyse both the productivity growth and technical efficiency of the farms of the Douro. For this purpose we use a stochastic production frontier effects model to compute the returns to scale, total factor productivity growth and the technical efficiency indices. The empirical results show that Douro farms experienced increasing returns to scale after 1995 and a total factor productivity growth of 4.7% per year, on average, which is, essentially, a consequence of a positive technical efficiency change.

1. INTRODUCTION

Due to the full integration of Portugal in the European Union (EU) in the nineties[1], together with an increased globalised economy and the boom in information technology, Portuguese agriculture has been the object of large structural changes. Between 1989 and 1997, the number of farms, the volume of labour and the agriculturally usable land decreased by 30%, 40%[2] e 5%, respectively, and the Agriculture Gross Value Added, at real prices, only increased at a rate of 0.7% per year, a significantly smaller growth than that of the Portuguese economy, 2.5%/ year[3]. Comparing the situation

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1. Although Portugal joined the EEC in 1986, the effects of its full integration into the EU - namely in terms of the role played by the European Agricultural Guidance and Guarantee Fund (EAGGF) Guarantee - were only felt in the last decade, mainly due to the end of the first phase of the transition period, in 1990 and the CAP reform, in 1992. MADRP (1999) provides a good overview of the structural changes that occurred in this period in Portuguese agriculture.
2. Corresponding to 400, 000 persons.
3. Despite this trend, the Portuguese agro-forestry sector still plays an important role in the national economy, contributing 10.5% to the Portuguese Gross Value Added (valued at market prices), in 1998. In the EU, the importance of this sector is only outweighed in the case of Greece.

with that of the EU as a whole, the average Portuguese farm income is still less than 30% of that of the average EU farmer (MADRP, 1999).

Although Portugal is a small country (3,700,161 ha of usable land and 381,794 farms), it has enormous differences in its climatic and orographic conditions, resulting in a wide diversity of agricultural activities spread across the different regions of the country. Among these is the homogenous agricultural region called the Douro, situated in the north eastern part of Portugal on the banks of the river Douro, including, roughly, the oldest wine dema cated area[4], known for centuries for its production of the fortified wine known world-wide as Port.

Currently, the Douro agricultural sector contributes 40% to its regional Gross Domestic Product (FRAH, 2000, p.98), comprising 139 097 ha of usable land and close to 32 000 farms, with an average size of 4,35 ha/farm (INE, 2000). However, between 1988 and 1998, there was a reduction both in Douro's number of farms (16%) and in its usable agricultural land of (9.5%). This zone, using the EU classification, may be included in the category of High Natural Value farming systems, where "in place of sustainable and relatively labour-intensive grazing regimes and the maintenance of features such as terracing and stock-proof walls, economic conditions lead to the land being under-managed" (European Commission, DG VI, 1997, p.20). Wine is the most important regional produce covering almost 1/3 of the total usable land, of which almost 78% is situated on steep hills where mechanisation is very difficult to undertake (FRAH, 2000).

Knowing that the competitiveness of the agricultural sector of the Douro region depends on the sustainable growth of the total factor productivity (TFP) of its farms, to define strategies that are able to move the production frontier and to use efficiently the available inputs, it is important to quantify technical efficiency and to explore the origins of the evolution of TFP.

In this context, the main objective of this paper is to study the changes on the productive performance of the Douro farming system during 1988-98. For this purpose we will analyse both technical efficiency and TFP growth over the study period and by type of farm. A Stochastic Frontier Approach (SFA) will be employed to measure technical efficiency (TE) and to decompose TFP growth into two different sources: inefficiency change (IC) and technical change (TC). Furthermore, we will obtain measures of partial input productivity and returns to scale (RTS).

The remainder of this paper is divided into four sections. Section two provides a description of the stochastic frontier model used in this paper. In Section three, data and empirical results are presented and discussed. The final section summarises the major conclusions of our research.

4. The Demarcated Area of Douro was established and regulated by a royal diploma, during the reign of José I, in 1756. Due the importance and value of its natural, cultural and scenic heritage, a part of the Demarcated Area of Douro was included in 2001 in UNESCO's "List of World Heritage Sites (Cultural, Living and Evolved Landscape)".

2. STOCHASTIC FRONTIER MODEL

Based on the concept of frontier functions, the measurement of technical efficiency[5] has been a popular field of research since the seminal paper by Farrel (1957). Basically, there are two approaches to computing productive efficiency indices, the DEA (data envelopment analysis) and the SFA (stochastic frontier approach). It is not possible to determine which of the two approaches is preferable, since the true level of efficiency is unknown. Because all deviations from the frontier are interpreted as inefficiency in the DEA, the SFA normally yields lower inefficiency level than DEA. Battese (1992), Bravo-Uretta and Pinheiro (1993), and Coelli (1995) all provide comprehensive surveys of frontier production models applied in agricultural economics.

The SFA approach has been applied in the analysis of the technical efficiency and productivity growth of farming systems (Battese and Broca, 1997; Coelli and Battese, 1996; Rebelo, 2000). These studies generally assume that the flexible functional form of the translog production frontier is appropriate in farm-level analysis, so that more general technologies can be accounted for than with the Cobb-Douglas model.

In our empirical analysis, a translog stochastic frontier production effects model proposed by Battese and Coelli (1995) is assumed to specify the production technology of Douro farms during 1988-1998. The model is defined by:

$$1nY_{it} = \beta_o + \sum_{j=1}^{5} \beta_j X_{jit} + \frac{1}{2} \sum_{j\leq k=1}^{5} \sum^{5} \beta_{jk} X_{jit} X_{kit} + V_{it} - U_{it} \qquad (1)$$

where:

- ln represents de natural logarithm;
- the subscripts i and t represents de i-th farm (1 =1,....,) and t-th year of observation (t =1,..., 11), respectively;
- Y is the gross value of agricultural product (sum of the gross value of crop output and livestock output)[6] in *contos*;
- X_1 is the logarithm of the total amount of land used (hectares);

5. Sometimes, measures of partial productivity such as yield per hectare or output per unit of labour are used to compute the efficiency of the Agriculture Sector (MADRP, 1999). However, these indices are impartial and imperfect measures of technical efficiency, because they do not take into account the differences in input bundles, which may affect partial productivity, but are not necessarily related to the efficiency or managerial quality of the firm. This is particularly important when we compare firms with different input mixes. This weakness is overcome by using measures of technical efficiency based on frontier production functions.

6. Given that the dependent variable in the frontier is the aggregated value of the agricultural output, rather than the physical quantity, the inefficiency effects could be influenced by allocative inefficiency. However, as during the study period input and output prices were similar for all farmers and the policy regarding the main items of Douro production (wine, essentially) remained the same, it is to be expected that the inefficiency effects in our frontier model are mostly associated with the technical inefficiency of production.

- X_2 is the logarithm of the total of labour consumed (in annual workman units – AWU) from family and hired labour;
- X_3 is the logarithm of the total amount of capital (sum of annual depreciation and service costs of building and machinery in *contos*);
- X_4 is the logarithm of the value (in *contos*) of other inputs (seeds, fertilisers, fuel and lubricants and other variable costs);
- X_5 represents the year of observation, where $X_5 = 1,...,11$;
- V_{it}s are random variables that capture the effects of the unspecified explanatory variable, namely, measurement error, random shocks and other statistical "noise", and are assumed to be independent and identically distributed with $N(0,\sigma^2_v)$ distribution and independent of the U_{it}s.
- U_{it}s are non-negative unobservable random variables associated with technical inefficiency of production, such that, for the given technology and levels of inputs, the observed output falls short of its potential output. U_{it} is obtained by the truncation (at zero) of the $N(m_{it}, s^2)$ distribution with[7]:

$$\mu_{it} = \delta_0 + \delta_1 Z_{1it} + \delta_2 Z_{2it} + \delta_3 Z_{3it} + \delta_4 Z_{4it} + \delta_5 Z_{5it} + \delta_6 X_5 + \delta_7 (X_5/2)^2 \qquad (2)$$

where:
- Z_1 is the weighting applied to crop output as a proportion of the gross value of the agricultural product;
- Z_2 is the weighting applied to family labour as a proportion of total labour consumed;
- Z_3 is the weighting applied to irrigated land on the amount of total land used;
- Z_4 is dummy variable that tries to capture the effects of full adhesion to EU, which takes value 0 if the year of observation is until 1992 and 1 after this year;
- Z_5 is a dummy variable that reflects the type of farmer, which takes the value 1 if the farm uses only family labour, and 0 otherwise;
- X_5, as in (1) represents the year of observation, where $X_5 = 1,...,11$.

The specification of the second order terms of (1) includes the variable X_5 in such a way that a non-neutral technical change can be considered. The neutral technical change is present if the coefficients of the interactions between the observed year (X_5) and the input variables are zero.

The specification of the model for the inefficiency effects, in equation (2), permits the level of technical inefficiency: to be influenced by variables that characterise the farm system

7. Compared to the traditional SFA models, this method, by introducing exogenously these variables in the model, evaluates directly and consistently the effects of inefficiency that result from the variables related to the structure and behaviour of the observed production units.

(Z_1, Z_2, Z_3), to differ from period to period (Z_4) and to vary according to the type of farmer (Z_5). In addition, the effects are assumed to change in a quadratic fashion over time. This parametric model permits the estimation of productivity growth by taking the derivative of the logarithm of the mean production with respect to time. The rate of productivity growth can be decomposed into technical and inefficiency changes, provided the inefficiency effects are stochastic and have a truncated-normal distribution.

The parameters of the frontier production model, defined by equations (1) and (2), are estimated[8] by the method of maximum likelihood using the software FRONTIER 4.1 (Coelli, 1996).

The hypothesis tests, involving parameters of the stochastic production frontier, is undertaken using the generalised likelihood-ratio test:

$$\lambda = -2 \{1n[L(H_0)/L(H_1)]\} \tag{3}$$

where $L(H_0)$ is the value of the likelihood function for the frontier model, in which the parameter restrictions specified by the null hypothesis, H_0, are imposed; $L(H_1)$ is the value of the likelihood function for the general frontier model; λ has a Chi-square (or mix Chi-squared) distribution with degrees of freedom equal to the difference between the parameters estimated under H_1 and H_0. The technical efficiency of a farm in the t-th year of observation, given the specifications of the model, is defined (Battese and Coelli, 1993) by:

$$TE_{it} = \exp(-U_{it}) \tag{4}$$

For the translog stochastic frontier production function (1), the elasticities of the mean product are estimated for the four inputs (land, labour, capital and other inputs). The returns to scale are calculated by the sum of these four elasticities.

Technical change (TC) and technical inefficiency change (IC) are two components of the productivity growth. Since the time variable, t, is included in the frontier production function (1) and in the inefficiency effects model (2), the respective rate (Battese and Broca, 1997) is given by:

$$\frac{\partial \ln E(Y)}{\partial t} = \frac{\partial X\beta}{\partial t} - C_{it} \frac{\partial U_{it}}{\partial t} \tag{5}$$

8. Alternatively, a two-step approach can be used: in a first step only the parameters of equation (1) are estimated, and in a second step a regression is undertaken of the technical (in)efficiency score on the exogenous variables included in (2). An early example of this approach is provided by Pitt and Lee (1981). Bravo-Ureta and Pinheiro (1993) summarise its pros and cons, and Battese and Coelli (1995) criticise the second step since the efficiency indices are not identically distributed.

where $\partial X\beta/\partial t$[9] and $C_{it}\partial\mu_{it}/\partial t$ represent the technical change and the technical inefficiency change, respectively, and C_{it} is given by:

$$C_{it} = \left\{1 - \frac{1}{\sigma}\left[\frac{\phi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)}{\Phi\left(\frac{\mu_{it}}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\mu_{it}}{\sigma}\right)}{\Phi\left(\frac{\mu_{it}}{\sigma}\right)}\right]\right\} \quad (6)$$

and ϕ and Φ represent the density and distribution functions of the standard normal random variable, respectively.

3. DATA AND RESULTS

3.1. Data

The data used in this study was made available by the Regional Division of the Ministry of Agriculture, Rural Development and Fisheries, from accounts of farms covered by the Farm Accounting Data Network (FADN, known by the Portuguese acronym RICA) and located in the homogeneous agricultural region of the Douro. Our observations were conducted from 1988 to1998, the latter being the most recent year for which information was available, and globally constitutes a pool of 874 observations. Annual data is expressed in terms of 1988 base year values, using price deflators (agricultural product price indexes for the outputs and the Gross Domestic Product deflator for capital and other inputs, respectively). Otherwise, all variables are expressed in terms of flows (quantity used in a given period), thereby allowing for elasticities to be comparable.

Table 1 contains some statistical information on the variables used in our model. It is important to emphasise that, in the study period, labour is being substituted for capital (an average decrease of 37.1% for labour and increase of 27.5% for capital). Likewise we can also see that the use of land and other inputs also decreased (16.7% and 28.3%, respectively).

9. The rate of TC can be decomposed further in two effects, pure and biased TC (Tzouvelekas et al., 1999) and the technical inefficiency change can be separated into pure inefficiency change and scale change (Färe et al., 1994). The computation of these indicators is outside the scope of this paper.

Table 1: Descriptive statistics on the output/input variables

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Y = Output *											
Max.	7719	8980	9335	12387	10140	13066	10344	16344	18197	15632	16589
Min.	159	132	208	202	123	87	234	97	60	96	106
Average	2467	2365	2485	2835	2346	1868	2525	2542	2922	2810	2684
C. of variation (%)	87.5	82.8	78.0	82.8	86.6	100.0	82.2	97.1	94.3	94.8	96.9
Y_1= Land (ha)											
Max.	50	51	52	53	51	55	43	43	43	44	43
Min.	0.28	0.27	0.39	0.28	0.28	0.28	0.1	0.28	0.28	0.28	0.28
Average	12	11	11	11	10	10	10	10	10	11	10
C. of Variation	94.8	94.5	92.6	89.6	87.1	86.7	83.5	91.7	94.4	85.2	89.2
X_2 = Capital											
Max.	763	592	949	1050	1396	1169	997	1817	1384	1730	1588
Min.	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Average	142	128	164	197	179	147	172	163	165	184	181
C. of variation (%)	1.18	106.2	109.5	115.1	139.8	136.6	123.4	177.5	147.9	143.0	162.0
X_3 = Labour (AWU)											
Max.	11.2	10.2	9.7	10.0	10.8	6.0	6.9	8.8	9.5	9.0	8.8
Min.	0.52	0.48	0.66	0.52	0.25	0.28	0.31	0.24	0.37	0.74	0.57
Average	3.5	2.8	3.0	3.1	2.7	2.5	2.4	2.4	2.4	2.4	2.2
C. of variation (%)	81.2	79.6	77.7	70.2	71.4	143.3	60.8	64.0	65.4	58.7	56.3
X_4 = Other inputs											
Max.	5415	2837	4635	4060	2725	2253	1860	3990	4216	4077	4920
Min.	18	29	1	16	13	1	2	23	10	11	15
Average	477	387	407	435	345	306	310	318	363	335	342
C. of variation (%)	1.49	116.8	165.3	147.3	126.2	121.3	107.9	144.6	145.6	143.8	156.6

** Contos (1000 escudos ≈ 5 euro) at 1988 price.*

3.2. Estimates and tests

Table 2 presents the maximum-likelihood estimates of the parameters in the translog stochastic frontier production function, given the specification for the technical inefficiency effects, as defined by equations (1) and (2).

Because the model defined by equations (1) and (2) involves such a large number of variables and parameters, in order to decide if a simpler model would provide a more accurate representation of the technology observed in the farming systems of the Douro, tests of several null hypotheses concerning the nature of the production function and of the inefficiency effects, were applied first.

Table 2: Estimates for parameters of the stochastic frontier and inefficiency effects model

Variable	Parameter	Estimates	Ratio t
Stochastic Frontier			
Constant	β_0	7.247	1.644
X_1	β_1	0.568	3.634
X_2	β_2	-0.168	-0.627
X_3	β_3	-0.059	-1.010
X_4	β_4	-0.068	-0.485
X_5	β_5	-0.181	-3.112
X_1X_1	β_{11}	-0.093	-2.356
X_1X_2	β_{12}	0.012	0.212
X_1X_3	β_{13}	-0.004	-0.221
X_1X_4	β_{14}	-0,052	-1.468
X_1X_5	β_{15}	-0.002	-0.196
X_2X_2	β_{22}	0,021	0.181
X_2X_3	β_{23}	0,038	1.623
X_2X_4	β_{24}	0,022	0.361
X_2X_5	β_{25}	0,047	3.697
X_3X_3	β_{33}	0,031	3.381
X_3X_4	β_{34}	-0.015	-1.026
X_3X_5	β_{35}	0.010	2.779
X_4X_4	β_{44}	0.075	2.316
X_4X_5	β_{45}	0.009	1.002
X_5X_5	β_{55}	0.008	1.318
Inefficiency effects			
Constant	δ_0	-0.458	-1.001
Z_1	δ_1	0.128	0.814
Z_2	δ_2	2.023	5.663
Z_3	δ_3	-0.098	-1.005
Z_4	δ_4	0.265	1.611
Z_5	δ_5	0.137	1.100
X_5	δ_6	-0.143	-1.549
X_5X_5	δ_7	0.000	0.006
Variance parameters			
	$(\sigma_v^2+\sigma^2)$	0,383	7.891
	γ	0,722	13.462

The null hypotheses involved and the correspondent value of the statistic tests are given in Table 3. The null hypotheses (Ho) specifies that:

- The second order coefficients in the translog production function are equal to zero, and hence the Cobb-Douglas function applies;
- The interaction terms involving the year of observation are zero, showing that there is a neutral technical change in production, relative to the inputs;
- The inefficiency effects in the production function are not present in the model, therefore, Douro farmers are fully technically efficient.

– Since the coefficients of all the seven explanatory variables in the inefficiency model (2) are simultaneously equal to zero, they are not useful in describing the inefficiencies of production of Douro farming systems.

Table 3: Likelihood-ratio test of null hypothesis (structural restrictions)

Null hypothesis, Ho	Statistic test λ	Critical value of λ (0,05)
$\beta_{jk} = 0, j \leq k = 1,2,\ldots,5$	114.30	24.99
$\beta_{j5} = 0, j = 1, 2, \ldots, 4$	61.92	9.49
$\gamma = \delta_0 = \delta_1 = \ldots = \delta_7$	674.28	16.27*
$\delta_1 = \ldots = \delta_7 = 0$	668.40	14.07

* This critical value is obtained from table 1 of Kodde and Palm (1986) In this case, because $\gamma = 0$ is on the boundary of the parameter space and the asymptotic distribution of λ is a mixed χ^2 distribution with degrees of freedom equal to 9 (number of restrictions).

From the statistical value of l, computed using (3), we can conclude that each one of the four restrictions is strongly rejected at a 5% significance level, and hence the stochastic frontier model, defined by equations (1) and (2), gives an adequate representation of the production technology observed among Douro farmers.

The estimate (0.722) and significance for g implies that the variance of the inefficiency effects is a significant component of the total variance of the error terms[10]. Furthermore, the d-estimates and the significance of the inefficiency effects model of equation (2) indicate that technical inefficiency tends to increase as the relative weight of family labour increases. These findings confirm our expectations, since farms with readily available family labour tend to use this resource less efficiently, due to seasonality and a reduced pressure to control labour costs in family farms (i.e. there is no need to pay – in the strict sense of the term – for family labour). The other coefficients, individually, are not statistically significant[11].

3.3. Elasticities, Technical efficiency, Technological change and Inefficiency change

Table 4 contains the values of: production elasticities for the four inputs, per year, and type of farm; returns to scale (RTS); technical efficiency (TE), productivity growth (PG) and its components technical change (TC), and inefficiency change (IC).

10. However, as Battese et al.(1998, p. 14) have stressed "γ is not correctly interpreted as the ratio of the variance of the inefficiency effect, U_{it}, to the sum of the variances of U_{it} and V_{it}, because σ^2 is the variance of the normal distributions *before truncation* (at zero) to obtain the distributions of the U_{it}s". The hypothesis of γ equal to 1 is also rejected (statistic t equal to 5.261), i.e., the adopted model is significantly different from the deterministic frontier model.

11. The non individual significance of the majority of these parameters, together with the global significance of the U_{it} regression, suggests the possibility of multicollinearity of the variable assumed as exogenous in the inefficiency effects.

Table 4: Production elasticities, returns to scale, technical change, inefficiency change, productivit growth and technical efficiency (averages)

	# farms	Land X_1	Labour X_2	Capital X_3	Other inputs X_4	RTS	TC	IC	PG	TE
Year										
1988	62	0.082	0.193	0.027	0.223	0.525	-0.045	-0.079	0.034	0.521
1989	63	0.087	0.237	0.035	0.222	0.581	-0.045	-0.075	0.030	0.568
1990	63	0.093	0.288	0.056	0.214	0.651	-0.033	-0.068	0.035	0.595
1991	75	0.081	0.344	0.069	0.232	0.726	-0.019	-0.058	0.039	0.641
1992	80	0.099	0.375	0.071	0.231	0.776	-0.021	-0.060	0.039	0.616
1993	82	0.102	0.413	0.076	0.230	0.821	-0.017	-0.065	0.048	0.600
1994	71	0.096	0.461	0.083	0.242	0.882	-0.001	-0.061	0.060	0.662
1995	88	0.095	0.504	0.088	0.261	0.948	-0.001	-0.049	0.048	0.679
1996	85	0.087	0.564	0.106	0.272	1.029	0.011	-0.044	0.055	0.716
1997	107	0.080	0.611	0.116	0.274	1.081	0.020	-0.043	0.063	0.711
1998	98	0.081	0.650	0.118	0.286	1.135	0.024	-0.036	0.060	0.713
Average	80	0.089	0.445	0.081	0.248	0.863	-0.009	-0.056	0.047	0.643
Type of farm										
Family	408	0.138	0.423	0.065	0.239	0.865	-0.026	-0.085	0.059	0.514
Others	466	0.046	0.464	0.095	0.256	0.861	0.006	-0.031	0.037	0.756

Using the mean values in our analysis, we can see that in all situations the production partial elasticities of the inputs are between 0 and 1, and with the expected sign, implying the producers are in the well known second stage of production (rational zone of production), that is, *ceteris paribus*, an increase in the consumption of an input corresponds to a less than proportional change in output. Among the inputs, labour is the one that exhibits the highest partial elasticity (average 0.445)[12], followed by other inputs (0.248), and finally, land and capital with almost identical partial elasticities, respectively, 0.089 and 0.081, suggesting that labour and other inputs have the greatest importance in the production technology of Douro farms. With the exception of the elasticity of land inputs, which remained fairly stable during the study period, all the other elasticities increased over the years, indicating that output increased with changes in the consumption of the inputs of labour, capital and other factors[13]. In other words, in general, given the external environment they faced, Douro farmers were nevertheless able to introduce changes in the production process that enabled them to improve their input use, as shown by the positive relative change in output.

12. We must highlight once more that in the Douro, and particularly in the production of grapes for wine, due to the often steep slopes of the land farmed and the characteristics of the plantation system, mechanisation is difficult. Therefore the use of labour in the production process is of the greatest importance, and explains the high value of its production elasticity.
13. This effect is especially relevant for labour, due to the value of its partial elasticity.

Table 5: Matrix of Pearson and rank (Spearman) correlation coefficients

		RTS	PG	TE	Land	Labour	Capital	O.inputs
Pearson	RTS	1.000	0.510*	0.310*	-0.105*	0.035	0.316*	0.171*
	PG		1.000	-0.052	0.239*	0.335*	0.454*	0.325*
	TE			1.000	0.279*	0.412*	0.174*	0.264*
	Land				1.000	0.516*	0.370*	0.312*
	Labour					1.000	0.276*	0.419*
	Capital						1.000	0.573*
	O. inputs							1.000
Spearman	RTS	1.000	0.524*	0.291*	-0.083*	0.128*	0.377*	0.232*
	PG		1.000	-0.059	0.257*	0.407*	0.614*	0.415*
	TE			1.000	0.386*	0.462*	0.168*	0.430*
	Land				1.000	0.601*	0.418*	0.552*
	Labour					1.000	0.363*	0.660*
	Capital						1.000	0.597*
	O. inputs							1.000

* Correlation is significant at the 0.01 level

From the analysis of the annual value and path of the partial input elasticities, there appear to be evidence of decreasing returns to scale (RTS) until 1995 (sum of output-inputs elasticities less than one) and increasing returns to scale after this year (sum of output-inputs elasticities greater than one)[14]. On the other hand, the correlation coefficients presented in Table 5 suggest that RTS is higher the less land and the more labour, capital and other inputs are used. This result is also confirmed, to some extent, when we compare farms by type, since family farms show returns to scale lower than those with other characteristics ("others").

From the mean values of TE, we can conclude that, based on the production factor consumption, the observed output of Douro farms corresponds only to 64.3% of the potential one (the frontier output), clearly indicating that input usage was inefficient, due to the adoption of inadequate management practices[15]. However, in recent years, these farmers were able to adopt management practices leading to a better input use, expressed by the continuous increase in the TE index. Moreover, and relatively to the technical economic orientation, the farms that show a higher and smaller TE index are, respectively, those that mainly produce grapes for wine (TE = 0.736), and those with a diversified farming system (TE = 0.454).

By type of farm, family farms are the most inefficient in input usage, exhibiting a TE index smaller (0.514) than those with non-family characteristics, the larger and more market orien-

14. In our set of observations, the dominant situation (67.2% of the total) is that of decreasing returns to scale. It is important to highlight that the hypothesis of constant returns to scale, applying the test described in (3), is rejected.
15. By classes, 48% and 52% of the observations have a TE index smaller and higher than 0.7, respectively, showing that a large number of farms have a TE index above the average. The modal class is, therefore, that exhibiting a TE index between 0.8 and 0.9.

ted farms (0.756), and also than the overall average (0.643). The positive sign of the correlation coefficients (table 5) between the TE index and the consumption level of the four production factors allows us to conclude that farmers can improve their technical efficiency by increasing factor consumption.

Table 4 also summarises the results of the PG over time and by farm type, as well as of its components, IC (catching-up) and TC. Until 1995, TC exhibits negative growth rates, but these are decreasing in absolute terms; after 1995, however, its values turn to slightly positive ones. In contrast, the values of IC are always negative[16] (corresponding to positive changes in technical efficiency), notwithstanding the fact that they decrease in absolute terms over time. These findings suggest that between 1988 and 1998, farms had a strong positive change in technical efficiency (expressed by the cumulative value of -63.8% and the average value of -5.6% for the IC), the impact of which, however, was weakened by the inability of farmers to introduce technological improvements capable of moving the production frontier outwards (as seen in the cumulative and average values of TC, -12.7% and -0.9%, respectively). The combination of these two effects led to a positive cumulative and annual growth rate of output (PG)[17] of 51.1% and 4.7%, respectively. That is, when facing a market that is becoming more and more competitive, Douro farmers tended to adopt strategies that led to a more efficient use of the available inputs, allowing them to move closer to the production frontier (expressed by the positive change of technical efficiency), although most of them, especially until 1995, were unable to induce positive changes in the frontier (innovations). These findings raise the following questions: (1) for how long will Douro farmers be able to maintain this positive trend in the productivity of their inputs, and (2) what investment strategies/policies should be applied so that a large majority of them are able to both internalise technological progress and move closer to the new production frontier (i.e. technologically catch up)?

Looking at the results by type of farm, family farms show a negative TC, but the highest IC index, in absolute terms, leading to a higher PG value than that of farms with non-family characteristics ("others"); nevertheless, even the latter have a positive TC value. These findings confirm our expectations, since in our study period it was the larger sized farms that tended to make larger investments in fixed assets. To this end, they used EAGGF-Guidance investment subsidies, leading, *a priori*, to a positive movement in the production frontier (higher TC). However, some farms experienced difficulties in moving towards this new frontier.

16. From the 874 observations, 50.8% (444 observations) and 0.57% (5 observations) exhibit negative values for TC and IC, respectively.

17. The correlation coefficients show that, predictably, the trend in this indicator is related positively with the input partial elasticities and RTS. Nevertheless, we cannot establish any linear relation between PG and TE (the linear and rank correlation coefficients are not significant).

4. CONCLUSIONS

A stochastic production frontier effects model was used to compute the returns to scale, total factor productivity growth and the technical efficiency indices. The empirical results show that Douro farms experienced increasing returns to scale after 1995 and a total factor productivity growth of 4.7% per year, on average, which is, essentially, a consequence of a positive technical efficiency change. Moreover, the indices of technical efficiency indicate that the observed output corresponds only in average to 64.3% of the potential output showing clearly an inefficient use of production factors caused by the adoption of inadequate management practices.

We are confident that our findings and conclusions concerning the production structure and performance of Douro farms could be further refined and improved, were we able to obtain additional information on other variables relating to the farms and farmers in our sample that undoubtedly also influence technical efficiency and productivity scores, namely, data on the physical resources of the farm, farmers' age, their professional background/education level, the extent of their use of extension services, and their ability to access market information.

In summary, despite the limitations of the results of our study, we think that they will be of great use in the definition and implementation of agricultural policies for the Douro region. Among these, we can refer, the introduction of technological innovations in vineyards, supported by European Union funds, and, simultaneously, the implementation of initiatives leading to a more efficient use of the available inputs (e.g., professional training, agricultural extension). Finally, the role of private and governmental institutions in assisting farmers to improve their managerial skills is crucial so that they can exploit the full potential of new technologies.

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