Efficiency of wine grape growers at farm level: a case study

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Abstract. To determine the key variables of the vineyard efficiency is imperative to account the combined effects of the inputs interactions since they have implications on the overall final production. This paper estimates the productive efficiency of a wine-farm sample from the Douro Demarcated Region (DDR) while identifies economic, social and environmental indicators that characterizes the DDR grape production system. The data was collected by face-to-face surveys performed at farm level to build a pilot study. The majority of the sampled twenty farms are dedicated to mountain viticulture and mainly feature the cordon (simple and double) training system. Through the Data Envelopment Analysis (DEA) method, the productive efficiency of the sampled was performed and the results clinched different efficiency scores. The main explanation is related to the heterogeneity of the adopted production system. In addition, they revealed how grape producers could improve their productive efficiency by adopting particular practices and identifying the key factors of their system.

1 Introduction

Due to the relatively abundant vineyard area and the melancholic wine history, Portugal assumes itself as an international reference in the wine sector. However, that accomplishment is hauntingly relative since the country seems to be struggling to gain solid relevance in the highly competitive wine market. According to the OIV [1] worldwide data, Portugal is the 11th largest vineyard area (190 thousands of hectares in 2016), 11th wine producer and concerning the exports (both volume and value) Portugal caps the ninth place [1]. Nonetheless, this country watched those rankings deprecate during the period 2012-2016 since 18% of the total vineyard vanished and that fact caused an impact on the wine production and volume exports (15% and 18% respectively) [1]. On the other hand, the Portuguese wine exports increased 4% in value on the aforementioned period [1], suggesting that despite of the smaller volume of wine exported, the value of each bottle of Portuguese wine increased. However, that positive value evolution is still way far from the world's overall export value growth, which is roughly 14% [1].

Douro Demarcated Region (DDR) is the most important Portuguese wine region capping 22% and 21% of the total Portuguese wine production and vineyard area respectively [2,3]. This region is characterized by a steep mountain viticulture known by the coexistence of heterogeneous production systems. Their farms are assembled in several blocks where each block usually features a different variety of grapes and distinctive management endeavours. The steep slopes difficult the mechanization of the production process and obligates the producer to rely on huge amounts of seasonal workers, which are currently scarce due to the severe depopulation and aging of the region. Those challenges substantially increase the costs of producing grapes in DDR resulting in foregoing lower productivity [4]. One of the main costs of producing wine comes from viticulture, therefore, improving the efficiency at the grape-growing level can have an important impact on the commercial success of the Portuguese wine sector.

This paper also aims the recognition of economic, social and environmental indicators, which are able to characterize the grape production system of DDR farms and estimate their productive efficiency afterwards.

The article is divided in five sections. Besides the overview of the main objective, the following section introduces the notion of productive efficiency, with a brief literature revision. The used methodology is described in section three and the gathered results in section four. Finally, section five summarizes the main conclusions and suggestions for further research.

2 Productive Efficiency

Pioneering studies of productive efficiency literature starts with the works of Koopmans [5] and Debreu [6]. The first introduced the concept of technical efficiency (TE) and Debreu [6] developed the first measure of technical efficiency designed as "coefficient of resource utilization". Afterwards, Farrel [7] announced the frontier model to measure the economic efficiency (EE) broken down in TE and allocative efficiency (AE). The first (TE) states that when a certain level of inputs is given and the Decision Making Unit (DMU) is able to produce the maximum level of outputs or, fixing a certain level of output, the DMU is able to minimize the level of input [5,8,9]. The AE reflects the ability of a firm to use the inputs in their optimal proportions (given their respective prices) to minimize the cost or maximize the revenue [8,10]. There is also another type, which is the scale efficiency that tells us if a DMU is operating on an optimal scale [11].

Several studies have already estimated the productive efficiency in wine sector. Marta-Costa et al. [12], Freitas [13], Coelli and Sanders [14], Moreira et al. [15] and Henriques et al. [16] put their efforts into studies that aim the efficiency calculation of the grape producers, while Sellers-Rubio et al. [17], Sellers-Rubio & Más-Ruiz [18] and Aparicio et al. [10] studied the efficiency at the wineries level. Urso et al. [19] acquaint the efficiency of grape and wine producers in the same paper. Tóth & Gál [20] research the efficiency of wine producers at a country level and Vidal et al. [21] study the efficiency of the different denomination of origin (DO) existing in Spain.

The most popular variables among several studies are the grapes (quantity) and the general wine production (quantity or value). Tóth & Gal [20], Coelli & Sanders [14], Moreira [15] and Freitas [13] studied the quantity of output produced, while Marta-Costa et al. [12], Urso et al. [19], Sellers-Rubio et al. [17], Sellers-Rubio & Más-Ruiz [18], Aparicio et al. [10], Vidal et al. [21] and Henriques et al. [16] studied the value of output that was produced. Regarding the input variables, there are three variables mostly used in the precedent articles: labour, capital and land. In addition, some studies considered other inputs such as the intermediate consumption, total specific costs and irrigation [12-14] even though irrigation is only important for dryland agriculture [14].

The variables used to determine the causes of inefficiency in the wine sector are not consensual. Some are related to inner characteristics, such as the size of the farm and the farmer's gender, age education [16,19,22]. Meanwhile other efforts pointed out other features such as the diversification/specialization of products [14, 16], irrigation [14,16,22], credit access, quality of human capital and per capita wine consumption [23].

3 Methodology

This work uses the Data Envelopment Analysis (DEA) method to estimate the productive efficiency in twenty vineyard farms from DDR. In order to identify the best practices in grapes production, we assumed that the farmers were following a cost minimizing (input-orientation) strategy.

The input oriented model considers that a company will be efficient if given certain availability of outputs that company is able to minimize the available resources (inputs). Bearing in mind that the input and output oriented models estimate exactly the same frontiers, in the end they will be able to label the same companies as the efficient ones [18]. The problem of the farmer is the selection of a minimal but admissible input combination without jeopardizing the yield [24].

We assume that any farm j ($j = 1, 2, 3… n$) produced a single output y_r (grape yield) using a combination of inputs x_{ij}. Following the constant returns to scale (CRS) input-oriented DEA model used by Cooper et al. [25], the efficiency of a farm relative to other farms is calculated using the following model (equation 1):

$$minimize \; \theta - \left(\sum_r s_r^+ + \sum_i s_i^- \right) \quad (1)$$

Subject to following constraints,

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta_0 x_{io}, \quad i = 1,2,…,m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{ro}, \quad r = 1,2,…,s$$

$$\lambda_j, s_r^-, s_r^+ \geq 0; \; \forall_i, j, r$$

where x_{ij} and y_{rj} are inputs and outputs respectively, which were defined earlier; λ_j is the vector of weights of the efficient farms helping in projection of inefficient farms to an efficient frontier (i.e. the distance of

inefficient farms from the frontier); θ is an index of farm's technical efficiency.

However, a typical variable-return to-scale (VRS) is considered in reality farming activity because of the potential economies of scale [26]. Banker et al. [27] extended the earlier work of Charnes et al. [28] including an extra constraint $\sum_j \lambda_j = 1$ in equation (1) leading to a VRS frontier. The TE obtained in CRS DEA model is divided into two components obtained by VRS DEA model (equation 2).

$$TE_{CRS} = TE_{VRS} \times SE \qquad (2)$$

The second step studies the determinants of the inefficiency on farms alongside a brief econometric analysis with a Tobit model that can be expressed by equation (3) [19].

$$\theta_j = \alpha + X_j \vec{\beta} + \varepsilon_j \quad j = 1, 2, \ldots, N \qquad (3)$$

where θ_j is the efficiency level of the *j-th* farm obtained by DEA, α is the estimated coefficient for the intercept, X_j is a matrix assembled by the explanatory variables of the respective vectors, β is a vector of the estimated coefficients, and ε_j is the stochastic error.

The data was gathered from a sample of 20 Portuguese grape producers by a structured face-to-face survey that was conducted with the owners or managers of the DDR holdings. This data is a preliminary sub-sample of the database that is being developed based on criteria such distinct spatial distribution in DDR and diversity of farms dimension and corresponding to the agricultural season of 2016-2017.

The used output variable was the grape production revenue in euros and the used inputs variables were the land (ha), labour (days), capital (euros) and intermediate consumption (euros). The determinants of the efficiency of farms used in tobit model were the vineyard area (ha), farmers' age, the grape production as the main source of income, the training systems adopted (cordon and guyot), and the vineyard landscaping (walled terraces/socalcos, patamares, vertical planting and plan). The studied grape farms have an overall average size of 14,75 ha but accounting only the space dedicated singularly to grapevines that value drops to 9,42 ha. In addition, there is a substantial disparity among the size of farms, since the smallest farm has only 1,96 ha and largest one farm caps a total area of 24,43 ha of vineyard. As stated before the farms on DDR are usually divided in several blocks, that fact is confirmed

by the sample mean value of 4,75 blocks within vineyard area.

Most of the grapes are produced using the cordon training system (75%), while only 25% selected the alternative guyot training system. According to the vineyard landscaping, the most are in levelled upland ("Patamares", 55%), followed by vertical planting (23%), plan (11%), walled terraces (5%) and mix situations (5%).

4 Results

The average values of the indicators from economic, social and environmental dimensions for the 20 studied farms are presented in Table 1, 2 and 3, respectively. The grapes production average is 4985 kg per ha but there are distinct productivities among farms, due to the production cycle of the vineyard and the productive system adopted. In addition, the corresponding revenue levels (without subsidies) are different due to the distinct prices payed to the high-quality grapes for Port and DO wines production. Summarily, the results show greater benefit/costs ratio for farms that adopt different training systems in their blocks (mixt), followed by the farms with only cordon system.

Table 1. Economic indicators of the studied grape farms (2017)

Training system	Cordon	Guyot	Mix	Total
Grape production (kg/Ha)	4873	4042	6057	4985
Revenue (€/Ha)	3251	2798	4015	3336
Capital (€/Ha)	51234	29360	47167	47139
Intermediate Consumption (€/Ha)	1078	1470	1426	1206
Real costs (€/Ha)	3301	3256	2937	3221
Benefit/cost Ratio	1,22	0,89	1,54	1,23
Grape production as main source of income (%)	46	33	75	50

Regarding the social domain (Table 2), the selected indicators bundled the farmers, education and age. The farmers have an average age of 50 years old and 55% of them have high education. In addition, the farmers with total dedication to vineyard, prospect of increasing or

maintaining vineyard area and willingness to continue the viticulture were considered. Moreover, 95% of the farmers intend to continue the viticulture activity and there are only 65% that fully dedicate themselves to this sector (without parallel professional activities). The farmers majority (80%) intend to at least maintain or even increase the vineyard area of the farm in the upcoming years.

Table 2. Social indicators of the studied grape farms (2017)

Training system	Cordon	Guyot	Mix	Total
Labour (days/Ha)	70	74	81	73
Farmers with high school (%)	62	67	25	55
Farmers age	47	47	62	50
Farmers with total dedication to vineyard (%)	54	67	100	65
Prospect of increasing or maintaining vineyard area (%)	77	67	100	80
Continuity on viticulture (%)	100	100	75	95
Activity heirs (%)	46	67	75	55

The results from the studied farms within the environmental dimension (Table 3) show that the Patamares and vertical planting dominate the vineyard landscaping due to their slopes, as showed by the physiographic index. All farms with guyot system adopted the integrated farming and the crop protection assumes lower values per ha.

Table 3. Environmental indicators of the studied grape farms (2017)

Training system	Cordon	Guyot	Mix	Total
Fertilizations (€/Ha)	157	308	161	181
Crop protection (€/Ha)	422	402	510	437
Integrated farming (%)	85	100	75	85
Organic farming (%)	8	0	0	5
Soil analysis (%)	85	100	100	90
Favourable waste destination (%)	92	67	100	90
Physiographic index of the landscape (IQFP)	2,7	0,6	1,8	2,2
Walled Terraces (*Socalcos*) (%)	8	0	4	5
Patamares (%)	53	81	34	55
Vertical planting (%)	23	5	44	23
Traction (H/Ha)	30	34	38	32

Table 4 shows some descriptive statistics of the sample of the 20 studied grape farms and Table 5 shows the results of the productive efficiency estimation trough DEA using the STATA 14 software [29].

Table 4. Descriptive statistics of variables for the studied grape farms

Variables	Mean	Std. dev.	Min	Max
Grapes production (€)	32702,5	30293,1	5875	128819
Vineyard area (ha)	9,42	6,81	1,96	24,43
Labour (days)	586,39	375,93	213,25	1575
Intermediate costs (€)	17623,35	28470,25	1288	123467
Capital (€)	404144,5	344361,1	64795	1259041

The average of overall TE (TE_{CRS}) of grape production is 75,65%, and it ranged from 35% to 100%. The most efficiency farms are described as DMU 1, 6, 14, 17, 18 and 20. In the VRS analysis, as expected, there are higher levels of pure TE (TE_{VRS}), where ten farms have a score of 100%. The average of TE_{VRS} is 91,38% and it ranges from 42,39% to 100%. The presence of scale efficiency (SE) was proved by larger average value of TE_{VRS} than TE_{CRS} and the average of SE is 83,02%.

The results shows that the performance of the farms is uneven due to the high levels of inefficiency of some farms compared to the best practices of the farms with the highest levels of the efficiency. The low efficient levels of farms (12 and 19) is due to the pure TE and to the SE, respectively. Thirteen farms exhibit increasing returns to scale, six exhibit constant returns to scale and only one exhibit decreasing returns to scale.

Table 5. Efficiency scores of grape farms

DMU	TE_{CRS}	TE_{VRS}	SE	RTS
1	1,000000	1,000000	1,000000	-
2	0,790624	0,925318	0,854435	irs
3	0,735250	1,000000	0,735250	irs
4	0,763829	0,957323	0,797881	irs
5	0,536637	1,000000	0,536637	irs
6	1,000000	1,000000	1,000000	-
7	0,557135	0,895958	0,621832	irs
8	0,997661	1,000000	0,997661	irs
9	0,573671	0,753590	0,761251	irs
10	0,620784	0,978312	0,634545	irs
11	0,909096	0,909248	0,999833	irs
12	0,363374	0,423914	0,857187	irs
13	0,544799	1,000000	0,544799	irs
14	1,000000	1,000000	1,000000	-
15	0,692430	0,743937	0,930765	irs
16	0,694269	0,714644	0,971489	drs
17	1,000000	1,000000	1,000000	-
18	1,000000	1,000000	1,000000	-
19	0,350069	0,973369	0,359647	irs
20	1,000000	1,000000	1,000000	-
Mean	0,7564814	0,9137807	0,8301606	

Irs: increasing returns to scale; drs: decreasing returns to scale.

Table 6 shows the tobit model results for TE_{VRS}. The results reveals that size has a directly effect on the pure TE, therefore larger vineyard area originates more efficient farms. The age has a negative relationship with the efficiency performance of the farm, revealing that the farmer aging lowers the performance of the farm. In addition, farms that have grape production as the main source of income have lowers levels of pure TE. Regarding to the training systems, the results reveal that guyot and cordon have a negative influence on the efficiency, however only the coefficient of cordon variable is statistically significant at 5%. For the vineyards landscaping, all coefficients show lowers levels of TE_{VRS}, but only the vertical planting is statistically significant at 1%. It should be detached, that farms that used a mix of training systems and several vineyard landscaping had a positive effect on the farm efficiency.

Table 6. Tobit model results for TE_{VRS}

Variables	Coefficient
Constant	2,137537***
Vineyard area	0,0056197
Farmers' age	-0,0064585
Grape as main source of income	-0,167565
Guyot training system	-0,3896096
Cordon training system	-0,403977**
Walled terraces/Socalcos	-0,0602633
Patamares	-0,4470291
Vertical planting	-0,6721773*
Plan	-0,4935155

Statistically variables: *=10%; **=5%; ***=1%

5 Conclusion

The challenge of maintaining or improving agricultural productivity in DDR is enormous. Researchers and policy-makers are constantly looking for technologies that are economically and environmentally attractive to improve the efficiency of the farms. In this experimental work, the TE estimation elucidates that the majority of the sampled farmers are not efficiently using the available technology.

The mean of overall TE of the 20 farms from DDR is 75,65%, revealing that farms could reduce 24,45% of the used inputs in average. However, this efficiency is very unequal between farms, some with high levels while less than 40% have low efficiency. In average,

these levels are mainly due to the scale efficiency, therefore farms are not operating at the efficient size.

About the determinants of the efficiency, some production practices proved to be more efficiency. For the 20 farms of the sample, the ones that use a mix of guyot and cordon training systems have better efficiency performances and cordon system seems to be the most inefficient. The same occurs in the vineyard landscaping, the farms that feature several systems appears to have better efficient performances and the vertical planting has a stronger negative relationship with efficiency. In addition, the farmers' age and their full dedication to the vineyard activity have negative influence on pure TE, while the size of vineyard area increase the efficiency scores.

To highlight that all results and conclusions of this work were obtained and studied for the twenty farms sample and cannot be extrapolated for DDR.

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