An Application of Data Envelopment Analysis (DEA) in Azores Dairy Farms

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Abstract

This research tries to measure the Azores dairy farms technical efficiency by applying a non-parametric efficiency analysis to a panel data of 122 dairy farms from the Azores, Portugal for 1996. The analysis used DEA with constant and variable returns to scale models, with an input-oriented model approach. Two outputs (milk production and subsidies) and three inputs (agricultural area, number of dairy cows, variable and fixed cost) were considered relevant. The results suggest that the average technical efficiency is very low (66,4%) compared with published research data and only a few (7%) dairy farms were found to be efficient.

Résumé

Ce travail se propose d'évaluer l'efficience des exploitations laitières des Açores, en utilisant une méthodologie non paramétrique d'efficience, Data Envelopment Analyses - DEA, sur l`information de 122 exploitations laitières, relative a l`année 1996. L`analyse utilisée a été le DEA, avec des modèles de revenus a l'échelle soit constante soit variée et une approche orientée a l`input. On a considéré deux outputs (production de lait et subventions) et trois inputs (surface agricole, nombre de vaches laitières et coûts variables et fixes). Les résultats suggèrent que l`efficience technique moyenne est très basse (66,4%) si comparée avec d`autres travaux sur le sujet, et seulement 7% des exploitations laitières ont été efficientes.

1. Introduction

The Azores islands belong to the Portuguese territory with a population of about 250,000 inhabitants; the main economic activity is dairy farming. Dairy policy depends on CAP (Common Agricultural Policy) of the European Union. Different authors have analyzed dairy farming by using different methodologies. This paper tries to study the sector form the agricultural economics point of view based upon farms typology behavior.

The methodology in this paper is based on the estimation of technical efficiency of dairy farms, using random selection of 122 dairy farms from the database (1996) of the European Union, Farm Accountancy Data Network (FADN).

Data Envelopment Analysis (DEA) is used to estimate the efficiency. Charnes, Cooper and Rhodes (1978) developed the method from the earlier works by Farell (1957). This non-parametric method has been used to estimate the efficiency in the organizational units in several areas; Cooper (1999) presents a general review of the past development and future possibilities of the methodology.

DEA involves the use of technical linear programming to construct a non-parametric piecewise surface (or frontier) over data, and also to enable the calculation of an efficient firm relative to its surface (Coelli, 1996). Any farm that lies below the frontier is considered to be inefficient. DEA permits to construct a best-practice benchmark from the data on inputs and outputs (Jaforullah and Whiteman, 1999).

We will use the LP approach, but reader should remember that another alternative approach is the use of statistical parametric techniques, based upon econometric methods, to construct a stochastic frontier.

DEA involves the concept of efficiency divided by Farell (1957) into: 1) technical efficiency, and 2) allocative efficiency. The technical efficiency measures the maximum equiproportion reduction in all inputs and still allows continued production of given outputs. The technical inefficiency measures the magnitude. The allocative efficiency reflects the ability of a firm to use the inputs in optimal proportions, given their respective price. These two concepts form the concept of economics efficiency (Coelli, 1995). The allocative inefficiency measures the magnitude of consequent loss. Similar considerations are applied to economics efficiency and inefficiency.

Therefore, the overall measure of technical efficiency can be disaggregated into three components: 1) pure technical efficiency due to producing within an isoquant frontier; 2) congestion due to over-utilization of inputs, and 3) scale efficiency, due to deviations from constant returns to scale (Weewsink et al., 1990).

Previous applications of DEA dairy farming were made in order to estimate the efficiency by different researchers in different parts of the world (table 1). We have summarized some recent papers on the subject.

Recently, Arzubi and Berbel (2001) estimated the technical dairy efficiency with DEA using 35 farms in Argentina. The average technical efficiency was 78.2% and about 11.4% of all farms were efficient to constant returns to scale. They divided the global technical efficiency (CRS) into two components, and they observed that there is a bigger pure technical inefficiency (16.5%) compared

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Table 1. *Dairy Farms DEA Efficiency Researches*

	Country	Year	Technical Efficiency	Farms Number	Efficient Farms
Arzubi and Berbel (2001)	Argentina	1997/98	78,2%	35	11,4%
Jaforullah and Whiteman (1999)	New Zealand	1996	83,0%	264	19%
Fraser and Cordina (1999)	Australia	1995	90,5%	50	24%
		1996	90,8%	50	20%
Cloutier and Rowley (1993)	Canada	1988	88,0%	187	15%
		1989	91,0%	187	21%
Gonzalez Fidalgo *et al.* (1996)	Spain	1991	78,0%	133	5%

with the scale inefficiency (6.1%). They explained this fact, with the 22 firms that were operating increasing constant returns to scale and 8 were operating decreasing returns to scale.

Also, Reinhard et al. (2000) estimated the efficiency measures for 163 highly specialized Dutch dairy farms from FADN. They compared two methods for calculating the efficiency, namely the stochastic frontier analysis and DEA. They concluded that both methods can estimate environmental efficiency scores, but they differ according to the methods used.

In New Zealand, Jaforullah and Whiteman (1999) examined the relationship between size and efficiency of dairy farms. The average technical efficiency was estimated at 89% and in general the results support a policy of encouraging increasing farm size. In this study, 19% of 264 dairy farms were found to be efficient.

DEA were used by Fraser and Cordina (1999) to assess technical efficiency of 50 dairy farms in Northern Victoria, Australia, over the periods 1994/95 and 1995/96. The average technical efficiency was 90.5% and 90.8% for 1994/95 and 1995/96, respectively. 24% of the dairy farms were efficient for the period 1994/95, but decreased by 20% in the subsequent period.

Cloutier and Rowley (1993) applied DEA to measure technical efficiency of 187 dairy farms in Quebec, Canada for the years 1988 and 1989. Their DEA model was based on the assumption of constant returns to scale. The technical efficiency of the Quebec dairy farms was 88 and 91% for 1988 and 1989, respectively; 15 and 21% of dairy farms were efficient. They suggest that their results show that larger farms are much more likely to appear efficient than the smaller ones.

In Spain, Gonzalez et al. (1996) estimated the technical dairy efficiency of a panel with 133 dairy farms in Asturias (Northern Spain). The average global technical efficiency was around 78%, but only a few (5%) were efficient.

Fare and Whittaker (1995) used the non-parametric methods to estimate the efficiency of 137 dairy farms. They also took into account the decomposition production into sub production processes with the outcome that a larger number of variables may be useful to be included in the model. They compared the efficiency with the dimension of the dairy farms (small, medium and large). The results show that using intermediate products increases the efficiency in any dimension of the dairy farms considered.

In Canada, Weersink et al. (1990) estimated the technical efficiency of 105 dairy farms in Ontario. As a result they found 43% of dairy farms efficient and their average technical efficiency was around 91.8%.

As we can see, DEA has been widely used in dairy farming analysis. We can find many other applications to agricultural economics such as Reinhard and Thijssen (2000) who estimated the nitrogen efficiency in 434 dairy farms in Germany. They used a shadow price; the mean nitrogen efficiency was around 56%, and the mean input-oriented technical efficiency was 84%.

On the other hand, some researchers, Tauer (2001), Maieta (2000), Brummer and Loy (2000), Reinhard et al. (1999), Alvarez and Gonzalez (1999) and Hallam and Machado (1996), use parametric methods (econometric) to estimate dairy farms efficiency. Also Tauer (1998) used DEA to evaluate the efficiency of some New York dairy farms using the Malmquist productivity index.

In this study, DEA was selected because it offers the opportunity of including more than one output and permits the relationship between all inputs and outputs simultaneously. DEA also yields a relative measure of efficiency more than the frequently reported partial indicators of farm efficiency such as milk production per hectare or milk production per cow. Finally, DEA does not require a parametric specification of a functional form to define the frontier.

The major limitations of DEA are that it is difficult conceptually to separate the effects of uncontrollable environmental variables and error measurements from the effect of differences in farm management and the presence of outliers. By using the stochastic frontier methodology one can find the causal factors may solve this.

2. Material and Method

The Azorean data of FADN -1996 permits to observe that, in general, dairy farms are small and most of them belongs to the owners. The average agricultural area is around 23.7 hectares (more than 85% is pasture) and the average number of dairy cows is about 23 per farm. The production system is primarily based on grazing, and the main product is milk (84%). Most expenses go on concentrates (27%), annual depreciation (13,6%), rents (10,6%) and fertilizers (9,8%) (Silva, 2001).

In previous years the European Union had national programs to increase the farms' areas and dairy production. In the period between1986 and 1996 the milk production had increased by around 70.9% as a result of the "milk quota systems" of the European market regulation.

The database was characterized by three types of grazing systems defined by Silva (2001). The first group of dairy systems was extensive (cows per hectare smaller than 1.4), the second group of dairy farms was medium intensive (1.4 to 2.4 cows per hectare), and the third intensive (bigger than 2.4 cows per hectare).

The dairy farms' technical efficiency was analysed by Data Envelopment Analysis Computer Program (DEAP) developed by Coelli (1996). This program is based on the optimisation model (1) developed by Charnes et al. (1978); it considers the input components ViXij as a constant (K).

$$\begin{aligned} &MaxE_j = \sum_{1}^{n} U_i Y_{ij} \\ &s.t.: \sum_{1}^{m} V_i X_{ij} = K \\ &\sum_{1}^{n} U_i Y_{ij} - \sum_{1}^{m} V_i X_{ij} \le 0 \\ &U_i, V_i \ge 0 \end{aligned} \qquad (1)$$

Y_{ij}, is the level of output i used by decision-making unit j, X_{ij}, is the level of input i used by decision-making unit *j*, and U_i and V_i are the non- negative variable weights associated with the solution of decision-making unit *j*, of outputs and inputs, respectively.

In our model two outputs were considered: y_1, liters of dairy produced, and y_2, subsidies received by farm (escudos). On the other hand, three groups of inputs were included: x_1, agricultural area (hectare), x_2, dairy herd (number) and x_3, dairy variables costs, i.e., fertilizer, feeding: concentrates, pasture and others and fixed costs, labor, annual depre-ciation of buildings and machinery, paid rents (escudos).

By adjusting this model to our case we measure efficiency, E_j, like this:

$$E_j = \frac{U_1 litres\ of\ milk + U_2 escudos\ of\ subsidies}{V_1 agriculture\ area + V_2 cows\ number + V_3 costs} \qquad (2)$$

Equation (2) E_j=1 means the dairy farms are efficient when compared with all the other firms, and when it is smaller than one, the dairy farms are inefficient.

The constant returns to scale model (CRS), corresponds to the original model developed by Charnes et al. (1978), that assumes all firms were operating at an optimal scale. Later Banker et al. (1984) suggested a model extending the original, in which the variable returns to scale (VRS), change the linear programming by incorporating convexity limitations (restrictions). This change permitted the division of technical efficiency (or global technical efficiency) into pure technical efficiency and scale efficiency.

If the CRS and VRS are run operated with some data and if there is some difference between firms, that is due to scale inefficiency. That inefficiency must be calculated from the difference between CRS and VRS. The pure technical efficiency coincides with VRS. The scale inefficiency, can be ex-plained as a result of the fact that scale level is not optimal (when CRS=1). The global technical efficiency (CRS) is the product of pure technical effi-ciency and scale technical efficiency. When not all decision-making units are operating at the optimal scale, it will result in technical efficiency, which can be confused with scale efficiency. The use of the VRS specification will permit the calculation of technical efficiency devoid of these scale efficiency effects.

Many studies have separated the technical efficiency scores obtained from a CRS DEA into two components: 1) one due to scale inefficiency and 2) another one due to "pure" technical inefficiency (Coelli, 1996). If there is a difference in the two technical scores for a particular decision-making unit, then this indicates that the decision-making unit has scale inefficiency and that scale inefficiency can be calculated from the difference between VRS and CRS technical efficiency scores.

The FADN database includes also mixed farming, therefore, before applying the DEA method, it was necessary to extract pure dairy farms from the global database. The selection of these farms was done as follows:

1) Select the farms with OTE (Technical and Economics Orientation) 4.1, 4.2 and 4.3. This classification, provided by the European Union for all agricultural farms, has to do with ruminants.
2) Refine the FADN database, and remove errors in the data.
3) Exclude those farms whose dairy production was below 3500 liters per cow each year.
4) Eliminate the dairy farms whose specialization ratio was more than 0,66. Avillez (1989) defined this ratio for the Azorean farms. It is defined by the following formula:

$$Specialisation = \frac{Total\ cows\ (meat + dairy) - dairy\ cows}{dairy\ cows} \qquad (3)$$

Finally, we apply DEA to 122 pure dairy farms in the Azores.

3. Results and discussion

The main results are (table 2):

- Only 9 dairy farms were efficient, thus representing a 7,4 % of the total number of farms.
- The average technical efficiency was 0,664. It is possible

Table 2. *Statistics of the Azorean Dairy farms (technical efficiency: increasing and decreasing, and constant)*

	CRSTE	VRSTE	SCAL
Mean	0,664	0,782	0,855
Standard Deviation	0,154	0,160	0,123
Maximum	1	1	1
Minimum	0,286	0,375	0,491
Efficient farms	9	25	9
IRS dairy farms			88
DRS dairy farms			25

Figure 1. *Milk Production and Technical Efficiency in Azores Dairy Farms*

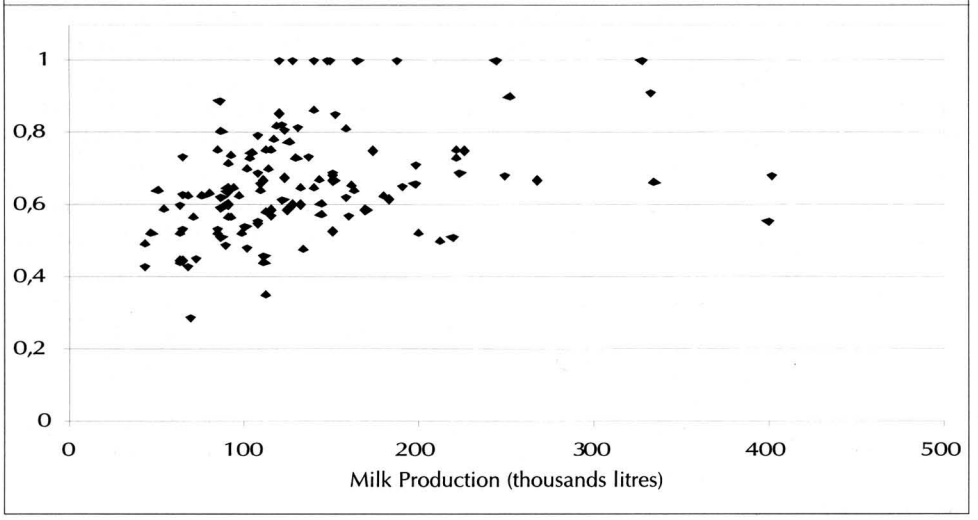
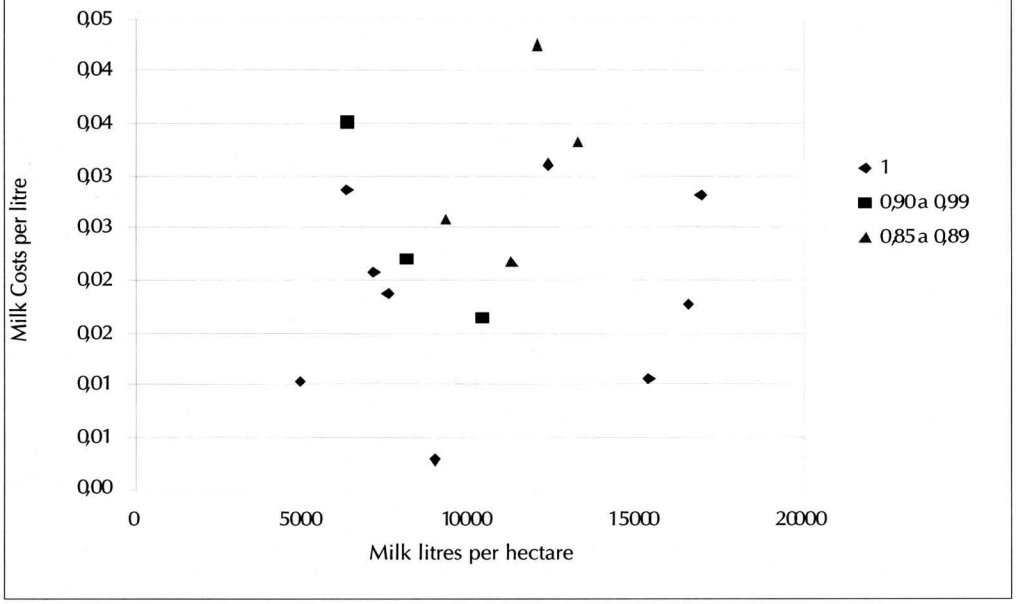


Figure 2. *Milk Costs per litre and milk production per hectare*



to produce the same amount of milk while saving approximately 33,6% of resources (or inputs).

These results showed that the Azorean dairy efficiency could be improved.

The global technical efficiency (CRSTE) is divided into two components, VRSTE and SCAL. Technical efficiency from variable returns to scale model increased to 0,782, and scale efficiency is 0,855.

Scale inefficiency (14,5%) may occur due to an operation below the opti-mal scale, as a result of the fact that a 72,1 % of dairy farms operate at in-creased returns to scale. And a 20,5% were operating at decreasing returns to scale.

In Figure 1, it can be observed that the efficient farms exist in any level of milk production. There is no direct relation between the technical efficiency and the milk production. However, most of the efficient farms are grouped within the 100 and 200 thousands liters of milk stratum.

Figure 2, shows that efficient farms have reduced costs of milk production per hectare. Another factor to be considered is that efficiency does not seem to be related to the amount of milk produced per hectare. This means that there are efficient dairy farms at any level of milk production per hectare. Larger dairy farms would be expected to have higher efficiency levels as mentioned by Tauer (2001).

Comparing efficiency in-groups of Azorean dairy farms (intensive, extensive and inter-mediate) as defined by Silva (2001), we found that there is not one production system with a higher number of efficient farms than the other. This means that the efficiency does not depend on the intensity of grazing, but probably on the importance of some fixed costs (equipment depreciation), and some variable costs (animal feeding). Silva (2001) found the animal feeding and equipment depreciation in the Azorean dairy farms of great importance, about 27% and 13,6% of total cost, respectively.

In the Azores dairy farms, technical efficiency is the lowest (66,4%) found when compared to published research (table 1). The above mentioned literature review reports a mean technical efficiency higher than 88%. Even the number of efficient farms (about 7%) is the second lowest reported value.

The small dimensions (around 25 hectares per farms) may explain this low efficiency in the Azores (smaller farms in New Zealand, Canada or Australia). As Cloutier and Rowley (1993) suggest, bigger farms are more efficient. What's more, the inefficiency in the Azorean dairy farms seems to be influenced by the great amount of fixed costs spent on agricultural equipment and animal feeding with concentrates.

4. Conclusion

The results show that the Azores dairy farms must increase their technical efficiency given that they operate above their resource capacity. It is now necessary to help those small dairy farms in order to make them more efficient.

The efficiency is not directly related to a specific production system. Re-sults show that there are efficient farms in any Azorean farm type: intensi-ve, extensive and intermediate, with different technologies.

Further research must be considered for the DEA concerning relationship between operational research and management science. Cooper (1999) suggests that DEA is a variant of multimodal programming. Using DEA and multicriteria decision-making efficiency must be compared, as sugge-sted by Stewart (1996) and Glokas (1997). Finally, it will be interesting to do further research combining different techniques, operational research and statistics.

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