AN APPLICATION OF DATA ENVELOPMENT ANALYSIS IN A SAMPLE OF DAIRY FARMS

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ABSTRACT

Data Envelopment Analysis is an operational research procedure aimed at measuring the relative efficiency of production units mainly in the non-market sectors of the economy.
This procedure is applied in agriculture and specifically in the dairy sector which displays the characteristics required in the empirical application of the procedure.
Farm management data from 86 dairy farms are used for the application of the DEA. Each farm is taken as a Decision Management Unit (DMU) the relative efficiency of which is measured.
The solution of the model demonstrates that fifty six farms are relatively efficient while indicating the necessity to reorganize the thirty remaining units to improve their efficiency.

RÉSUMÉ

L'Analyse d'Enveloppement des Données est une procédure de recherche opérationnelle visant à mesurer l'efficience relative des unités de production dans les secteurs non-marchands de l'économie.
Cette procédure est appliquée en agriculture et notamment dans le secteur laitier qui présente les caractéristiques requises pour l'application empirique de la procédure. On utilise les données de la gestion de 86 entrepriscs laitières pour l'application de l'AED. Chaque entreprise est considérée une Unité de Gestion Décisionnelle (UGD) dont on mesure l'efficience.
La solution du modèle fait ressortir que ciquante six entreprises sont relativement efficientes mais il faut réorganiser les trente unités qui restent pour améliorer leur efficience.

The non-parametric method initiated as Data Envelopment Analysis (DEA) by Charnes, Cooper and Rhodes (1978, 1979, 1981) is based on Farrell's proposed activity analysis.
It provides an alternative to the parametric approaches used to make estimations of frontiers in economics.
In contrast to the parametric approaches DEA does not require that we make any assumption about the functional form or about the use of prices for the aggregating of inputs and of outputs of a production unit.
Consequently DEA as a method is particularly attractive in the case of multiple-output and multiple-input production units when prices are not available or when there is no objective way of aggregating either input or output.
This explains that DEA has been applied mostly in the public sector, in a range of non-profit production units.
Its being widely accepted acts as a testimony of the procedure's strength and applicability (Fried et al. 1993, Silkman 1986).
It is worth noting that DEA is applicable to any sector of the economy as an approach to measure the efficiency of multi-output and multi-input production units.
Most of the studies of efficiency in the agricultural sector follow the general methodology employed by Lau and Yotopoulos (1971, 1973).
The renewed interest in measuring efficiency is due to methodological improvements in the development of parametric and non-parametric approaches and has yielded a considerable amount of empirical work.
Examples of this work using data from agricultural farms are the studies of Bravo-Ureta and Rieger (1990), Neff et al. (1993), Parikh and Shah (1994), and Fare and Whittaker (1995).
This work focuses on comparing results taken from parametric and non-parametric approaches.
Some applications of DEA in agriculture can be found in studies of this type.
Though they are of high theoretical interest, they cannot be used to derive information for management purposes since inputs and outputs are not usually adequately disaggregated.
DEA applications for management purposes are limited.
The study of Byrnes et al. 1987 which measures the relative productive efficiency of Illinois grain farms is an example. The application of DEA in our study follows similar lines, i.e. to identify the sources of inefficiency of dairy farms and to provide improvement targets for the inefficient running farms.
The provision of detailed input and output data derived from a farm management survey of a sample of dairy farms is an advantage that the study exploits.
The results reflect the disaggregation of input and output and can be put to practical use. Indications are obtained as to how inefficient farm management can be made efficient by adjusting the use of resources and the mixture of the output.
The effect of the required adjustments of the inefficient farms on the mean sample farm is estimated. Finally, the results indicate that, given the existing quota imposed in milk production, the most important

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measure to be taken in consideration is the necessary adjustment of the use of resources.

THE BASIC VERSION OF DEA MODEL

There is a number of multiple-input multiple-output production units to be evaluated, which are taken as Decision Management Units (DMUs). Each DMUs consumes varying amounts of different inputs to produce different outputs. DEA uses the set of production units in the sample to construct an efficiency frontier consisting of all possible linear combination of efficient production units. The efficiency frontier represents applicable technique since it reflects the practices implemented by existing production units. It also represents efficient techniques since it is exclusively defined in terms of the techniques used by efficient production units. Consequently the efficient units lie by definition on the frontier while the inefficiency of units that are not on the frontier is indicated in direct proportion to their distance from the frontier. The framework for the DEA was initiated by Farrell (1957) and reformulated as a mathematical programming model by Charnes, et al. (1978). A general overview and a detailed development of the approach was provided by Fried et al. (1993), while the extensions that have been proposed and a discussion of the advantages and limitations of the approach can be found in Seiford and Thrall (1990). The proposed measure of efficiency of any DMU is obtained as the maximum of a ratio of weighted outputs to weighted inputs subject to the condition that the similar ratios for every DMU be less than or equal to unity. The DEA model for a specific DMU is formulated as a non linear programming problem and stated as:

$$\max h_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} \upsilon_i x_{ik}}$$

Subject to: $$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} \upsilon_i x_{ij}} \leq 1; \; j = 1 \ldots n$$

$$u_r, \upsilon_i \geq 0 \qquad r = 1,\ldots\ldots,s \qquad i = 1,\ldots\ldots,n$$

Where (y_r, x_i) are the observed output and input values, respectively; ur and õi are the variable weights to be determined by the solution of this problem; n is the number of the units (DMUs); s is the number of outputs; m is the number of inputs; and hk is the relative efficiency of k unit. The above non-linear ratio programming model is converted to a linear programming model (Charnes et al. 1978) mainly for computational tractability.

The primal linear programming DEA model is the following:

$$\max \sum_{r=1}^{s} y_{rk} u_r - \sum_{i=1}^{m} x_{ik} \upsilon_i$$

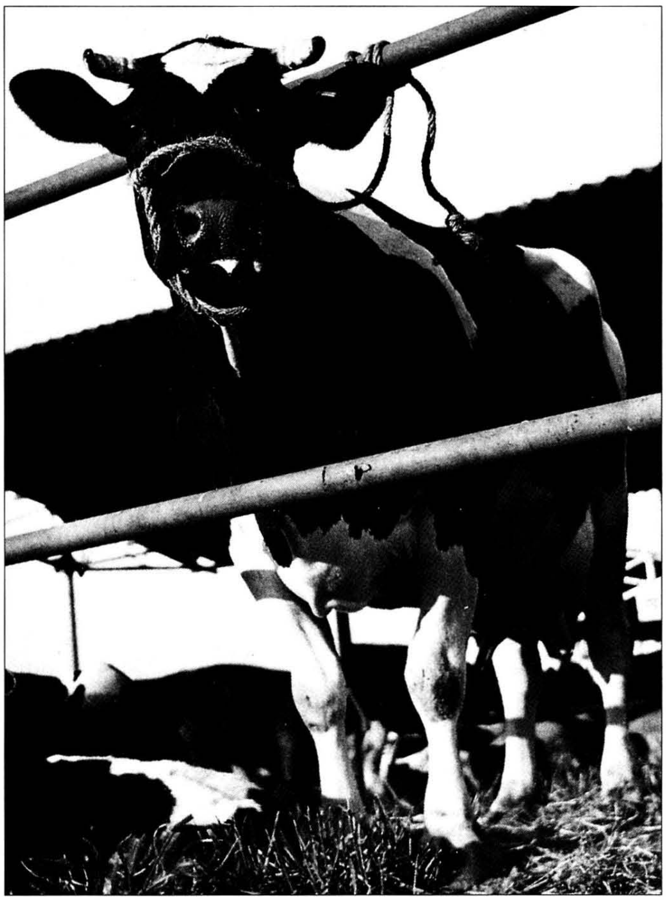
S.t.

$$\sum_{r=1}^{s} y_{rj} u_r - \sum_{i=1}^{m} x_{ij} \upsilon_i \leq \text{for} \quad j = 1,\ldots\ldots\ldots\ldots,n$$

$$u_r \geq 1 \quad \text{for} \quad r = 1,\ldots\ldots,s \qquad \upsilon_i \geq 1 \quad \text{for} \quad i = 1,\ldots\ldots,n$$

where all variables and parameters are as defined earlier.

The DEA analysis requires the solution of the linear programming problem of the above form, one for each decision making unit. The yr_j and x_{ij} are the observed values for the DMUs and are constant; the decision variables are u_r, v_i, which are the input and output weights and cannot be interpreted as values in the economic sence. Instead, for each unit they determine the discrepancy between the common practice of the effi-



ciently run units and that of the unit being considered. The dual variables of the solutions are s_r, e_i, λ_j ,.
The sets of s_r and e_i are output slacks and excess input slacks, respectively. For efficiently run units these are zeros. A decision-making unit k is efficient if it satisfies the condition $u^k y - v^k x = 0$. For a DMU that is inefficient, the solution actually identifies a subset of efficient DMUs ($\lambda > 0$) called efficient reference set, of which the convex combination determines the outputs and inputs that make a DMU efficient. For the binding dual constraints, if $\lambda_k = 1$ $\lambda_j = 0$ for $j \neq k$, then a DMU is efficient. There are two basic types of DEA models referred to as constant returns-to-scale and variables returns-to-scale. The extent of appropriateness of a particular DEA model is determined by economic and other assumptions regarding the data set to be analysed. Both models were applied, but the solution of the variable returns-to-scale model indicated that no returns-to-scale existed in the sample of farms being considered. The results of a DEA solution can be significant for management purposes in three important ways. First, DEA indicates the efficiency rate of each DMU relative to all other DMUs in the sample. This measure makes possible the identification of the DMUs that need reorganization. Second, whenever a DMU is less than perfectly efficient, DEA brings to light a subset of perfectly efficient DMUs that can be used to formulate management practices aiming at improvement. Third, DEA provides a matrix of cross-efficiencies. The cross-efficiency matrix is generated by the efficiency rates calculated by the input and output weights of one DMU and the input and output level of another. The cross-efficiencies can identify DMUs that are efficient but that use different bundles of inputs and produce a different combination of outputs. In addition the efficiency rates can be used as dependent variables to estimate the relationship between efficiency and factors which are not included in the DEA model.

DATA USED AND MODEL STRUCTURE

Farm management data for 86 dairy farms are used for the application of the DEA. The source of data is a farm management survey of dairy farms carried out during the 1990-91 period (Psychoudakis, et al. 1992). The sample farms are located in the central and western Macedonia, in Greece, which are the main milk producing areas of the country. They represent newly organised farms in these areas and reflect the current structure of dairy farming in Greece. They have the required characteristics, i.e. multiple output and multiple inputs, necessary for the empirical application of the DEA. Each farm is taken as a Decision Management Unit (DMU), the relative efficiency of which is measured.
The application of DEA involves the identification and measurement of relevant inputs and outputs which are common in all units. The relevant inputs are:

i. the number of dairy cows in the herd,
ii. the acreage on non irrigated land in hectares
iii. the acreage of irrigated land in hectares
iv. labour used in hours,
v. variable costs in thousands of drachmas
vi. purchased feedstuffs converted into the equivalent quantity of barley in tonnes
vii. the value of used buildings in thousands of drachmas, and
viii. the value of used machinery in thousands of drachmas.

The outputs produced are:
i. milk production in tonnes
ii. veal (carcass weight) in tonnes
iii. Beef meat (carcass weight) in tonnes
iv. the value of cash crops in thousands of drachmas.

Land is used for the production of feedstuffs or for growing cash crops. Variable costs include expenses for seeds, agrochemical, fuel and contract operations. The value of the outputs considered and the cost of the inputs included represent the total gross output and total annual cost of the farm respectively. Since quantities are used only for inputs and outputs, exept for variable costs and the value of cash crops, the technical efficiency is estimated.
Table 1 presents the input-output coefficients per dairy cow of the mean farm. These coefficients are representative of existing dairy farming in the areas considered, however the relatively high standard deviations indicate the existance of a wide range in the use of inputs and in the mixture produced outputs. The mean farm of the sample breeds 31.6 dairy cows while the size of the herd is of 70 heads including the followers. The annual milk production per dairy cow is 4416.2 litres, which is above the existing production quota per dairy cow in Greece (3400 litres per dairy cow). The farms produce also on average 93,7 kgr of veal (carcass weight) per dairy cow, and 84.8 kgr of Beef meat (carcass weight), while the value of cash crops per dairy cow is 48.0

Table1 ***Input - output coefficients of the mean farm.***

Outputs - Inputs		Mean	St.Dev.
Outputs			
Milk yield	Lit per dairy cow	4416,2	1074,8
Veal (carcass weight)	kgr per dairy cow	93,7	85,2
Beef meat (carcass weight)	kgr per dairy cow	84,8	113,5
Cash crops	000's dr.per dairy cow	48,0	69,6
Inputs			
Dairy cows in the herd	Number	31,6	22,1
Land non-irrigated	Stremmas per dairy cow	2,5	4,1
Land irrigated	Stremmas[1] per dairy cow	3,1	2,9
Labour	Hours per dairy cow	168,4	83,8
Variable Cost	000's dr.per dairy cow	64,0	84,5
Purchased feedstuffs[2]	kgr per dairy cow	4391,5	4338,0
Buildings	000's dr.per dairy cow	244,8	234,8
Machinery	000's dr.per dairy cow	208,9	177,9

[1]One stremmas equal to 0.1 ha.
[2]Equivalent quantity of barley.

thousand drachmas. For the production of these outputs the farms use the bundle of inputs shown in **table 1**. The Linear programming model contains 12 decision variables (s=4 plus m=8) and consists of 98 constraints (86 DMU+12) and the objective function. The DEA analysis involves solving the above problem 86 times , one solution for each decision making unit. The solution reported here is only part of the analysis since all basic DEA models are considered but meaningful results are taken from the constant returns to scale model only.

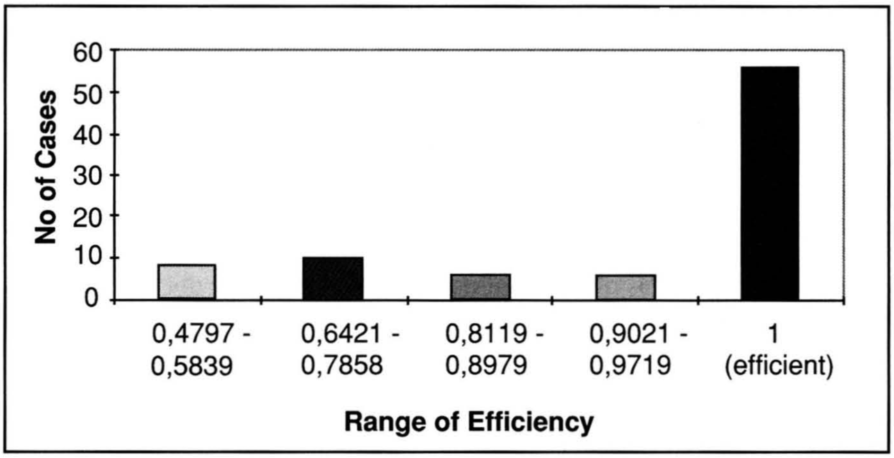


Figure 1 - Distribution of Efficiency Ratio.

RESULTS

The average efficiency ratios of the sample farms is 0.9141 meaning that the relative efficiency of the eighty six farms is 8.6 percent below what can be achieved. The average discrepancy below the efficiency level for the sample farms is determined by the number of relatively efficient farms and the range of the ratios of the relatively inefficient farms, shown in **table 2** and **figure 1**. Fifty six farms are found to be relatively efficient (h=1). i.e. the maximum relative efficiency is achieved.

Table 2 ***Number of cases according to their efficiency ratios.***

Range of Efficiency	No of Cases	%	Mean Efficiency
0.4797 - 0.5839	8	9,3	0,5463
0.6421 - 0.7858	10	11,6	0,7494
0.8119 - 0.8979	6	8,1	0,8514
0.9021 - 0.9719	6	5,8	0,9402
1 (efficient)	56	65,2	1,0000
Total	**86**	**100,0**	**0,9141**

This means that these farms organize their inputs and produce a composition of outputs using existing technology efficiently. Therefore, no increase in the outputs can be achieved by reorganizing the same bundle of inputs or the decrease in the inputs will result decrease in the outputs. The remaining thirty farms achieve efficiency levels below maximum (h<1) with the given technology. These farms can reorganize their inputs and the composition of outputs in order to become relatively efficient. For presentation reasons the sample farms are grouped according to their level of efficiency (**table 2**). The DEA analysis ratios make it possible to identify the DMUs that are in need of attention and to determine the extent of the improvement measures. This is achieved in **table 3** for the four groups of inefficient farms. The output slacks (s) and the excess inputs slacks(e) show the required adjustments, i.e. the increase in each output and the decrease in each input, for the four groups of farms in order to obtain their efficient running. There are no explicit trends in the increase of outputs or in the decrease in inputs according

Table 3 ***Required reorganization of relatively inefficient farms to become efficient.***

Outputs and Inputs		Range of efficiency ratio							
		0.4797 - 0.5839		0.6421 - 0.7858		0.8119 - 0.8979		0.9021 - 0.9719	
Outputs		y	s	y	s	y	s	y	s
Milk production	ton	74,7	24,8	175,1	16,6	95,5	13,4	135,4	10,6
Veal (Cercass weight)	ton	2,4	0,2	3,9	0,1	1,5	0,4	2,6	0,5
Beef meat (carcass weight)	ton	0,2	0,7	1,6	0,8	2,2	0,3	3,7	0,6
Cash crops	000's dr.	588,9	55,4	1571,4	223,0	866,6	97,8	1904,7	48,8
Inputs		x	e	x	e	x	e	x	e
Dairy cows	number	22,6	3,6	42,0	7,1	23,3	2,4	36,4	6,9
Land non-irrigated	ha	4,3	2,2	11,5	4,2	9,8	2,8	17,1	5,1
Land irrigated	ha	7,2	1,7	11,8	1,2	7,0	1,0	11,6	1,7
Labour	Hours	4463,0	1183,3	6185,7	1247,4	3814,3	1062,1	6353,3	136,1
Variable costs	000's dr.	1060,2	250,3	3384,4	363,8	1165,4	298,9	1821,0	171,9
Purchused feed	ton	134,2	82,5	163,7	60,9	79,5	14,7	129,7	11,5
Buildings (value)	000's dr.	5749,2	1884,9	10786,8	4061,6	6075,7	1969,3	11150,5	5863,0
Machinery (value)	000's dr.	4738,6	1033,6	9142,7	3152,8	4484,5	841,0	10346,2	3072,0

to the level of efficiency, except for the increase in beef meat and for the required decrease in the purchased feedstuffs. Thus, the DEA analysis matched with the complexity of the production process uncovers relations that are often hidden in the empirical analysis. Moreover it provides valuable details for management purposes which are not produced when parametric approaches are used.

The efficient reference set for each farm is available but not reported since it is of practical use to the managers of the farm only. The resulting information allows the construction of a hypothetical peer-farm for each inefficiently run one that would be rated as efficiently run, while the comparison between them indicates which inputs are being overused and which outputs are being underproduced and, thus in each case, suggesting by how much each input and output levels need to be adjusted.

Table 4 presents the required adjustment of the mean sample farm. The required adjustment of overutlized inputs are more important than the required adjustment of the outputs. Thus, it suggests that the main source of technical inefficiency is due to misallocation of resources. This point is very interesting given the quota regime for milk production.

It suggests that, given the quota regime improvement of technical efficiency can be sought mainly by adjusting the quantities of used inputs.

Table 4 ***The required reorganization of the mean farm.***

Output and Input		Existing	Adjustment	Reorganized	Change %
Outputs					
Milk production	ton	139.6	5.9	145.6	4.2
Veal (carcass weight)	"	3.0	0.1	3.1	3.1
Beef meat (carcass weight)	"	0.2	2.7	2.9	8.4
Cash crops	000's dr	1319.2	41.3	1560.5	2.7
Inputs					
Dairy cows	no	31.6	–1.8	29.8	5.7
Land non-irrigated	ha	7.8	–1.2	6.5	15.8
Land irrigated	ha	9.9	–0.5	9.4	6.2
Labourhours	hours	5325.0	–339.0	4986.0	6.4
Variable costs	000's dr	2022.2	–98.4	1923.8	4.9
Purchased feed	ton	138.9	–16.6	122.3	11.9
Building	000's dr	7739.5	–1194.1	6545.4	15.4
Machinery	"	6604.2	–872.5	5731.7	13.2

Conclusions

DEA, a procedure specifically designed to measure relative technical efficiency of production units in the non-market sectors of the economy, was applied to a sample of Dairy farms displaying the necessary characteristics for its empirical application. DEA was chosen to assess the technical efficiency of Diary farms for two reasons. First, technical efficiency has gained importance under the Common Agricultural Policy which impose production quotas and almost fixes prices. Second, the limited availability of data sources makes the application of the most commonly used methods of multiple regression analysis difficult. The results of the solution identify the inefficiently run farms which are grouped according to their level of efficiency into four groups. Accordingly the necessary adjustments of inputs and outputs is suggested by the dual variables of the solution. The construction of the peer hypotechnical efficient farm of the mean farm of the sample using the output slacks and input excess suggests that the main source of inefficiency in dairy farming is the misallocation of resource. ●

References

Bravo-Ureta, B.E., L. Rieger (1990). Alternative Production Frontier Methodologies and

Dairy Farm Efficiency. Journal of Agricultural Economics Vol. 41: 215-226.

Byrnes, P., R. Fare, S. Grosskoph and S. Kraft (198). Technical efficiency and size: The case of Illinois grain farms. European Review of Agricultural Economics. Vol. 14: 367-381.

Charnes, A. W. Cooper and E. Rhodes, (1978). "Measuring the efficiency of decision making units", European Journal of Operational Research, Vol 2: 429-444.

Charnes, A. W.W.W. Cooper and E. Rhodes (1979). Short communication: Measuring the efficiency of Decision Making Units. European Journal of operational Research. Vol. 3(4): 339.

Charnes, A. W.W.W. Cooper and E. Rhodes (1981). Evaluation Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through. Management Science 27(6): 668-697.

Fare, R., and G. Whittaker (1995). An Intermediate Input Model of Dairy Production Using Compex Survey Data. Journal of Agricultural Economics Vol. 46(2): 201-213.

Farrell, M. J.(1957). "The measurement of productive efficiency", Journal of the Royal Statistical Society, Series A (General), Part III, Vol. 120.

Fried, H.O., C.A. Knox Lovell, S.S. Sehmidt (ed.) (1993). The measurement of productive Efficiency: Techniques and Applications. Oxford University Press.

Neff, D.L., P. Garcia and C.H. Nelson (1993). Technical Efficiency: a comparison of Production Frontier Methods. Journal of Agricultural Economics. Vol. 44, No 3: 479-489.

Lau, L.J. and Yotopoulos, P.A. (1971). A Test for Relative Efficiency and Application to Indian Agriculture. American Economic Review, Vol LXI, : 94-109.

Lau, L.J. and Yotopoulos, P.A. (1973). A test for relative economic efficiency: some further results. American Economic Review, Vol LXIII: 214-223.

Parikh, a., and K., Shah (1994). Measurement of Technical Efficiency in the North-West Frontier Province of Pakistan. Journal of Agricultural Economics Vol. 45(1): 132-138.

Psychoudakis, A., B. Manos and A. Karalazos (1992), "The economics of dairy farming", General Secretariat of Research and Technology, Athens.

Silkkman, R.H. (ed.) (1986). Measuring Efficiency: An Assessment of Data Envelopment Analysis. San Francisco: Jossey-Boss.

Seiford, L.M., and R.M. Thrall (1990). Recent Developments in DEA: The Mathematical Programming Approach to frontier Analysis. Journal of Econometrics, Vol. 46: 7-38.