

A microeconomic approach for agricultural development: a dea application to greek sheep farms

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1. Introduction

Agricultural development is not only a desirable goal per se for its implications on the rural population welfare, but it can also contribute to a country's economic growth through intersectorial flows. Mundlak (2002) states that there is a strong interdependence between agriculture and economic environment expressed through the influence exerted by international prices and policies on the choice of agricultural technology, on the use of resources and, therefore, on the overall agricultural development. The expansion of agricultural output attainable via increased productivity and improved resource allocation and the increase in farm incomes are the two basic elements underlying the notion of agricultural development. The driving forces behind it are the relative factor and the resource endowments of agriculture and technological innovation both of which affect the rate of productivity growth of the agricultural sector. Hayami & Ruttan (1985) in their influential 'theory of induced innovations' stress the role played by the technological change and the productivity growth in the pursuit of agricultural development. Countries able to overcome rela-

Abstract

This paper explores the potential for increased profitability and improved farm income for sheep farms in Greece, as a result of the reorganization of farm input use. The method applied for the microeconomic analysis is DEA using data from the Greek (FADN) Network for the period 2000–2002. Results show that given the existing technology, the majority of farms exhibit technical inefficiency and can reduce inputs by more than 25% in the short run and by more than 40% in the long run, while maintaining the same level of output. Following the reorganization of inputs, sheep farms become profitable (32 €/ewe) without even making any size adjustments. Farm income also increases by 28% in the short run and by 38% in the long run. Given that most of the farms operate with increasing returns to scale, they need to enlarge their size to achieve lower production costs. If they make these scale adjustments, profitability and farm incomes increase even more which is conducive to agricultural development.

Key words: efficiency, DEA, profitability, farm income, agricultural development.

Résumé

Cet article étudie la possibilité de l'accroissement du profit et de l'amélioration du revenu d'exploitations agricoles des moutons en Grèce, comme conséquence de la réorganisation des entrées utilisées par l'exploitation. La méthode, exploitée pour l'analyse microéconomique et appliquée aux données du réseau grec (RICA) pendant la période 2000-2002, s'appelle DEA. Étant donné la technologie existante, les résultats montrent que la plupart des exploitations présentent une inefficacité technique et peuvent réduire les entrées de plus de 25% à court terme et de plus de 40% à long terme, en maintenant le même niveau de sorties. Après la réorganisation des entrées, les exploitations deviennent rentables (32 €/brebis) sans pour autant changer leur taille. De plus, le revenu d'exploitation augmente de 28% à court terme et de 38% à long terme. Étant donné que la plupart des exploitations agricoles fonctionnent avec des rendements d'échelle croissants, il faut qu'elles agrandissent leur taille afin d'assurer des dépenses de production inférieures. Si l'on fait les ajustements d'échelle mentionnés ci-dessus, la rentabilité et les revenus de l'exploitation agricole augmenteront davantage, au bénéfice du développement de l'agriculture.

Mots-clés: efficacité, DEA, rentabilité, revenu d'entreprise, développement agricole

tive scarcities and resource constraints by creating technological innovations succeeded in accelerating the rate of productivity growth and experienced a faster agricultural development.

Besides the macroeconomic approach to agricultural development and its determining factors, the sector's productivity growth depends to a large extent on the economic performance of individual farms. For a given technology, the discovery of inefficiencies at the microeconomic level of the farm unit can set in motion policies for their correction and therefore lead to enhanced productivity growth and increased farm income which will in turn generate agricultural development. Any measurable deviation from the production frontier facing the farm under currently available technology can offer valuable insights regarding the ex-

istence of technical inefficiency and/or lack of managerial ability that may hinder its prospects. Data Envelopment Analysis (DEA) is a methodology used in frontier modeling and is particularly useful for comparing efficiency differences between farms with similar technological processes (Morrison Paul, 1999; Coelli et al, 1998). The identification of inefficient farms within a particular agricultural sector and the unraveling of the specific sources of inefficiency, being a technical or scale inefficiency, can be a helpful tool for policy makers in promoting the growth of that sector with subsequent positive effects on overall agricultural de-

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velopment. Our research focuses on: investigating, with the application of DEA, the existence of possible inefficiencies at farm level in a particular agricultural sector, examining the potential sources of inefficiency and looking at the effects the adjustment of these inefficiencies might bring to in terms of profitability and farm income. Efficiency improvements, at a specific technological level, will affect productivity growth and ease the agricultural development.

The agricultural sector in Greece plays an important role in the development of the country with a relatively high contribution to the Gross Domestic Product (6.7%) and to the employment rate (16%). Greece is among the main EU producers of sheep milk and meat, accounting for 10 per cent of total EU production. Sheep farming is the largest livestock sector in Greece, accounting for 30 per cent of the total value of livestock output. Sheep milk and meat are also among the major agricultural commodities. Sheep milk and meat are also among the major agricultural commodities with a share of around 9 per cent of the total value of agricultural production. Milk and meat production is nearly 670,000 tonnes and 80,000 tonnes, respectively, per year. There are more than 100 thousand sheep farms, with varying degrees of specialisation, most of which are located in less-favoured and mountainous areas where employment opportunities outside farming are limited.

This paper, taking into account the relative significance of the sheep-farming sector in Greek agriculture, investigates the potential for increased profitability of sheep farms and improved farm income that could occur due to the reorganization of on-farm input utilization. The following section analyzes the DEA methodology and explains the efficiency measures that will be computed. The third section includes the specification of the model applied in the sheep sector and gives a detailed account of the dataset used in this study. The fourth section presents research results on farm technical and scale efficiency and on farm profitability and income before and after any adjustment in the use of inputs. Eventually, some concluding comments are offered relating research findings about the agricultural development in Greece.

2. Methodology

A non-parametric approach, referred to as Data Envelopment Analysis (DEA) (Charnes et al., 1978) is used for the purposes of this research. It is a mathematical programming approach, which can handle very effectively the need for a multi-input and multi-output process and is suitable for estimating the efficiency in cases where profits are not the only goal. An additional advantage of the DEA is that it avoids parametric specification of technology as well as the distributional assumption for the inefficiency term (Coelli, 1995).

In recent years, DEA has become a central technique in productivity and efficiency analysis, applied to different aspects of economics. DEA has been used in comparing organizations (Sheldon, 2003), firms (Fare et al., 1996; Chen

and Ali, 2004) and regions (Karkazis and Thanassoulis, 1998). In agriculture, DEA has been applied in several cases, like cotton (Shafiq and Rehman, 2000) and horticulture farms (Iraizoz et al., 2003). In the livestock sector, DEA has been applied to dairy farms (Fraser and Cordina, 1999; Reinhard et al., 2000;), pig farms (Sharma et al., 1999; Lansink and Reinhard, 2004; Galanopoulos et al, 2006) and sheep farms (Fousekis et al, 2001).

DEA is a linear programming method that calculates the frontier production function of a set of decision-making units (farms in our case) and evaluates the relative technical efficiency of each farm, allowing us to make a distinction between efficient and inefficient farms. Those identified as “efficient” are given a rating of one, whereas the degree of technical inefficiency of the rest is calculated on the basis of the Euclidian distance of their input–output ratio from the frontier (Coelli et al., 1998). Technical efficiency (TE) represents the ability of a farm to produce the maximum physical output given a set of inputs and technology (Output-Oriented, O-O) or, alternatively, to produce the same output with the maximum feasible reductions in inputs given the technology set (Input-Oriented, I-O) (Farrell, 1957). The selection between I-O and O-O model may vary according to the specific purpose of research and the unique characteristics of the set of decision-making units under study. In this study, the input-oriented model is used, which is more appropriate for the purpose of research, as in the agricultural sector a farmer has more control over inputs rather than over output levels, which may be exogenously determined. Additionally, the inelastic demand of most agricultural products makes cost reduction a better means of promoting agricultural economic development with respect to output increase. Moreover, in the majority of cases, the choice of orientation has only a minor influence on the efficiency scores obtained (Coelli et al, 1998).

In the I-O model, TE under Constant Returns to Scale (CRS), also called the “Overall” Technical Efficiency (OTE), is obtained by solving the following DEA model:

$$\begin{array}{ll}
 \text{Min } \theta_i^{\text{CRS}} & \\
 \theta_i^{\text{CRS}}, \lambda & \\
 \text{subject to: } & X\lambda \leq \theta_i^{\text{CRS}}x_i \quad (1) \qquad \theta_i^{\text{CRS}}x_i - X\lambda \geq 0 \quad (1)' \\
 & Y\lambda \geq y_i \quad (2) \qquad \qquad \qquad \xrightarrow{-y_i} \quad +Y\lambda \geq 0 \quad (2)' \\
 & \lambda \geq 0 \quad (3) \qquad \qquad \qquad \xrightarrow{\qquad}
 \end{array}$$

Consider the situation with k farms, each producing m outputs by using n different inputs, θ_i^{CRS} is the efficiency of farm number i (specific farm), under CRS, called OTE, x_i is the vector of inputs ($n \times 1$) used by the i farm, y_i is the vector of outputs ($m \times 1$) produced by the i farm, X is the matrix of inputs of all k farms ($n \times k$) in the sample, Y is the matrix of outputs of all k farms ($m \times k$) in the sample,

λ is a vector of weights ($k \times 1$) attached to each of the efficient farms.

A separate linear programming (LP) problem is solved to obtain the OTE score for each of k farms in the sample. θ is a scalar with boundaries of one and zero. If $\theta_i^{CRS} = 1$, the farm is on the frontier and is technically efficient. If $\theta_i^{CRS} < 1$, then it is technically inefficient.

The "Overall" Technical Efficiency (OTE or θ^{CRS}) measure can be decomposed into "Pure" Technical Efficiency (PTE) and Scale Efficiency (SE) by solving a Variable Returns to Scale (VRS) DEA model, which is obtained

by replacing the constraint (3) with the constraint: $\sum_{j=1}^k \lambda_j = 1$

(4) and replacing the θ_i^{CRS} with the θ_i^{VRS} . The last one is the Technical Efficiency measure under VRS. Because the VRS analysis is more flexible and envelops the data in a tighter way than the CRS analysis, we have $\theta_i^{VRS} \geq \theta_i^{CRS}$. This relationship is used to obtain a measure of the Scale Efficiency (SE) of each farm:

$$SE_i = (\theta_i^{CRS}) / (\theta_i^{VRS}) \quad (5)$$

where $SE_i = 1$ indicates scale efficiency or constant returns to scale and $SE_i < 1$ indicates scale inefficiency due to the presence of either increasing or decreasing returns to scale.

Statistical analysis was conducted with the Statistical Package for the Social Sciences (SPSS v.14.0). The accounting method was used for the estimation of economic results of sheep farms.

3. Data Description and Model Specification

Data used for the present study are taken from the Greek Farm Accounting Data Network (FADN) for the period 2000 – 2002. Data collection in the FADN is conducted through the use of questionnaires distributed by agriculturists specialised in the field of accounting. A stratified random sampling approach is used and the sample is stratified according to the production orientation, the geographical regions, the total number of farms in each region, and farm size in order to reflect national averages. Production orientation is determined according to the main source of revenue, using two thirds of gross margin as relevant benchmark figure. At least two thirds of the gross margin of each sheep farm come from sheep products. The different regions-strata of Greece for FADN are: a) Thessaly, b) Thrace and Macedonia, c) Peloponnesus, Epirus and Ionian Islands, d) Crete, Aegean Islands, Athens and West Greece. It is pointed out that farms in the field of observation of the FADN system have an economic size greater than 2 European Size Units. Finally, the sample consists of 217 sheep farms.

The FADN database is very detailed and consists of 467 variables. It includes technical, economic and other data (like the age of the farm manager) for each farm (observa-

tion). In particular, there are detailed input data, like family and hired labour work units and expenses, variable input costs by category (e.g. feed expenses), herd size measured by the number of animals, fixed assets by category (machinery, buildings, etc.), measured in monetary terms, various costs consisting of veterinary expenses (e.g. antibiotics), fuel and electric power, depreciation, taxes and other miscellaneous expenditures. The accounting method was used for the economic analysis of the inputs and for the creation of the cost components: labour cost, land cost, variable (mainly feeding) cost, (annual) cost of fixed assets, and other costs. On the other hand, there are detailed output data, like milk and meat production (quantities), gross revenue of sheep production, gross revenue from less important products like cereal products and the total gross returns of farms (in monetary terms). There are also detailed data about the subsidies for each product. All monetary variables have been converted to euros, using the official drachma/euro exchange rate.

The initial FADN data set provides those data needed to estimate the economic outputs, but it is very disaggregated, especially in terms of number of inputs and outputs; thus, to make the DEA estimation feasible, some aggregation is required. Such aggregation is a source of potential bias in estimating technical efficiency but value-aggregation is often applied in the relevant literature (e.g. Sharma et al., 1999; Iraizoz et al., 2003; Lansink and Reinhard, 2004), as it is necessary when the use of actual input levels would result in either too many inputs included in the model or in the exclusion of certain inputs. In both cases results can also be biased, given that, in the first case the inclusion of additional input variables in the DEA model results in increased efficiency scores, whereas in the second case, the excluded variables could be of significant magnitude.

4. Results

The applied model in this study consists of four inputs and one output. Inputs include labour, fixed capital, feeding and all other expenses. The labour variable includes both family and hired labour. Fixed capital includes all the annual expenses of fixed assets, such as the interest costs, depreciation, maintenance, insurance and some other annual expenses of lesser importance. Feeding expenses include the annual cost of feedstuffs. Some of the other expenditures are electricity, veterinary costs, taxes etc. Gross returns of farms include revenues from sheep production. Subsidies are not taken into account in the model, in order to measure the real efficiency of farms, without any regulatory distortions. All variables have been normalized by an additional variable, namely the number of productive animals (ewes).

The average size of sheep farms in the sample equals 175 ewes. According to table 1, the main categories of production expenses of sheep farms are feedstuffs (34%) and labour (33%). Adding the annual expenses of the fixed assets in the above-mentioned inputs, the proportion of the

three inputs in the production expenses is 85.6%. The total production expenses of a sheep farm average about 165 €/ewe.

Variable	Expenses (€/farm/ewe)
Labour	54.35
Feed	56.23
Annual expenses of capital	30.46
Other Expenses	23.78
Production expenses	164.82

The main economic results of sheep farms are then computed in two different situations, one taking into account the subsidies given to the farms and the other excluding them from the calculations. The reason for this comparison is to assess the farms' real economic performance without any distorting influence from the implementation of the agricultural policy. The results, included in table 2, indicate that there is a net profit of 13.3 €/farm/ewe, when subsidies are included in the estimation of a farm's gross income. In contrast, when subsidies are not incorporated in gross income, farms show a loss of 11.5 €/farm/ewe on average. The farm income is also substantially less in this case, about 69 €/farm/ewe. It appears that, with the existence of subsidies, the level of profitability is artificially sustained and if the sheep sector was not under protection all costs might not be covered. These economic results are of great importance for sheep farming and its prospects for future growth. The viability of farms in the long run and the prosperity of a sector cannot rely on financial transfers from other economic sectors; instead, it should strive to improve efficiency and consequently increase productivity. A competitive sector can only make contributions towards a genuine and sustainable agricultural development.

Variable	Subsidies included (€/farm/ewe)	Subsidies not included (€/farm/ewe)
Gross return	178.14	153.31
Profit or loss	13.32	- 11.51
Gross Margin	109.71	84.88
Farm Income	93.68	68.86
Family Farm Income	85.93	61.10

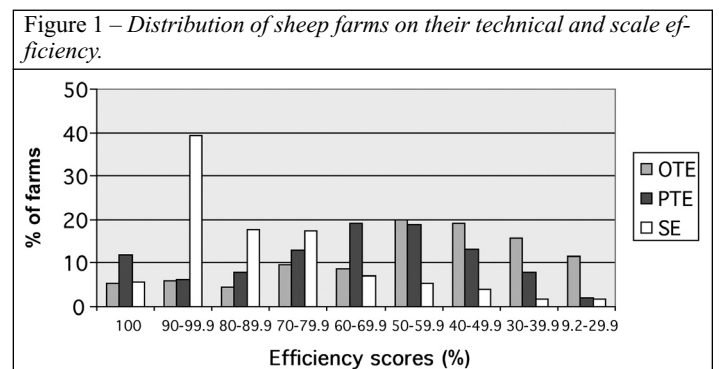
DEA models are estimated using the DEA Excel Solver by Joe Zhu (Zhu, 2003). The estimated mean technical efficiency measure for sheep producers is 66.3% for the Variable Returns to Scale DEA model (PTE under VRS) and 54.4% for the Constant Returns to Scale DEA model (OTE under CRS). This implies that farms could on average reduce their inputs by 33.7% without any size adjustments and by 45.6% when size adjustments are made, maintaining in both cases the same level of output (table 3).

The technical efficiency measure under VRS (PTE) specifies the possible efficiency improvement that can be achieved without altering the scale of operations. Hence, it can be viewed as a short run efficiency measure indicating the reduction in inputs necessary to improve the economic performance in the short run. The Overall Technical Efficiency (OTE) and the Scale Efficiency (SE) measures require the farm to increase or decrease its scale of operation and hence should be viewed as long run measures that point to the necessary reduction in inputs for the long run improvement in efficiency. The cumulative effect of raising efficiency would in general be conducive to agricultural development. The Scale Efficiency of sheep farms is 82% and a comparison between the "pure" technical efficiency and the scale efficiency measures indicates that the former has a greater impact on the farm efficiency level and productivity (table 3).

OTE		PTE		SE	
Mean	St Dev	Mean	St Dev	Mean	St Dev
54.4	22.0	66.3	20.6	82.0	18.5

The efficiency scores ($0 < \theta \leq 1$) are converted to percentages (%).

Figure 1 illustrates the distributions of technical and scale efficiency measures of sheep farms, respectively. It is obvious that there is considerable variation in the performance of sheep farms in Greece. The variation is greater in the case of technical efficiency than scale efficiency. Some farms are fully technical efficient under the VRS model (12.1% of the sheep farms), but only half of them are still efficient when the factor size is taken into account (CRS model). There are some other farms that operate very close to the frontier (efficiency scores between 90 and 99.9%), but the majority of farms exhibit "pure" technical inefficiency higher than 25% and overall technical inefficiency greater than 40%. Therefore, approximately two fifths of the farms exhibit "overall" technical inefficiency greater than 50%, but only about half of them show such great inefficiency in the VRS model. This means that many of these very inefficient farms in the CRS model exhibit substantial scale inefficiency.



Very numerous farms exhibit scale efficiency greater than 90%, but the majority of farms have scale inefficiency greater than 10% (54.9% of sheep farms). One third of the sheep farms have scale inefficiency greater than 25%; these farms have a serious problem of either overproducing or underproducing, given their size. The majority of the farms are scale – inefficient (94.7%) and only a few farms are scale – efficient, operating under constant returns to scale (5.3%). Most of the farms (66.2%) are operating under increasing returns to scale. These farms need to move down their long-run average cost curve and increase their size, in order to succeed in cost saving. The remaining farms (28.5%) are operating under decreasing returns to scale and need to decrease their size in order to achieve input efficiency. These results are similar to those obtained in other studies (Fousekis et al, 2001) and can be explained by the existence of small-sized farms in Greece, often referred to as a structural drawback of the Greek agricultural sector.

As we have already mentioned, there is a loss of 11.5 €/ewe in the current levels of production due to inefficiency. However, the reorganization of inputs in order to approach the production frontier alters the profitability of the sheep sector. According to results presented in table 4, if farms wanted to eliminate their technical inefficiency without making size adjustments, they would have an average net profit of 32.1 €/ewe. At the same time, farm income would increase from 68.9 €/ewe to 88.1 €/ewe (without taking subsidies into account). If the technically efficient farms operated at an optimal size as well, they would gain an even higher net profit of 47.4 €/ewe and earn an even larger farm income (95.2 €/ewe).

Variable	€/farm/ewe ¹
Loss before the reorganization of inputs	- 11.51
Profit after the reorganization of inputs (VRS model)	32.08
Profit after the reorganization of inputs (CRS model)	47.44
Farm Income before the reorganization of inputs	68.86
Farm Income after the reorganization of inputs (VRS model)	88.07
Farm Income after the reorganization of inputs (CRS model)	95.20

¹ Farm subsidies are not included in gross returns.

5. Conclusions

This paper has applied the DEA methodology as an analytical tool to explore at the microeconomic level the potential shortcomings in the efficiency of Greek sheep farms that may create a set back for the sector and hinder its future growth. Bearing in mind its relative importance for Greek agriculture and taking into consideration that sheep farms are located in less-favoured and mountainous areas, with restricted employment opportunities outside farming, it is possible to understand that the performance of the sector can have a marked effect on the agricultural development in Greece.

The analysis of farm efficiency showed that there could be significant improvements in the sector through the reorganization of farm inputs. The economic development of every inefficient farm is feasible because for each inefficient farm there is at least another efficient one. Given the existing technology, the majority of farms exhibit serious technical inefficiency and can reduce inputs by more than 25% in the short run and by more than 40% in the long run, maintaining in both cases the same level of output. Farms can reduce their use of inputs by 34% on average in the short run and, by making scale adjustments, they can further save on inputs in the long run.

It is worth noting that inefficiency firstly reflects a non-optimal management of inputs and secondly non-optimal scale operations. Consequently, sheep farms, which are on average operating at a loss, become profitable (32 €/ewe) after the reorganization of their inputs without even implementing any adjustments in the scale of operation. Subsidies have not been included to avoid any policy distortions and to measure the real level of profitability. Following size adjustments, profitability improves even more as most of the farms operate at a sub-optimal size. Thus, on average, farms need to increase their size in order to achieve lower production costs, due to the existence of increasing returns to scale. Beyond profits, the reorganization of inputs can have a positive effect also on farm income, which is another important economic result for the agricultural development. More specifically, correcting technical inefficiency will increase income by 28% in the short run and by 38% in the long run.

The conclusion that can be drawn is that technical efficiency and herd size are important factors affecting the Greek sheep-farming sector. If technical inefficiencies are eliminated and farm size adjustments occur, there will be benefits for the overall agricultural development.

References

- Charnes, A., Cooper, W.W., Rhodes, E., (1978). “Measuring the efficiency of decision making units”. *European Journal of Operational Research* 2, 429-444.
- Chen, Y. and Ali, A.I., (2004). DEA MP measure: new insights with an application to computer industry. *European Journal of Operational Research* 159 (1), 239-249.
- Coelli, T., Prasada Rao, D.S. and Battese, G.E., (1998). “*An Introduction to Efficiency and Productivity Analysis*”. Kluwer Academic Publishers, Massachusetts.
- Coelli, T.J., (1995). “Recent developments in frontier modelling and efficiency measurement”. *Australian Journal of Agricultural Economics*, 39, 219-245.
- European Commission, Directorate General for Agriculture, (2004). “*The Agricultural Situation in the European Union: 2004 Report*”.
- Fare, R., Grosskopf, S., Tyteca, D., (1996). “An activity analysis model of the environmental performance of firms”. *Ecological Economics* 18, 161–175.

- Farrell, M.J., (1957). "The measurement of productive efficiency". *J.R. Stat. Soc. Ser. A* 120, 253-281.
- Fousekis, P., Spathis, P and K. Tsimboukas (2001), "Assessing the efficiency of sheep farming in mountainous areas of Greece. A non parametric approach", *Agricultural Economics Review*, 2(2), pp. 5-15
- Fraser, I. and Cordina, D., (1999). "An application of DEA to irrigated dairy farms in Northern Victoria, Australia". *Agricultural Systems* 59, 267-282
- Galanopoulos, K., Aggelopoulos, S., Kamenidou, I and Mattas, K. (2006). "Assessing the effects of managerial and production practices on the efficiency of commercial pig farming". *Agricultural Systems* 88, 125-141.
- Hayami, Y., Ruttan, V.W., (1985). *Agricultural Development: An International Perspective*, Johns Hopkins University Press, Baltimore.
- Iraizoz, B., Rapun, M. and Zabaleta, I., (2003). "Assessing the technical efficiency of horticultural production in Navarra", *Agricultural Systems* 78, 387-403.
- Karkazis, J. and Thanassoulis, E., (1998). "Assessing the effectiveness of regional development policies in Northern Greece using Data Envelopment Analysis". *Socio-Economic Planning Science* 32 (2), 123-137.
- Lansink, A.O. and Reinhard, S. (2004). "Investigating technical efficiency and potential technological change in Dutch pig farming". *Agricultural Systems* 79, 353-367.
- Morrison Paul, C., (1999). *Cost structure and the measurement of economic performance*, Kluwer Academic Publishers.
- Mundlak, Y., (2002). *Agriculture and Economic Growth: Theory and Measurement*, (ed), Harvard University Press, Cambridge, MA.
- Reinhard, S., Lovell, K.C.A. and Thijssen, G.J., (2000). "Environmental efficiency with multiple environmentally detrimental variables estimated with SFA and DEA". *European Journal of Operational Research* 121, 287-303.
- Shafiq, M. and Rehman, M., (2000). "The extent of resource use inefficiencies in cotton production in Pakistan Punjab: an application of Data Envelopment Analysis". *Agricultural Economics* 22, 321-330.
- Sharma, K.R., Leung, P.S. and Zaleski, H.M., (1999). Technical, allocative and economic efficiencies in swine production in Hawaii: a comparison of parametric and non-parametric approaches. *Agricultural Economics* 20, 23-35.
- Sheldon, G., (2003). The efficiency of public employment services: a nonparametric matching function analysis for Switzerland. *Journal of Productivity Analysis* 20,49-70.
- Zhu, J., (2003). "Quantitative Models for Performance Evaluation and Benchmarking" Springer's International Series, USA.