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PROCEEDINGS

Edited by: Ali Emrouznejad, Rodney Green, Vladimir Krivonozhko

Organized by

Institute for Systems Analysis of Russian Academy of Sciences
and
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GLOBAL CONSULTING

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FOREWORD

This volume includes papers presented at the DEA Symposium 2002 in Moscow organized by the Institute for Systems Analysis of Russian Academy of Sciences and Global S. Consulting Company.

The DEA approach was given much attention and it rapidly expanded around the world since the first publications submitted by Charnes, Cooper, Banker and Seiford *et al*, which appeared in the 70-s and 80-s. Now, DEA is widely implemented in various spheres of academic and business activities. Today, the number of papers on DEA accounts for several thousands.

The leading international Congresses and Conferences devote considerable attention to this subject. I would like to mention some of them: IMACS WORLD Congress 2000 (Lausanne), EURO2001 (Rotterdam), OR'43 (Bath), INFORMS 2001 (Miami) and the forthcoming IFORS 2002 in Edinburgh.

Our Symposium will be wholly devoted to the DEA approach, including theory and methodology, its applications in different sectors and also to new developments. The Symposium continues a series of successfully conducted DEA events, the previous ones were held in Brisbane (Australia, 2000) and in Wernigerode (Germany, 1998). We are happy to inform you that 55 delegates from 26 states of the world are going to present their reports at our meeting.

The papers accepted by the program committee were classified into six themes, which are Theory and Methodology, Financial Institutions, Production Systems, Applications in the Public Sector, Applications in Agriculture and Novel Applications of DEA.

We hope that this volume together with the active discussion at the Symposium will contribute a lot to reach the aim of the DEA Symposium 2002 to bridge the gap between research and business practice in DEA development.

I would like to take this opportunity to thank the review and program committee and the keynote speakers who have shared their expertise and spent a lot of time to organize this Symposium.

But what is most important, we appreciate your personal participation in the Moscow DEA Symposium 2002.

Chair of the Organizing Committee,

Prof. Vladimir Krivonozhko

A Free (Dis)Aggregation Hull Approach to Efficiency Measurement

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Abstract

Superficially, the free disposal hull production possibility set (pps) can be regarded as a binary version of the Banker, Charnes and Cooper pps, in which only one component of the vector, λ, is non-zero and of necessity equal to 1. We therefore propose, by analogy with a pps due originally to Koopmans, a new pps which retains the binary characteristic of the components of λ but permits more than one component to be non-zero. Thus a given DMU's performance is assessed not only against the individual DMUs included in the sample but also against composite DMUs obtained by simple aggregation. This approach is demonstrated and investigated on a published data set.

Keywords: DEA, data envelopment analysis, FDH, free disposal hull

1. Introduction

In a nutshell, a production possibility set (pps) or reference technology can be thought of as a declaration of the totality of production activities that might plausibly have been observed on the evidence of the activities actually observed. Data envelopment analysis (DEA) uses the frontier of the pps, defined in terms of observed activities deemed efficient and specific linear/convex combinations thereof, to evaluate the observed activities. Therefore choice of an appropriate pps is important, perhaps crucial. Hitherto, most frequently used in practical applications are those associated with Charnes, Cooper and Rhodes (CCR) or Banker, Charnes and Cooper (BCC) (e.g. Cooper et al 2000, Dekker and Post 2001).

In practice, regions of an adopted pps may be empty of observed activities and it is then a matter of speculation as to whether this is because such activities are not actually possible or just not present in the 'sample' of observations. Dekker and Post(2001) refer to two "evils" providing dilemmas in selecting a pps and interpreting the results of its use: specification error and finite sample error.

Absence of observations is often attributed to the linearity/convexity inherent in the CCR and BCC pps's which themselves are considered by many as being more concerned with analytic convenience than economic realism (McFadden 1978). There has therefore been considerable interest in relaxing these assumptions (e.g. Petersen 1990, Bogetoft 1996, Dekker and Post 2001, Kuosmanen 2001, Post 2001) so as to better fit the observations. In fact, the pps that achieves the best fit to the observations is the free disposal hull (FDH) introduced by Deprins et al(1984) and Tulkens(1993). Whilst Thrall(1999) challenged the economic meaning of FDH this was strongly rebutted by Cherchye et al(2000) and FDH remains an attractive, but probably underused, approach to efficiency measurement. It is attractive because it measures the efficiency of a decision making unit (DMU) against an actually observed performance (i.e. that of a specific efficient DMU) rather than against a 'synthetic' DMU obtained as a linear/convex combination of a number of efficient DMUs. However this attractiveness is mitigated by a number of factors. Firstly, the effect of finite sample error inherent in practical applications of CCR or BCC is likely to be exacerbated in FDH. Secondly, FDH requires

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access to binary, rather than linear, programming software for its implementation. (It is appreciated that Tulkens(1993) implements FDH without explicit recourse to binary programming. However his algorithm uses complete enumeration to compare all pairs of DMUs to test for (weak vector) dominance and it is debatable whether this approach is computationally effective when compared with commercially available binary programming software.)

Our approach possibly ameliorates the former of these factors at the expense of definitely requiring binary programming for its implementation. Essentially we extend the FDH pps to include synthetic DMUs that are obtained by aggregating the activities of the DMUs in subsets of the set of DMUs being evaluated. Thus a DMU, apparently efficient (i.e. undominated) when compared with all other individual DMUs, might nevertheless be seen as inefficient when compared with an aggregate performance. There is therefore a managerial challenge to such a DMU to consider the benefit of reorganising its activities so as to achieve the combined performance of the DMUs comprising the aggregate with which it is compared. This challenge, of course, would not be available via FDH.

In the next section we deal with some preliminary matters and then go on to outline our proposal in section 3. We illustrate this in section 4 and conclude with a brief discussion in section 5.

2. Preliminaries

There is a set of n DMUs identified by the index set $D = \{1,\ldots,n\}$. Denoting the column vectors of m inputs and s outputs for DMU $j \in D$ by $x_j \in \Re_+^m$ and $y_j \in \Re_+^s$ respectively, these vectors can be organised into the m-by-n and s-by-n data matrices, X and Y, whose columns have an obvious correspondence with the DMUs. For s-DEA purposes (s = CCR, BCC, FDH etc), an empirical (i.e. based on the observed data) production possibility set T(s) can be represented generically as:

$$T(s) = \{(x,y) \mid x \geq X\lambda,\ y \leq Y\lambda;\ \lambda \in \Lambda(s)\} \qquad (1)$$

where the condition $\lambda \in \Lambda(s)$ constrains the elements of column vector λ as required by s. The (input-based) efficiency of DMU j, $\theta_j(s)$, then follows from the mathematical program:

$$\theta_j(s) = \{\min \theta \mid \theta x_j \geq X\lambda,\ y_j \leq Y\lambda;\ \lambda \in \Lambda(s)\} \quad \forall j \in D \qquad (2)$$

In (1) and (2), $\lambda \in \Lambda(s)$ =:

$$\lambda_j \geq 0 \ \forall j \in D \qquad \text{(for s = CCR)} \qquad (3)$$

$$\lambda_j \geq 0 \ \forall j \in D;\ \Sigma_{j \in D}\, \lambda_j = 1 \qquad \text{(for s = BCC)} \qquad (4)$$

$$\lambda_j \in \{0,1\} \ \forall j \in D;\ \Sigma_{j \in D}\, \lambda_j = 1 \qquad \text{(for s = FDH)} \qquad (5)$$

(As an aside, sometimes the equality constraint in (4) is rendered as an inequality, either ≤1 or ≥1. The resulting overlapping production possibility sets are variously named in the literature according to their effect on the varying returns to scale characteristic implicit in T(BCC), e.g. T(N[I|D]RS), for non-[increasing|decreasing] returns to scale. For the sake of brevity, we will not refer to these further although for the most part their incorporation in to what follows is straightforward.)

(2) is obviously a linear program in cases (3) and (4) whereas it is a binary program in case (5).

Assuming (2) is solved on behalf of each DMU j under investigation to give $\theta_j(s)$ and vector $\lambda^{(j)}$ then the set of efficient DMUs is given by:

$$E(s) = \{j \in D \mid \theta_j(s) = 1\} \tag{6}$$

and the so-called reference set for DMU j is given by:

$$R_j(s) = \{i \in D \mid \lambda_i^{(j)} > 0\}. \tag{7}$$

From (3), (4) and (5) it is evident that:

$$T(CCR) \supset T(BCC) \supseteq T(FDH) \tag{8}$$

with the consequence that:

$$\theta_j(CCR) \leq \theta_j(BCC) \leq \theta_j(FDH) \qquad \forall j \in D. \tag{9}$$

and it is this nesting/ordering that leads to Dekker and Post's(2001) "evils" and consequently the situation where, typically, relatively few DMUs are efficient with CCR/BCC whereas the majority are apparently efficient with FDH, <u>for the same data:</u>

$$|E(CCR)| \leq |E(BCC)| << |E(FDH)|) \tag{10}$$

FDH's rather stringent test for dominance means that a DMU declared non-efficient almost certainly is. However it is almost certainly the case that FDH is excessively conservative in its efficiency/non-efficiency pronouncements and therefore an insufficient number of DMUs are challenged to seek improvement.

3. Proposal

Grosskopf(1986), whilst discussing the various linear/convex reference technologies mentioned above, draws attention to a further alternative attributed to Koopmans(1977). This has had relatively little attention in the DEA literature but is used e.g. in Fare and Primont(1984) and Kao(1998). In our notation where s = K (for Koopmans):

$$\Lambda(K) = \lambda_j \in [0,1] \ \forall j \in D \tag{11}$$

If the power set of D is P(D) and $q \in P(D)$, consider the vectors $x_q = \Sigma_{p \in q} x_p$ and $y_q = \Sigma_{p \in q} y_p$. Effectively q is a composite DMU obtained by aggregating the inputs and outputs of its constituent DMUs. Kao(1998) shows that (11) is equivalent to:

$$\Lambda(K) = \lambda_q \geq 0 \ \forall q \in P(D); \ \Sigma_{q \in P(D)} \lambda_q = 1 \tag{12}$$

i.e. T(K) over D is equivalent to T(BCC) over P(D).
Our proposal is now to replace the open interval [0,1] in (11) by the binary set {0, 1}. Thus:

$$\Lambda(.) = \lambda_j \in \{0,1\} \ \forall j \in D \tag{13}$$

This can be shown to be equivalent to:

$$\Lambda(.) = \lambda_q \in \{0,1\} \ \forall q \in P(D); \ \Sigma_{q \in P(D)} \lambda_q = 1 \tag{14}$$

and (13) represents a free disposal hull defined over P(D) i.e. it contains not just the DMUs under consideration but all composite DMUs obtained by simple aggregation. We call this pps the Free (Dis)Aggregation Hull (FD/AH) over the set of observations D.
The efficiency of DMU $j \in D$ is now evaluated via the binary program:

$$\theta_j(FD/AH) = \{\min \theta \mid \theta x_j \geq X\lambda, \ y_j \leq Y\lambda; \ \lambda_j \in \{0,1\} \ \forall j \in D\} \quad \forall j \in D \tag{15}$$

In contrast with FDH, the reference set for a DMU is not now restricted to a single DMU. Clearly this mitigates a practical advantage of FDH where those concerned with the management of an apparently non-efficient DMU are presented with an unambiguous benchmark. Now, the benchmark is a synthetic DMU, but an aggregate rather than a linear/convex 'blend', and considerably easier on managerial intuition (Epstein and Henderson 1989).

To close this section we note that Tulkens(1993) briefly entertains a pps where the binary constraints in FDH are replaced by integer constraints. Bogetoft (1996) calls this the "free replicability hull" (FRH) in that the pps now contains synthetic DMUs obtained by aggregating multiple copies, possibly up to some upper bound (UB), of observed DMUs. These synthetic DMUs are now available against which to perform the efficiency calculations. In both sources this extension is rather vaguely specified but the spirit is captured by:

$$\Lambda(\text{FRH}) = \lambda_j \in \{\text{integer}\}\ \forall j \in D;\ \lambda_j \leq UB_j \text{ and/or } \Sigma_{j \in D}\, \lambda_j \leq UB \quad (16)$$

4. An Example Application

Vanden Eeckaut et al(1993) investigate the efficiency of 235 Belgian municipalities in terms of a single input: total cost (1986), and six outputs serving as proxies for services delivered. These are: (1) total population; (2) length of roads; (3) number of senior citizens; (4) number of beneficiaries of minimal subsistence grants; (5) number of crimes registered; (6) number of students enrolled in primary schools. They provide their data in Appendix 1 of their paper and we use this data and some of their results in this section. The primary focus of their work is FDH but the authors also consider CCR, NIRS and BCC.

Table 1 reproduces part of their findings in the first 6 columns compared with our FD/AH approach in column 7 (column 8 will be considered later). The ordering suggested in (10) is clearly substantiated with 189 of the 235 DMUs apparently efficient under FDH but only 17 efficient under CCR. Considering column 7, the effect of using FD/AH compared with FDH can be clearly seen. It would seem that of the 189 DMUs deemed efficient under FDH only 80 remain so under FD/AH. Thus 109 of the formerly efficient DMUs (155 in total) can now be presented with a challenge to improve. Table 2, again partly derived from Vandeen Eeckaut et al(1993), shows an estimate of the apparent costs of inefficient operation under each pps, where apparent excess costs are obtained from Σ_j Total Cost$_j(1 - \theta_j(s))$. Thus the 918 BFr(10^6) under FDH is revealed as an order of magnitude higher under FD/AH.

Total Cost BFr(10^6)	# of DMUs	CCR # efficient	NIRS # efficient	BCC # efficient	FDH # efficient	FD/AH # efficient	FD/AH2 # efficient
<99	88	13	15	19	70	61	62
100-199	82	2	11	11	63	13	19
200-299	25	1	4	4	20	5	7
300-499	23	1	5	5	21	1	3
>500	17	0	7	7	15	0	0
Total	235	17	42	46	189	80	91

Table 1. Number of DMUs deemed efficient according to the various pps's in various categories of Total Cost.

PPS	CCR	NIRS	BCC	FDH	FD/AH	FD/AH2
Apparent Excess Cost	14206	8238	8202	918	10011	7326

Table 2. Apparent excess cost in BFr(10^6) aggregated over all non-efficient DMUs according to the various pps's.

At a more detailed level, Table 3 shows the situation for DMU 19 which is efficient under FDH but whose efficiency under FD/AH is 0.73 when compared with a composite of DMUs 16 and 220. Thus the management of DMU 19 remains unchallenged under FDH but questions along the following lines might reasonably be posed: Can DMU 19 be reorganised (disaggregated?) to resemble a combination of DMUs 16 and 220 at a cost of less than 334(1-0.73) BFr(10^6)?

	Total Cost	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6
DMU19	334	11961	1813	393	94	532	330
DMU16	172	8547	1172	437	45	405	423
DMU220	72	4823	743	121	51	139	193
Composite	244	13370	1915	558	96	544	616

Table 3. DMU 19 compared with DMUs 16 and 220 and the composite of 16 and 220.

|E(FD/AH)|	1	2	3	4	5	6	7	8	9
# DMUS	15	47	42	28	15	3	4	0	1

Table 4. Distribution of the cardinality of reference sets of 155 DMUs not efficient under FD/AH.

As is indicated by Table 4 the situation for 93 of the DMUs would be more complex than for DMU 19. These DMUs have reference set cardinalities greater than two, perhaps as large as nine. In a sense, the optimisation in (15), with its 'knapsack problem' overtones, may be seen as stimulating a search for particularly fortuitous combinations of 'small' DMUs to stack up against 'larger' DMUs. In order to investigate and control for this possibility we appended a constraint: $\Sigma_{j\in D}\ \lambda_j \leq 2$ to (15), in order to restrict the cardinality of composites to two DMUs at most. The results of this modification appear in columns 8 and 7 of Tables 1 and 2 respectively. The number of efficient DMUs increases from 80 to 91 and of the 93 DMUs non-efficient under FD/AH with reference sets greater than two, 82 remain so when the reference set cardinality is constrained. Naturally there is a corresponding decrease in the apparent excess.

5. Discussion

The reason for our designation "(Dis)Aggregation" should now be apparent. In line with our opening sentence we are suggesting that if DMUs A and B exist then it is plausible to suggest that DMU A+B, formed by (freely) aggregating A and B's activities, could exist. If DMU C is now dominated by DMU A+B then it is plausible to suggest that DMU C could (freely) disaggregate to resemble A and B. Of course there is no suggestion that A+B exists except as a notional entity or that C should actually disaggregate. In practical terms merely that there may be clues in the way that A and B organise affairs that may be of use to C in securing a more efficient performance. Any costs of reorganisation would need to be offset by the cost savings of this greater efficiency.

If we regard FD/AH as 'canonical', FD/AH2 with its somewhat arbitrary constraint on reference set cardinality is analogous to linear/convex DEA with additional constraints to secure results more intuitively or pragmatically palatable (e.g. Cooper et al 2000). In fact, the framework established here is quite general and can be extended in a number of directions, the subject of other research. Also of interest is the asymptotic behaviour of the estimator θ_j(FD/AH) (Park et al 2000).

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Alternative Transformations and Duality of Linear Fractional Programming Generalised DEA Model

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Abstract

This paper discusses alternative solutions and dual formulations of linear fractional programming DEA models. These solutions lie between the two usual solutions from denominator or numerator normalisation. The consequent results provide alternative solutions between those from input- and output-oriented models for constant returns to scale DEA models and global optimal solutions which are better than those from input- and output-oriented models for variable returns to scale DEA models. A non-linear fractional programming multiplier form of the variable returns to scale DEA model is revealed and the basic DEA models are summarised from a generalised viewpoint.

Keywords: data envelopment analysis, duality, linear fractional programming

1. Constant returns to scale DEA model

The following CCR constant returns to scale DEA model is given by Charnes, Cooper and Rhodes (1978, 1979):

$$\text{Maximize } \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{1}$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1,\ j = 1,\dots,n;$$

$$u_r \ge \varepsilon,\ r = 1,\dots,s;$$

$$v_i \ge \varepsilon,\ i = 1,\dots,m.$$

(1) was usually solved by being transformed into one of two equivalent linear programming model, ie. input-oriented model by denominator normalisation or output-oriented model by numerator normalisation.

If, in (1), we set

$$t = \frac{1}{\phi_k \sum_{i=1}^{m} v_i x_{ik}},\ \mu_r = t u_r,\text{ and } \nu_i = t v_i,\text{ then } \sum_{r=1}^{s} \mu_r y_{rj} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\phi_k \sum_{i=1}^{m} v_i x_{ik}} \text{ and } \sum_{i=1}^{m} \nu_i x_{ij} = \frac{\sum_{i=1}^{m} v_i x_{ij}}{\phi_k \sum_{i=1}^{m} v_i x_{ik}}.$$

the input-oriented equivalent model becomes,

$$\text{Maximise } \phi_k \sum_{r=1}^{s} \mu_r y_{rk} \tag{2}$$

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subject to
$$\sum_{i=1}^{m} v_i x_{ik} = \frac{1}{\phi_k}$$
$$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0,\ j = 1,\dots,n;$$
$$\mu_r \ge \varepsilon t,\ r = 1,\dots,s;$$
$$v_i \ge \varepsilon t,\ i = 1,\dots,m;$$
$$t \ge 0.$$

If, in (1), we set

$$t = \frac{1}{\theta_k \sum_{r=1}^{s} u_r y_{rk}},\ \mu_r = t u_r, \text{ and } v_i = t v_i, \text{ then } \sum_{r=1}^{s} \mu_r y_{rj} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\theta_k \sum_{r=1}^{s} u_r y_{rk}} \text{ and } \sum_{i=1}^{m} v_i x_{ij} = \frac{\sum_{i=1}^{m} v_i x_{ij}}{\theta_k \sum_{r=1}^{s} u_r y_{rk}}.$$

the output-oriented equivalent model becomes,

$$\text{Minimise}\ \theta_k \sum_{i=1}^{m} v_i x_{ik} \tag{3}$$

subject to
$$\sum_{r=1}^{s} \mu_r y_{rk} = \frac{1}{\theta_k}$$
$$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0,\ j = 1,\dots,n;$$
$$\mu_r \ge \varepsilon t,\ r = 1,\dots,s;$$
$$v_i \ge \varepsilon t,\ i = 1,\dots,m;$$
$$t \ge 0.$$

(1), (2) and (3) are in multiplier form. The dual is called the envelopment form. The dual of (2) and (3) are identical and can be written as,

$$\text{Minimise}\ \frac{\theta_k}{\phi_k} \tag{4}$$

subject to
$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \phi_k y_{rk},\ r = 1,\dots,s;$$
$$-\sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- = -\theta_k x_{ik},\ i = 1,\dots,m;$$
$$\varepsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right) \ge 0$$
$$\lambda_j \ge 0,\ j = 1,\dots,n;$$
$$s_r^+ \ge 0,\ r = 1,\dots,s;$$
$$s_i^- \ge 0,\ i = 1,\dots,m.$$

Equation (4) is the dual of (1) and can be viewed as a mixed-oriented constant returns to scale model. Obviously, setting $\phi_k = 1$, (4) becomes the input-oriented CCR model; while setting $\theta_k = 1$, (4) becomes output-oriented CCR model. Algorithms for (4) and (5) below can be found in O'Brien and Wu (2001).

2. Variable returns to scale DEA model

Similar to BCC variable returns to scale DEA model given by Banker, Charnes and Cooper (1984), the convex constraint can be imposed as in (4) to obtain the envelopment form of a mixed oriented variable returns to scale DEA model,

$$\text{Minimise} \frac{\theta_k}{\phi_k} \tag{5}$$

subject to

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \phi_k y_{rk}, r = 1,\ldots,s;$$
$$-\sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- = -\theta_k x_{ik}, i = 1,\ldots,m;$$
$$\varepsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right) \geq 0$$
$$\sum_{j=1}^{n} \lambda_j = 1;$$
$$\lambda_j \geq 0, j = 1,\ldots,n;$$
$$s_r^+ \geq 0, r = 1,\ldots,s;$$
$$s_i^- \geq 0, i = 1,\ldots,m.$$

(5) can reach different sub-optimal solutions depending on the value of θ_k or ϕ_k. Actually, $\sum_{j=1}^{n} \lambda_j = 1$ in (5) can be written as $-\sum_{j=1}^{n} y_{ro}\lambda_j = -y_{ro}$ and $\sum_{j=1}^{n} x_{io}\lambda_j = x_{io}$, and (5) becomes

$$\text{Minimise} \frac{\theta_k}{\phi_k} \tag{6}$$

subject to

$$\sum_{j=1}^{n} (y_{rj} - y_{ro})\lambda_j - s_r^+ = \phi_k y_{rk} - y_{ro}, r = 1,\ldots,s;$$
$$-\sum_{j=1}^{n} (x_{ij} - x_{io})\lambda_j - s_i^- = -(\theta_k x_{ik} - x_{io}), i = 1,\ldots,m;$$
$$\varepsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right) \geq 0$$
$$\lambda_j \geq 0, j = 1,\ldots,n;$$
$$s_r^+ \geq 0, r = 1,\ldots,s;$$
$$s_i^- \geq 0, i = 1,\ldots,m.$$

To obtain input-oriented and output-oriented models, write (6) as (6') and (6") respectively,

$$\text{Minimise} \frac{\theta_k}{\phi_k} \tag{6'}$$

subject to

$$\sum_{j=1}^{n} (y_{rj} - y_{ro})\lambda_j - s_r^+ = \phi_k y_{rk} - y_{ro}, r = 1,\ldots,s;$$
$$-\sum_{j=1}^{n} (x_{ij} - x_{io})\lambda_j - s_i^- + \theta_k x_{ik} = x_{io}, i = 1,\ldots,m;$$

$$\text{Maximise} \frac{\phi_k}{\theta_k} \tag{6''}$$

subject to

$$-\sum_{j=1}^{n} (y_{rj} - y_{ro})\lambda_j + s_r^+ + \phi_k y_{rk} = y_{ro}, r = 1,\ldots,s;$$
$$\sum_{j=1}^{n} (x_{ij} - x_{io})\lambda_j + s_i^- = (\theta_k x_{ik} - x_{io}), i = 1,\ldots,m;$$

$$\varepsilon\left(\sum_{r=1}^{s}s_r^{+}+\sum_{i=1}^{m}s_i^{-}\right)\geq 0$$
$\lambda_j\geq 0, j=1,\ldots,n$;
$s_r^{+}\geq 0, r=1,\ldots,s$;
$s_i^{-}\geq 0, i=1,\ldots,m$.

$$-\varepsilon\left(\sum_{r=1}^{s}s_r^{+}+\sum_{i=1}^{m}s_i^{-}\right)\leq 0$$
$\lambda_j\geq 0, j=1,\ldots,n$;
$\sum_{r=1}^{s}\mu_r y_{rk}=\frac{1}{\theta_k}, r=1,\ldots,s$;
$s_i^{-}\geq 0, i=1,\ldots,m$.

Their duals are (7) and (8) respectively,

$$\text{Maximise}\ \phi_k\sum_{r=1}^{s}\mu_r y_{rk}-\left(\sum_{r=1}^{s}\mu_r y_{ro}-\sum_{i=1}^{m}v_i x_{io}\right)\quad(7)$$

subject to $\sum_{i=1}^{m}v_i x_{ik}=\frac{1}{\phi_k}$

$\sum_{r=1}^{s}\mu_r(y_{rj}-y_{ro})-\sum_{i=1}^{m}v_i(x_{ij}-x_{io})\leq 0,\ j=1,\ldots,n$;
$\mu_r\geq \varepsilon t,\ r=1,\ldots,s$;
$v_i\geq \varepsilon t,\ i=1,\ldots,m$;
$t\geq 0$.

$$\text{Minimise}\ \theta_k\sum_{i=1}^{m}v_i x_{ik}+\left(\sum_{r=1}^{s}\mu_r y_{ro}-\sum_{i=1}^{m}v_i x_{io}\right)\quad(8)$$

subject to $\sum_{r=1}^{s}\mu_r y_{rk}=\frac{1}{\theta_k}$

$\sum_{r=1}^{s}\mu_r(y_{rj}-y_{ro})-\sum_{i=1}^{m}v_i(x_{ij}-x_{io})\leq 0,\ j=1,\ldots,n$;
$\mu_r\geq \varepsilon t,\ r=1,\ldots,s$;
$v_i\geq \varepsilon t,\ i=1,\ldots,m$;
$t\geq 0$.

Setting $\sum_{r=1}^{s}\mu_r y_{ro}-\sum_{i=1}^{m}v_i x_{io}=\omega_k$ and $\phi_k=1$, (7) becomes input-oriented model; while setting $\sum_{r=1}^{s}\mu_r y_{ro}-\sum_{i=1}^{m}v_i x_{io}=\omega_k$ and $\theta_k=1$, (8) becomes output-oriented model.

To obtain mixed-oriented multiplier form, (6) can be written as either of the following,

$$\text{Minimise}\ \frac{\theta_k}{\phi_k}\quad(6'»)$$

subject to

$\sum_{j=1}^{n}(y_{rj}-y_{ro})\lambda_j-s_r^{+}=\phi_k y_{rk}-y_{ro}, r=1,\ldots,s$;

$-\sum_{j=1}^{n}(x_{ij}-x_{io})\lambda_j-s_i^{-}+\theta_k x_{ik}-x_{io}=0, i=1,\ldots,m$;

$\varepsilon\left(\sum_{r=1}^{s}s_r^{+}+\sum_{i=1}^{m}s_i^{-}\right)\geq 0$

$\lambda_j\geq 0, j=1,\ldots,n$;
$s_r^{+}\geq 0, r=1,\ldots,s$;
$s_i^{-}\geq 0, i=1,\ldots,m$.

$$\text{Maximise}\ \frac{\phi_k}{\theta_k}\quad(6»»)$$

subject to

$-\sum_{j=1}^{n}(y_{rj}-y_{ro})\lambda_j+s_r^{+}+\phi_k y_{rk}-y_{ro}=0, r=1,\ldots,s$;

$\sum_{j=1}^{n}(x_{ij}-x_{io})\lambda_j+s_i^{-}=\theta_k x_{ik}-x_{io}, i=1,\ldots,m$;

$-\varepsilon\left(\sum_{r=1}^{s}s_r^{+}+\sum_{i=1}^{m}s_i^{-}\right)\leq 0$

$\lambda_j\geq 0, j=1,\ldots,n$;
$s_r^{+}\geq 0, r=1,\ldots,s$;
$s_i^{-}\geq 0, i=1,\ldots,m$.

Their duals are

$$\text{Maximise}\ \phi_k\sum_{r=1}^{s}\mu_r\left(y_{rk}-\frac{y_{ro}}{\phi_k}\right)\quad(9)$$

subject to $\sum_{i=1}^{m}v_i\left(x_{ik}-\frac{x_{io}}{\theta_k}\right)=\frac{1}{\phi_k}$

$$\text{Minimise}\ \theta_k\sum_{i=1}^{m}v_i\left(x_{ik}-\frac{x_{io}}{\theta_k}\right)\quad(10)$$

subject to $\sum_{r=1}^{s}\mu_r\left(y_{rk}-\frac{y_{ro}}{\phi_k}\right)=\frac{1}{\theta_k}$

$$\sum_{r=1}^{s}\mu_r(y_{rj}-y_{ro})-\sum_{i=1}^{m}v_i(x_{ij}-x_{io})\le 0,\ j=1,\dots,n; \qquad \sum_{r=1}^{s}\mu_r(y_{rj}-y_{ro})-\sum_{i=1}^{m}v_i(x_{ij}-x_{io})\le 0,\ j=1,\dots,n;$$
$$\mu_r\ge \varepsilon t,\ r=1,\dots,s; \qquad \mu_r\ge \varepsilon t,\ r=1,\dots,s;$$
$$v_i\ge \varepsilon t,\ i=1,\dots,m; \qquad v_i\ge \varepsilon t,\ i=1,\dots,m;$$
$$t\ge 0. \qquad t\ge 0.$$

If $t=\dfrac{1}{\phi_k\sum_{i=1}^{m}v_i(x_{ik}-\frac{x_{io}}{\theta_k})}$, $\mu_r = tu_r$, and $v_i = tv_i$ are set in (9) or $t=\dfrac{1}{\theta_k\sum_{r=1}^{s}u_r(y_{rk}-\frac{y_{ro}}{\phi_k})}$, $\mu_r = tu_r$, and $\mu_r = tu_r$ are set in (10), the multiplier form of (5) can be obtained as

$$\text{Maximise}\ \frac{\sum_{r=1}^{s}u_r(y_{rk}-\frac{y_{ro}}{\phi_k})}{\sum_{i=1}^{m}v_i(x_{ik}-\frac{x_{io}}{\theta_k})}=\text{Maximise}\frac{\sum_{r=1}^{s}u_ry_{rk}(1-\frac{y_{ro}}{\hat{y}_{rk}-s_r^+})}{\sum_{i=1}^{m}v_ix_{ik}(1-\frac{x_{io}}{\hat{x}_{ik}+s_i^-})} \qquad (11)$$

subject to
$$\frac{\sum_{r=1}^{s}u_r(y_{rk}-y_{ro})}{\sum_{i=1}^{m}v_i(x_{ik}-x_{io})}\le 1,\ j=1,\dots,n;$$
$$u_r\ge\varepsilon,\ r=1,\dots,s;$$
$$v_i\ge\varepsilon,\ i=1,\dots,m.$$

(x_{io}, y_{ro}) is an efficient DMU which is in the reference set for DMUk. (11) demonstrates that its optimal value relies on θ_k and ϕ_k, i.e., the projected point ($\hat{x}_{ik}, \hat{y}_{rk}$), while (1) does not. (11) is not a linear fractional programming but is a more general fractional programming and a generalised DEA model. The CCR linear fractional programming DEA model (1) is mere its special case with $x_{io}=0$ and $y_{ro}=0$.

3. Summary of basic DEA models

The original idea for DEA due to Farrell (1957) lay dormant for twenty-one years before it was expressed in a more practical form. Charnes et al (1962, 1978, 1979) noted that this fractional programming problem could be transformed into an equivalent linear programming problem. DEA was extended to

- a "multiplicative" base DEA model by Charnes et al (1982, 1983) by replacing the ratio of a weighted sum of the outputs to a weighted sum of the inputs with the ratio of a powered product of the outputs to a powered product of the inputs;
- a variable returns to scale DEA model by Banker et al (1984) by imposing a convex constraint in the dual equivalent linear programming DEA model, i.e. an additional variable is added into (reduced from) the functional as well as constraints of the primal equivalent input-orientation (output-orientation) linear programming DEA model to separate technical efficiency from total efficiency;
- an "additive" base DEA model by Charnes et al (1985) by replacing the ratio of a weighted sum of the outputs to a weighted sum of the inputs with the difference between a weighted sum of the outputs and a weighted sum of the inputs; and
- a "mixed-orientation" model by O'Brien et al (2001) by conducting alternative transformations and duality of linear fractional programming and the envelopment form of linear fractional programming DEA model.

The basic DEA models can be summarised as in the following table.

		Constant Returns to scale	Variable Returns to scale
Fractional Programming		CCR-Linear Fractional Programming	OW-Non Linear Fractional Programming
Equivalent Linear Programming transformed from Fractional Programming	Input-Orientation	CCR-Input Orientation	BCC-Input Orientation
	Mixed-Orientation	OW-Constant returns to scale	OW-Variable returns to scale
	Output-Orientation	CCR-Output Orientation	BCC-Output Orientation
Linear Programming	Additive	?[1]	CCGSS
Log-Linear Programming	Multiplicative	CCSS-Units Variant	CCSS-Units Invariant

4. Conclusion

The alternative transformations discussed in this paper provide a general solution rather than a representative one to the linear fractional programming problem and the results presented here apply more generally to any fractional programming problem with concave numerator, convex denominator and convex constraint.

As an added bonus these results and the DEA models described in this paper provide alternate constant returns to scale solutions and global variable returns to scale solutions for DEA of the standard linear fractional programming model.

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[1] This constant returns to scale model can be easily conducted from CCGSS model by relaxing convexity constraint from its envelopment form and has actually been available even in 5.0 version of IDEAS by choosing CRS for Form of Surface and Base for Orientation in Model Management box. However, the literature in which this model appears first might be the chapter of Ali and Seiford in Fried, Lovell, and Schmidt (1993).

About Structure of Boundary Points in DEA

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Abstract
In this paper, we establish relations between sets of input and output boundaries, set of weakly Pareto-efficient points and the boundary of T. Theoretical results presented in the paper are illustrated by examples.

Keywords: data envelopment analysis

1. Introduction

In scientific literature[1-3] on DEA, much attention is paid to calculation of various economic factors such as efficiency measures, returns to scale, marginal rates of substitutions.
Our aim was to develop a constructive technique to visualize the frontier in multidimensional space of inputs and outputs.

For this purpose we proposed a family of parametric optimization algorithms[4,5] that allows us to reduce the efficiency analysis of production units to the investigation of the well-known functions in economics such as production function, isoquant, isocost, isoprofit, see also the authors' paper in this issue.

In essence, parametric algorithms cut the boundary of production possibility set T in different directions and build parametric curves that belong to the boundary of T. So, the question arises: what is the structure of the boundary points?

In the DEA approach,[6] the union of input and output boundaries is considered to coincide with the set of weakly Pareto-efficient points. For reasons given below, this point of view deserves to be reassessed.

In this paper, we establish relations between sets of input and output boundaries, set of weakly Pareto-efficient points and the boundary of T. Theoretical results presented in the paper are illustrated by graphical examples. The paper deals mainly with the BCC model. However, this approach can be extended to other DEA models without any loss of generality.

2. Background

Consider a set of n observations of actual production units (X_j, Y_j), $j=1, \dots, n$, where the vector of outputs $Y_j=(y_{1j}, \dots, y_{rj}) \geq 0$ is produced from the vector of inputs $X_j=(x_{1j}, \dots, x_{mj}) \geq 0$. The production possibility set T is the set $\{(X,Y) \mid \textit{the outputs } Y \geq 0 \textit{ can be produced from the inputs } X \geq 0\}$.

Set T is empirically specified by the following postulates.[1]

Postulate 1 (Convexity). If $(X,Y) \in T$ and $(X',Y') \in T$, then $(\lambda X+(1-\lambda)X', \lambda Y+(1-\lambda)Y') \in T$ for all $\lambda \in [0,1]$.

Postulate 2 (Monotonicity). If $(X, Y) \in T$ and $X' \geq X$, $Y' \leq Y$, then $(X', Y') \in T$.

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Postulate 3 (Minimum extrapolation). T is the intersection set of all T', satisfying Postulates 1 and 2, and subject to the condition that each of the observed vectors $(X_j, Y_j) \in T', j = 1, \dots, n$. Production possibility set T can be represented in the algebraical form[1]

$$T = \{(X,Y) /\ X \geq \sum_{j=1}^{n} X_j \lambda_j,\ Y \leq \sum_{j=1}^{n} Y_j \lambda_j, \\ \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j > 0,\ j = 1,\dots,n\}. \tag{1}$$

BCC (Banker, Charnes and Cooper) input-oriented model given below enables us to find some efficient points on the frontier.

$$\min\ \theta - \varepsilon \left\{ \sum_{k=1}^{m} s_k^- + \sum_{i=1}^{r} s_i^+ \right\}$$

subject to

$$\theta x_{ko} - \sum_{j=1}^{n} x_{kj} \lambda_j - s_k^- = 0,\ k=1,\dots,m, \tag{2}$$

$$\sum_{j=1}^{n} y_{ij} \lambda_j - s_i^+ = y_{io},\ i=1,\dots,r,$$

$$\lambda_j, s_k^-, s_i^+ \geq 0,$$

where x_{kj} and y_{ij} represent the observed inputs and outputs of production units $j=1,\dots, n$. Unit (X_o,Y_o) is under investigation in problem (2).

Definition 1 Unit $(X_o,Y_o) \in T$ is called BCC-efficient with respect to input-oriented BCC model if and only if optimal solution of (2) satisfies a) $\theta^* = 1$, b) all slacks s_k^{-*}, s_i^{+*} $k=1,\dots, m$, $i=1,\dots, r$, are zero.

We denote the set of efficient points of T with respect to input-oriented BCC model by $Eff_I\ T$.

If the first condition in definition 1 is satisfied, then unit (X_o,Y_o) is called input weakly efficient with respect to BCC model. We denote the set of these weakly efficient points by $WEff_I\ T$. In the DEA literature,[2,6] this set is also called input boundary.

BCC output-oriented model can be written in the following manner

$$\max\ \eta + \varepsilon \left\{ \sum_{k=1}^{m} s_k^- + \sum_{i=1}^{r} s_i^+ \right\}$$

subject to

$$\sum_{j=1}^{n} x_{kj} \lambda_j + s_k^- = x_{ko},\ k=1,\dots m, \tag{3}$$

$$\sum_{j=1}^{n} y_{ij} \lambda_j - s_i^+ = \eta y_{io},\ i=1,\dots r,$$

$$\sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \geq 0,\ s_i^+ \geq 0,\ s_k^- \geq 0 \text{ for all } j, k, i.$$

Definition 2 Unit $(X_o,Y_o) \in T$ is called BCC-efficient with respect to output-oriented BCC model if and only if optimal solution of (3) satisfies a) $\eta^* = 1$, b) all slacks s_k^{-*}, s_i^{+*} $k=1,\dots, m$, $i=1,\dots, r$, are zero.

Let us denote the set of efficient points with respect to output-oriented BCC model by $Eff_O\ T$.

If the first condition in definition 2 is satisfied, then unit (X_o,Y_o) is called output weakly efficient with respect to BCC model. We denote the set of these weakly efficient points by *WEff$_O$ T*. In the DEA literature,[2,6] this set is also called output boundary.

In DEA theory,[7] it was established that unit $(X_o,Y_o)\in$ *Eff$_I$ T* if and only if $(X_o,Y_o)\in$ *Eff$_O$ T*. So, let *Eff T* denote both *Eff$_I$ T* and *Eff$_O$ T*.

Definition 3 (Pareto-efficiency) Production unit $(X^*,Y^*)\in T$ is efficient if and only if there is no $(X,Y)\in T$ and $(X,Y)\neq(X^*,Y^*)$ such that $X\leq X^*$, $Y\geq Y^*$.
We denote the set of Pareto-efficient points by *Eff$_P$ T*.

Definition 4 (Weak Pareto-efficiency) Production unit $(X', Y')\in T$ is weakly efficient if and only if there is no $(X, Y)\in T$ such that $X < X'$, $Y > Y'$.
We denote the set of weakly Pareto-efficient points by *WEff$_P$ T*.

In DEA approach,[7] it is known that unit $(X_o,Y_o)\in$ *Eff T* if and only if $(X_o,Y_o)\in$ *Eff$_P$ T*. Therefore, let *Eff T* stand for *Eff$_P$ T*.

However, relationships between sets *WEff$_I$ T*, *WEff$_O$ T* and *WEff$_P$ T* are not so evident as for efficient points. In the next section, we compare and contrast these sets and establish relations between them.

There are many optimization models in the DEA framework. In this paper, we dwell mainly on BCC model, without any loss in generality, since the proposed approach can be extended to other DEA models.

3. Main results

Let I_x and I_y be index sets of a production unit $Z=(X,Y)\in E^{m+r}$ and be associated with vectors X and Y, respectively, where $|I_x|=m$ and $|I_y|=r$. Let vector $d=(d_x,d_y)\in E^{m+r}$, where $d_x\in E^m$ and $d_y\in E^r$, denote the direction in space E^{m+r}. We assume that $||d||_2=1$. Next, let *Bound T* denote the boundary of set T. Let us recall that point $(X',Y')\in$ *Bound T* if and only if for all $\varepsilon>0$, the open ball centered at (X',Y') with radius ε contains both points that belong to T and points that do not belong to T.

Lemma Let production unit $Z_o\in T\setminus$ *WEff$_P$ T*, then for any vector $d=(d_x,d_y)\in E^{m+r}$ satisfying $d_x\leq 0$, $d_y\geq 0$ there exists $\varepsilon_0>0$ such that $(Z_o+\varepsilon d)\in T$ if $\varepsilon\leq\varepsilon_0$.

Proof If $Z_o\notin$ *WEff$_P$ T*, then according to definition of weak efficiency there exists direction $d=(d_x,d_y)\in E^{m+r}$, where $d_x<0$ and $d_y>0$, and $\varepsilon>0$ such that $(Z_o+\varepsilon d)\in T$.

Let $Z'=Z_o+\varepsilon d$. Using the monotonocity of T, we can write

$$(Z'+\sum_{i\in I_x}\mu_i e_i-\sum_{i\in I_y}\rho_i e_i)\in T\,,\quad \mu_i,\ \rho_i\geq 0\,, \tag{4}$$

where $e_i\in E^{m+r}$ is an identity vector with a one in position i.

From (4), it follows that one can choose such $\mu_i,\ \rho_i\geq 0$ that

$$Z'+\sum_{i\in I_x}\mu_i e_i-\sum_{i\in I_y}\rho_i e_i=(Z_o+\varepsilon d')\in T\,,$$

where $d'=(d'_x, d'_y)\in E^{m+r}$, $d'_x\leq 0$, $d'_y\geq 0$.

This relation completes the proof. □

Notice that for some $Z_o \in WEff_P\ T$ there exist vector $d=(d_x,d_y)$, $d_x \leq 0$, $d_y \geq 0$ and $\varepsilon>0$ such that $(Z_o+\varepsilon d) \in T$.

Moreover, for the general multiobjective optimization problem it can be shown that there exist points Z which are not weakly Pareto-efficient, however some directions for them may not be feasible.

Theorem 1 For BCC models production unit $Z_o = (X_o,Y_o) \in WEff_P\ T$ if and only if $Z_o \in$ *Bound T*.

Proof Let $Z_o \in WEff_P\ T$, then according to the definition of weak Pareto-efficiency there exists $d \in E^{m+r}$ such that $(Z_o+\varepsilon d) \notin T$ for any $\varepsilon>0$. Hence, $Z_o \in$ *Bound T*.

Conversely, let $Z_o \in$ *Bound T*. Suppose that $Z_o \notin WEff_P\ T$. Then, according to lemma, there exists $\varepsilon>0$ such that the following relation holds

$$Z_\delta = Z_o + \varepsilon(-\sum_{i\in I_x}\mu_i e_i + \sum_{i\in I_y}\rho_i e_i) \in T, \quad \mu_i, \rho_i \geq 0. \tag{5}$$

Next, using monotonocity of T, we can write

$$Z'_\delta = Z_o + \varepsilon(\sum_{i\in I_x}\mu'_i e_i - \sum_{i\in I_y}\rho'_i e_i) \in T, \quad \mu'_i, \rho'_i \geq 0. \tag{6}$$

Taking into account convexity of T and using (5) and (6), we obtain

$$\lambda Z_\delta + (1-\lambda)Z'_\delta = \{Z_o + \varepsilon[\sum_{i\in I_x}\xi_i e_i + \sum_{i\in I_y}\xi'_i e_i]\} \in T, \tag{7}$$

where $0 \leq \lambda \leq 1$,

$$-\lambda\mu_i + (1-\lambda)\mu'_i = \xi_i,\ i \in I_x, \tag{8}$$
$$\lambda\rho_i - (1-\lambda)\rho'_i = \xi'_i,\ i \in I_y.$$

From (7) and (8), it follows that $\xi_i, i \in I_x$, $\xi'_i, i \in I_y$, can be given any real values by choosing appropriate values $\lambda, \mu_i, \mu'_i, \rho_i, \rho'_i$. Hence, Z_o is contained in set T with some ball of radius ε. Thus, we have $Z_o \notin$ *Bound T*, contradicting the assumption. This completes the proof. □

Corollary Let production unit $Z_o \in WEff_O\ T \cup WEff_I\ T$, then $Z_o \in WEff_P\ T$.

Proof Solving problem (2) or (3), we obtain an optimal point which belongs to *Bound T*, hence by virtue of Theorem 1 this point belongs to $WEff_P\ T$. □

Furthermore, we state sufficient condition that unit Z_o is contained in the intersection of weakly efficient sets according to input-oriented and output-oriented BCC models, however unit Z_o is not efficient.

Theorem 2 Let production unit $Z_o=(X_o,Y_o) \in ri\ \Gamma$, here $ri\ \Gamma$ stands for relative interior of Γ, where facet Γ of set T is represented in the form

$$\Gamma = \sum_{j\in J} Z_j\lambda_j + \sum_{i\in I_1}\mu_i e_i - \sum_{i\in I_2}\rho_i e_i, \tag{9}$$
$$\sum_{j\in J}\lambda_j = 1,\ \mu_i, \rho_i \geq 0,$$

where J is a subset of vertices of set T, I_1 and I_2 are index subsets of vectors Z_j, I_1 and I_2 are associated with vectors X and Y, respectively, and $|I_1|<m$, $|I_2|<r$. Let also be $z_{ij}\neq 0$, $i=1,...m+r$, $j\in J$. Then $Z_o \in WEff_O\, T \cap WEff_I\, T$, however $Z_o \notin Eff\, T$.

Proof By virtue of theorem conditions, we can write

$$\begin{aligned}&\sum_{j\in J} z_{ij}\lambda_j = z_{io},\, i\in (I_x \setminus I_1)\cup(I_y \setminus I_2), \quad \sum_{j\in J} z_{ij}\lambda_j < z_{io},\, i\in I_1, \\ &\sum_{j\in J} z_{ij}\lambda_j > z_{io},\, i\in I_2, \quad \sum_{j\in J}\lambda_j = 1,\ \lambda_j \geq 0.\end{aligned} \tag{10}$$

Suppose that $Z_o \notin WEff_I\, T$. Then, solving the problem (2), we obtain $\theta^*<1$. By the theorem assumption, all inputs and outputs of production units are positive, hence $z'_{io}=\theta^* z_{io}<z_{io}$ $i\in I_x$. Therefore for point $Z_o=(X_o,Y_o)$ there exist direction $d_x \geq 0$ and $\varepsilon>0$ such that $(X_o - \varepsilon d_x, Y_o) \in T$. Then it can be shown that there exist direction e_i, $i\in (I_x \setminus I_1)$, $e_i \in R^m$ and $\varepsilon>0$ such that

$$(X_o - \varepsilon e_i, Y_o) \in T. \tag{11}$$

In addition, by using monotonocity of T, we can write

$$(X_o + \varepsilon e_i, Y_o) \in T, \ i\in(I_x \setminus I_1). \tag{12}$$

However, relations (11) and (12) contradict facet determination (9). So, it follows that $\theta^*=1$. Moreover, by virtue of (10), slacks associated with $i\in I_2$ are non-zero. Hence, we have $Z_o \in WEff_I\, T$.

In a similar way, it can be proved that $Z_o \in WEff_O\, T$. This means that $Z_o \in WEff_O\, T \cap WEff_I\, T$ and $Z_o \notin Eff\, T$. □

In the following theorem, we assert that unit Z_o can belong to the set of weakly efficient points with respect to output-oriented BCC model, however this point is not weakly efficient with respect to input-oriented model.

Theorem 3 Let production unit $Z_o = (X_o,Y_o) \in ri\, \Gamma$, where facet Γ of set T is represented in the form

$$\Gamma = \sum_{j\in J} Z_j\lambda_j + \sum_{i\in I_x} \mu_i e_i, \ \sum_{j\in J}\lambda_j = 1,\ \lambda_j, \mu_j \geq 0, \tag{13}$$

here J is a subset of vertices of set T. Then $Z_o \in WEff_O\, T$ and $Z_o \notin WEff_I\, T$.

Proof Using relation $Z_o \in ri\, \Gamma$ and (13), one can conclude

$$\sum_{j\in J} Z_{ij}\lambda_j < Z_{io},\, i\in I_x.$$

Hence, solving problem (2), we obtain $\theta^*<1$. This means that $Z_o \notin WEff_I\, T$.

Next, taking into account the determination of facet Γ (13) and using monotonocity of T, we conclude that there are no vectors e_i, $i\in I_y$ and $\varepsilon>0$ such that $(Z_o + \varepsilon e_i) \in T$. Hence there is no $d_y \geq 0$ such that $(X_o, Y_o+d_y) \in T$. However slacks associated with $i\in I_x$ are non-zero. This means that $Z_o \in WEff_O\, T$. □

Theorem 4 Let production unit $Z_o = (X_o,Y_o) \in ri\, \Gamma$, where facet Γ of set T is represented in the form

$$\Gamma = \sum_{j\in J} Z_j\lambda_j - \sum_{i\in I_y} \mu_i e_i, \quad \sum_{j\in J}\lambda_j = 1, \quad \lambda_i, \mu_i \geq 0,$$

here J is a subset of vertices of set T. Then unit $Z_o \notin WEff_O\, T$ and $Z_o \in WEff_I\, T$.
The proof of Theorem 4 is similar to the previous one.

In the next theorem, we show that weakly Pareto-efficient points may not be weakly efficient points with respect to BCC models.

Theorem 5 Let production unit $Z_o = (X_o,Y_o) \in ri\,\Gamma$, where facet Γ of set T is represented in the form

$$\Gamma = \sum_{j\in J} Z_j\lambda_j + \sum_{i\in I_x\setminus I_{xo}} \mu_i e_i - \sum_{i\in I_y} \rho_i e_i, \tag{14}$$

$$\sum_{j\in J}\lambda_j = 1,\ \mu_i,\ \rho_i \geq 0,$$

here J is a subset of vertices of set T, I_{xo} is a index subset of set I_x such that $1 \leq |I_{xo}| < m$, $z_{kj} = 0$, $k \in I_{xo}$ and $j \in J$. Then $Z_o \in WEff_P\,T$, however $Z_o \notin WEff_O\,T \cup WEff_I\,T$.

Proof By virtue of theorem conditions and using (14), we can write

$$\sum_{j\in J} z_{ij}\lambda_j < z_{io},\ i \in I_x \setminus I_{xo}, \qquad \sum_{j\in J} z_{ij}\lambda_j = z_{io} = 0,\ i \in I_{xo},$$

$$\sum_{j\in J} z_{ij}\lambda_j > z_{io},\ i \in I_y, \qquad \sum_{j\in J}\lambda_j = 1,\ \lambda_j \geq 0.$$

Then, it follows that for problem (2) and (3) we obtain $\theta^* < 1$ and $\eta^* > 1$. Hence, $Z_o \notin WEff_O\,T \cup WEff_I\,T$.

Next, unit $Z_o \in \Gamma$, therefore unit Z_o belongs to the boundary of T and by Theorem 1 $Z_o \in WEff_P\,T$. This completes the proof. □

The following theorem summarizes the main results of this section. Its proof is based on previously stated results.

Theorem 6 For BCC models (2) and (3) the following relations hold

$WEff_I\,T \cup WEff_O\,T \subset WEff_P\,T = Bound\,T$.

In Theorems 2-5, sufficient conditions are considered when production unit Z_o is contained in sets $WEff_I\,T$, $WEff_O\,T$, $WEff_P\,T$. It may be noted that there are other sufficient conditions when unit Z_o is contained in these sets. However, we do not consider these conditions, since our aim is only to reveal the relations between sets $WEff_I\,T$, $WEff_O\,T$, $WEff_P\,T$ and $Bound\,T$.

Notice also that all relations between the sets in theorems do exist, this can be shown by examples. However, all relations between those sets may not exist simultaneously in some specific models.

Next, in many practical DEA models the boundary of T coincides with set $(WEff_O\,T \cup WEff_I\,T)$. For this reason many papers on DEA consider this set as extended frontier. From Theorem 6, it follows that it is more expedient to determine set $WEff_P\,T$ as extended frontier, as it defined in paper.[6]

4. Graphical examples

To reveal intrinsic features of the proposed approach, let us consider relations between efficient points in figures.

In Figure 1, a two-dimensional BCC model is depicted. Similar figures are often taken to illustrate BCC models in DEA theory.[7] Piecewise linear curve *MABCDL* is a set of weakly Pareto-efficient points and a boundary of production possibility set T. Curve *ABCDL* represents set $WEff_O\,T$. Curve *MABCD* is set $WEff_I\,T$. Intersection of these sets is a set of efficient points. Point $F_1 \in WEff_I\,T$, however $F_1 \notin WEff_O\,T$. On the contrary, point $F_2 \in WEff_O\,T$ and $F_2 \notin WEff_I\,T$. Hence for this model $WEff_I\,T \cap WEff_O\,T = Eff\,T$ and the following relations hold $WEff_I\,T \cup WEff_O\,T = WEff_P\,T = Bound\,T$.

In Figure 2, two-inputs/one-output BCC model is shown. Points A, C, D, E represent the observed production units that determine production possibility set T. Point B is a projection of unit A onto orthant X_1OX_2 . Let also segment AE be parallel to orthant X_1OX_2. For this model, the interior of ray AL_1 belongs to the intersection of sets $WEff_I\ T$ and $WEff_O\ T$. However, the interior of ray AL_1 is not contained in $Eff\ T$. Facet $MEAL_1$ belongs to set $WEff_O\ T$. Facet L_1ABL_2 is a subset of weakly efficient points with respect to input BCC model. Therefore for this model, we obtain $WEff_I\ T \cap WEff_O\ T \neq Eff\ T$ and $WEff_I\ T \cup WEff_O\ T = WEff_P\ T = Bound\ T$.

Again, Figure 3 demonstrates a three-dimensional BCC model. Facet $LABX_1$ belongs to the orthant X_1OY. Let segment AE be parallel to orthant X_1OX_2. Facet $LAEM$ represents set $WEff_O\ T$. In addition, ray EM is contained in $WEff_I\ T$. However, the interior of ray AL is not contained in $WEff_I\ T$. The interior of facet $LABX_1$ belongs to $WEff_P\ T$. However, the interior of facet $LABX_1$ is not contained in $WEff_I\ T$ or $WEff_O\ T$. Hence, for this model we obtain $WEff_I\ T \cap WEff_O\ T \neq Eff\ T$, $\quad WEff_I\ T \cup WEff_O\ T \subset WEff_P\ T = Bound\ T$.

Thus, we have considered all possible cases that were given in theorems 2-5.

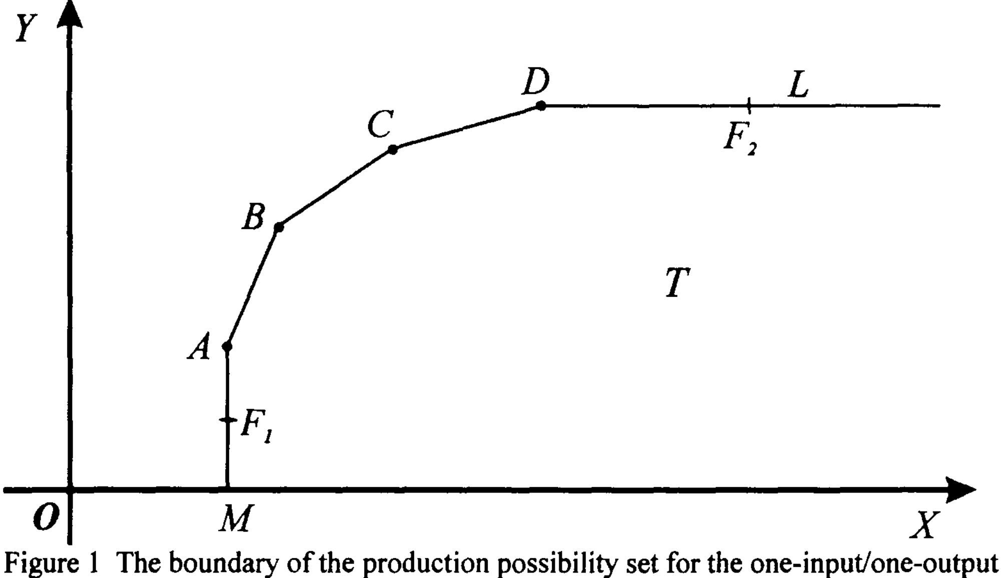

Figure 1 The boundary of the production possibility set for the one-input/one-output BCC model.

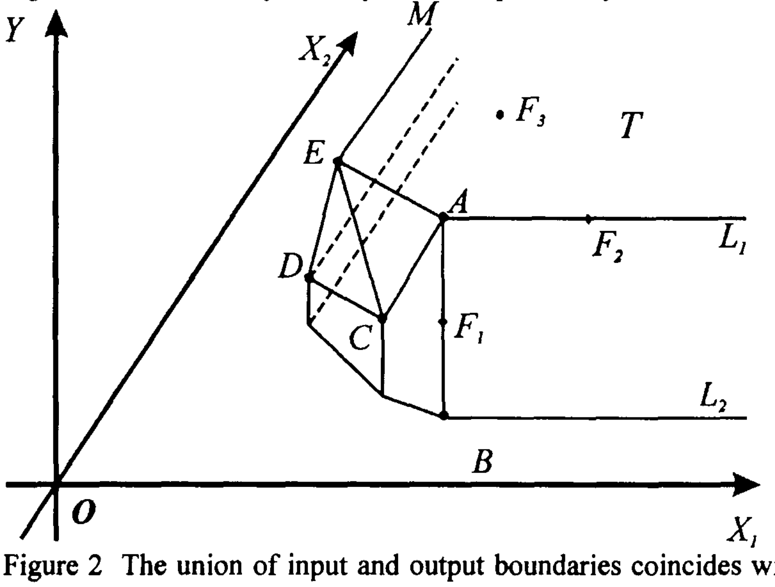

Figure 2 The union of input and output boundaries coincides with the set of weakly Pareto-efficient points.

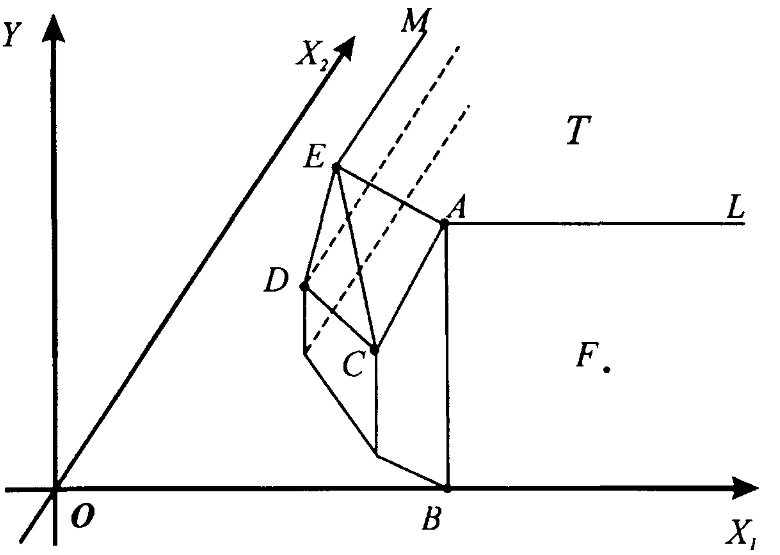

Figure 3 The union of input and output boundaries is contained in the set of weakly Pareto-efficient points.

5. Conclusion

In this paper, we investigate the structure of boundary points in DEA. These theoretical grounds are necessary to construct parametric algorithms and to interpret the DEA modelling results. The paper dwell mainly on the BCC models, though, the proposed approach can be extended to other DEA models. Illustrative examples demonstrate the theoretical results of the paper.

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Efficient and Close Targets in Data Envelopment Analysis (DEA)

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Abstract

This paper draws attention for the fact that traditional Data Envelopment Analysis (DEA) models do not provide the closest possible targets (or peers) to inefficient units, and presents a procedure to obtain such targets. It focuses on non-oriented efficiency measures both measured in relation to a Free Disposal Hull (FDH) technology and in relation to a convex technology. The approaches developed for finding close targets are applied to a sample of Portuguese bank branches.

1. Introduction

One of the key practical outcomes in an efficiency assessment is the identification of targets. Targets may be identified by any DEA model, radial or non-radial, oriented or non-oriented. Our focus here is on non-oriented (and therefore non-radial) models of efficiency, which assume that production units are able to control, and thus change, inputs and outputs simultaneously. A drawback of the existing non-oriented DEA models [like the hyperbolic model introduced by Färe, Grosskopf, and Lovell (1985) or the additive model due to Charnes et al. (1985)] is that they either impose strong restrictions on the movements towards the efficient frontier, or they aim at maximising slacks. Both these facts contribute to finding targets and peers that may not be the closest possible to the units being assessed. If Pareto-efficiency can be achieved by inefficient units with less effort than that implied by targets derived using traditional DEA efficiency models, then it is at least of practical value to find the closest targets for each inefficient unit we can. Close targets in this sense are in line with the original spirit of DEA of showing each unit in the best possible light.

The idea of finding closest targets and peers has appeared in the literature both associated with oriented models [see for example Coelli (1998), or Cherchye and Puyenbroek (2001)] and non-oriented models [see for example Frei and Harker (1999) or Golany, Phillips, and Rousseau (1993)]. It is our intention to explore this issue for the most general case of non-oriented efficiency measures. In addition, the analysis will be restricted to technical efficiency.

2. Non-Radial-non-oriented Measures of Efficiency

Non-oriented DEA models, like the additive model of Charnes et al. (1985) or its variant the RAM (**R**ange **A**djusted **M**easure) as proposed by Cooper, Park, and Pastor (1999), explicitly maximise slacks in their objective functions. The Russell graph measure of Färe, Grosskopf, and Lovell (1985) (of which the hyperbolic measure of efficiency is a special case), or the directional distance function introduced by Chambers, Chung, and Färe (1996, 1998) also maximise slacks, though this is not explicit in the objective function. Such models, therefore, are not able to provide close and efficient targets to inefficient units they identify.

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Our objective is on the one hand to find an appropriate measure of efficiency and, on the other hand, to operationalise this measure so targets can be found which are Pareto-efficient and close to some inefficient unit. Two requirements for an appropriate measure of efficiency in a non-oriented context are: (i) it should be capable of incorporating all the sources of inefficiency, while at the same time (ii) retaining the meaning of radial efficiency measures. The above mentioned directional and hyperbolic measures do not satisfy the first requirement, while the RAM, the additive model, and the Russell graph measure do not satisfy the second requirement. A measure that satisfies both requirements is that developed by Brockett et al. (1997), which will be referred to as BRWZ throughout. The BRWZ efficiency measure is shown in (1).

$$BRWZ_o = \frac{1}{m}\left(\sum_{i=1}^{m}\frac{x_{io}-e_i^*}{x_{io}}\right)\times\frac{1}{s}\left(\sum_{r=1}^{s}\frac{y_{ro}}{y_{ro}+s_r^*}\right) \Leftrightarrow BRWZ_o = \frac{\sum_{i=1}^{m}h_{io}\times\sum_{r=1}^{s}1/g_{ro}}{m\times s} \quad (1)$$

The first expression in (1) assumes that all inefficiencies are captured by additive slack values, e_i^* and s_r^*, where the star denotes an optimal value of the input and output slacks as resulting from the solution of some DEA model which projects units on the Pareto-efficient boundary. The second expression for the BRWZ measure in (1) makes it possible to show that the BRWZ measure is closer to the meaning of radial efficiency measure. In addition, if we assume that all inputs change equiproportionately (each h_i = θ) and that outputs are not allowed to change (each $g_r = 1$), then the BRWZ measure reduces to θ, which coincides with the Farrell measure of input efficiency. The BRWZ measure is also units invariant which is a considerable advantage.

3. Closer Targets and Efficiency

Let us first define the notion of closeness of targets. In general, we say that unit B is closer to A than to C, if moving from A to B requires smaller changes in inputs and outputs than those required in moving from A to C. Such changes can be expressed in terms of ratios of input and output levels at the two different points concerned, where the larger the ratios the closer the points will be. Obviously in a non-oriented space with multiple inputs and outputs one needs to choose a form of aggregating such ratios. In our case, the BRWZ efficiency measure was chosen for this aggregation. Thus, the closer the target point to an observed point the higher the BRWZ efficiency as a measure of the distance between the two points.

The closeness between two points can also be measured using an L_p metric. Such metrics are not expressed in ratio form but in difference form. Therefore they have the disadvantage of not being units invariant. The L_p distance between two points (A and B) is given by $\left[\sum_{i=1}^{n}|A_i - B_i|^p\right]^{1/p}$. We can illustrate concepts of closeness between points using a simple one input - one output example as shown in Figure 1. Unit F is FDH and BCC inefficient, where in the first case it is dominated by units B and C. Unit C is closer to F than is unit B. This can be seen in
Table 1 where the BRWZ measure and some metric distances between points F, C, and B are presented. Clearly point B is the point that maximises the sum of slacks (see L_1 metric), meaning that the non-oriented models we saw previously - additive, RAM, and Russell Graph measure - identify point B as the target of unit F rather than point C. This happens both for the case of FDH and convex technology. In the convex context the closest point in terms of the BRWZ measure is point (5, 5.33) – a convex combination between points B and D.
Table 1 shows that this point is closer to F than the target point B in terms of the BRWZ measure and in terms of the L_1 norm, but not in terms of the two other norms. We favour

comparisons based on the BRWZ measure because it is units invariant, - a characteristic that is important when units of measurement are subjective.

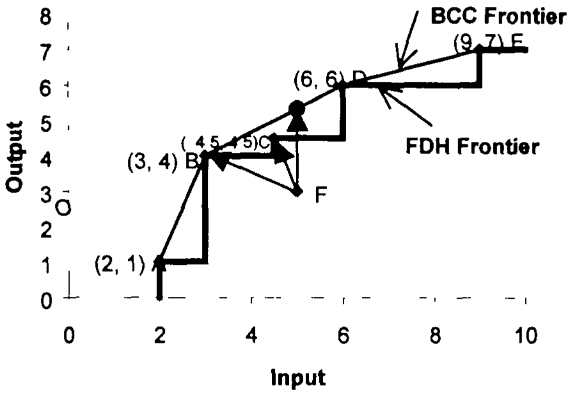

Figure 1: One input/output example

Point	BRWZ	L_1	L_2	L_∞
B	45%	3	$\sqrt{5}$	2
C	60%	2	$\sqrt{2.5}$	1.5
(5, 5.33)	56.25%	2.33	$\sqrt{5.44}$	2.33

Table 1: Distance of F from points C, B, and **(5, 5.33)**

4. Identifying Closer Targets in a FDH Technology

The approach developed in this paper takes advantage of the fact that in FDH targets correspond to a single observed unit (peer), which simplifies their identification and the calculation of efficiency. Calculating efficiency requires first the knowledge of the set of dominating units for each dominated unit, and then the selection of the one (the closest) that should be used as the peer.

Our approach follows three steps:

> **Step I** Determine the set of non-dominated units (100% FDH efficient);
> **Step II** Determine a peer unit for each dominated unit;
> **Step III** Calculate the efficiency score.

Step I partitions the set of observed units into two sets: *ND* and *D*. *ND* is the set of non-dominated (or dominating) units (units in relation to which no other unit exists presenting all lower or equal inputs and all higher or equal outputs) and *D* is the set of the remaining units, called dominated. Although this operation can be performed for each unit by comparing it with all the other units or with the current non-dominated set, there are more efficient implementations used, especially in multiple objective combinatorial optimization. In our case we used an algorithm presented in Borges (2000), together with other well known quad tree algorithms to identify non-dominated units.

Step II finds a peer unit for each inefficient or dominated unit. In order to find this unit, we consider a subset

of *ND*, named K_o, consisting of the units that dominate the unit o being assessed. For each inefficient unit, its closest peer is determined through the BRWZ efficiency measure, that is, calculating (2) for every unit $k \in K_o$, where the subscript o identifies the inefficient unit being assessed.

$$Peer\ of\ unit\ o = \max_k \left(\frac{\sum_{i=1}^{m} x_{ik} / x_{io}}{m} \times \frac{\sum_{r=1}^{s} y_{ro} / y_{rk}}{s} \right) \qquad \textbf{(2)}$$

Step III generates the efficiency of the unit being assessed in reference to the peer unit identified in the previous step. The measure of efficiency is given directly from the value obtained in (2). Therefore, steps II and III take place simultaneously.

5. Identifying Closer Targets in a Convex Technology

Extending the above procedure to convex technologies is not straightforward because in this case target points are not to be restricted to observed units but to convex combinations of Pareto-efficient units. As a result, an enumeration oriented procedure, which calculates the BRWZ measure for a set of potential target points can no longer be applied. The approach to follow in the case of convex frontiers is to use a DEA model where the BRWZ is maximised. However, in order to assure that the maximum BRWZ projection corresponds to a Pareto-efficient point one needs to impose some restrictions on the reference set [see for example Golany, Phillips, and Rousseau (1993) and Frei and Harker (1999)]. For this purpose we identify efficient facets through Qhull as proposed by Olesen and Petersen (2001). This software identifies all full dimension efficient facets (FDEF) in a DEA model, and provides a supporting hyperplane equation for each facet. The procedure can also be modified to identify non-full dimensional efficient facets.

Our procedure for finding the closest targets in convex technologies consists of three steps:

Step I Determine the set of Pareto-efficient units (E) by solving the additive model;
Step II Determine all Pareto-efficient facets (F_k) using QHull;
Step III For each F_k $k = 1,\ldots, K$ solve model (3) to find the closest targets for inefficient unit o.

$$Max \left\{ \begin{array}{l} BRWZ_o = \frac{1}{m \times s}\left(\sum_{i=1}^{m} h_{io} \times \sum_{r=1}^{s} 1/g_{ro}\right) \mid \sum_{j\in I_k} \lambda_j y_{rj} = g_{ro} y_{ro} \ , \sum_{j\in I_k} \lambda_j x_{ij} = h_{io} x_{io}, \\ \sum_{j\in I_k} \lambda_j = 1, \ \ \lambda_j \geq 0, \ \ g_{ro} \geq 1, \ \ 0 \leq h_{io} \leq 1 \end{array} \right\} \qquad \textbf{(3)}$$

In order to assure projection to the Pareto-efficient frontier, only points on F_k are considered as potential projections of unit o in (3). The final BRWZ efficiency measure of unit o is the maximum value found for the measure after model (3) is solved for all K facets. Step III is repeated for each inefficient unit for which we wish to identify the closest targets. We used GAMS and its non-linear programming solver (CONOPT) to solve (3).

6. An Illustrative Application to Bank Branches

The above procedures were applied to a sample of 24 Portuguese bank branches which are located in mid sized cities (as classified by the bank) in the northern region of Portugal. An intermediation approach of banking activities will be used, as this requires in principle non-oriented models. In this sense on the input side cost related variables are used (staff costs and other operating costs), and on the output side revenue related variables are used (value of current accounts, value of credit, and interest revenues). We assume that all inputs and outputs are discretionary. The data correspond to the month of July 2001 and values are expressed in thousands of Euros. Here only a few results of some inefficient units are exemplified.

For the FDH case, the application of the additive units invariant model, the RAM model, and the Russell graph model result in the same peers for inefficient units in all the cases. This is illustrated in Table 2, which shows the BRWZ measure calculated *a posteriori* in relation to the targets identified by these models. It also shows the BRWZ efficiency measure obtained under our closer target (CT) FDH procedure.

Ineff. Unit	B3	B5	B9	B13	B15	B19	B21	B22	B59
Peer Unit	B10	B10	B16	B10	B10	B10	B10	B10	B10
BRWZ Effcy	67.02%	77.26%	64.7%	74.85%	53.57%	68.15%	71.87%	52.76%	74%
BRWZ CT Effcy	67.02%	77.26%	64.7%	74.85%	53.57%	81.30% (B20)	71.87%	78.00% (B52)	74%

Table 2: Results from additive-FDH, RAM-FDH, FGL-FDH and CT procedure

The BRWZ measure has the same value under all the procedures for identifying targets, except in two cases. The reason for this is simple: unit B10 dominates most of the units in the sample and most of them are solely dominated by this unit. As the set of potential referents consists of a single unit there is not much for the alternative procedures to choose. Only in two cases is there a genuine choice of targets to be made: the case of inefficient units B19 and B22. The first unit is dominated by B10 and also by B20, and the second unit is dominated by B10, B26, B50 and B52. The application of our CT procedure clearly identifies closer targets to units B19 and B22 (respectively B20 and B52) as testifies a higher value of the CT BRWZ efficiency score in Table 2. These higher efficiency scores also correspond to lower metric distances.

In the convex VRS technology case, the application of the CT procedure to the bank branches example results (in its first step) in a set of efficient units, which are used in QHull to identify the set of efficient facets. These are: F_1 = {B10, B16, B20, B29, B50}; F_2 = {B20, B27, B29, B50, B57}; F_3 = {B10, B20, B27, B29, B50}; F_4 = {B10, B27, B56, B57}; F_5 = {B10, B11, B16, B29}; F_6 = {B10, B11, B26, B29}; F_7 = {B10, B26, B27, B29}, where the first three facets are full dimensional and the last four are not. In the third step, model (3) was applied to each inefficient unit in relation to each efficient facet. The facet chosen for projection in each case was the one maximising the objective function of model (3).

We applied the additive, the RAM and the CT procedure to our data set. Results in terms of the BRWZ show for all units better results of the CT procedure than the two other models. This confirms that our model shows each inefficient unit in a much better light than the other two models not only in terms of the BRWZ measure but also in terms of L_p metric measures. Take for example units B15 and B59 shown in Table 3. Results for these units show closer targets identified by the CT procedure for convex technologies than those identified by the additive model (the same being true for the RAM model). This fact is expressed in higher BRWZ efficiency scores and smaller L_p metrics, as illustrated for the two cases above (this fact can however be generalised to the entire sample of units). Interestingly the additive model tends to identify most of the inefficiencies associated with outputs, while the CT procedure for convex technologies identifies most of the inefficiencies associated with inputs. For the additive model the average BRWZ-input efficiency is 98.27% and the average BRWZ-output efficiency is 73.36%, while the corresponding values for the CT procedure are 90.72% and 92.03%, respectively. This clearly indicates that our procedure and the additive model identify different directions for improvement of inefficient units. The choice of the model to use should not, thus, be taken lightly.

	B15			B59		
	Observed	Targets Additive	Targets CT convex	Observed	Targets Additive	Targets CT convex
x_1	11.717	11.717	11.487	13.338	13.338	12.606
x_2	29.314	24.726	16.122	24.820	24.820	19.030
y_1	4070.630	5682.936	4070.630	4354.301	6073.258	4475.281
y_2	6418.995	14409.226	6418.995	10889.840	14368.013	10889.840
y_3	40.328	69.268	45.086	57.033	74.865	57.033
L_1		9636.066	18.181		5214.962	127.502
L_2		8151.330	14.027		3879.796	121.121
L_∞		7990.231	13.193		3478.173	120.980
BRWZ		53.58%	73.83%		74.56%	84.82%

Table 3: Distance to targets from inefficient units in the VRS case

Conclusion

The analysis of non-oriented measures of efficiency and their use to identify the closest targets for inefficient units was performed both considering FDH and convex technologies. The chosen criterion of closeness is based on the maximisation of the BRWZ efficiency measure, which has the advantage over other efficiency measures of capturing all the sources of inefficiency and retaining a meaning that is close to that associated with radial oriented efficiency measures. In order to use this measure multi-stage procedures are required both in the FDH and in the convex case to find the closest targets. The application of our procedure to a real bank branch example shows that it provides closer and easier-to-achieve targets in both, the FDH and convex, cases.

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Constructions of Economic Functions in DEA Using Parametric Optimization Methods

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Abstract

The aim of this paper is to present and to substantiate a technique to visualize DEA modelling results without a loss of mathematical rigour. The proposed family of parametric optimization methods allows one to construct an intersection of the frontier with a two-dimensional plane determined by any pair of given directions. This approach reduces the efficiency analysis of production units to the investigation of well-known functions in economics.

Keywords: DEA, parametric optimization algorithms.

1. Introduction

Data Envelopment Analysis (DEA) is a powerful approach for efficiency investigation of production units, see Banker, Charnes and Cooper;[1] Cooper, Seiford and Tone.[2] Many scientific publications are devoted to DEA applications in the financial area, see, for instance, Thompson et al.[3]

In mathematical economics, it is very convenient for mathematicians to operate in terms of efficient surfaces, support hyperplanes, Pareto-efficient facets, reference sets, production correspondences, etc., for details see Pitaktong, Brockett, Mote and Rousseau.[4] However, it is rather difficult for a manager to imagine the behaviour of production unit in the multidimensional space of inputs and outputs. The aim of this paper is to present a technique that enables one to visualize DEA modelling results without a loss of mathematical rigour.

A family of parametric optimization methods developed by our group allows one to construct an intersection of the frontier with a two-dimensional plane determined by any pair of given directions. This approach reduces the efficiency analysis of production units to the investigation of well-known functions in economics, see, for instance, Varian,[5] such as production function, isoquant, isocost, isoprofit, etc.

This paper develops the results that were presented at the 16th IMACS World Congress 2000 on Scientific Computation, Applied Mathematics and Simulation, Lausanne[6] and at the International DEA Symposium 2000, Brisbane, see Krivonozhko et al.[7]

2. Background

Consider a set of n observations of actual production units (X_j, Y_j), $j=1, \dots, n$, where the vector of outputs $Y_j=(y_{1j},\dots,y_{rj}) \geq 0$ is produced from the vector of inputs $X_j=(x_{1j},\dots,x_{mj}) \geq 0$. The production possibility set T is the set $\{(X,Y) \mid$ *the outputs* $Y \geq 0$ *can be produced from the inputs* $X \geq 0\}$.

Set T is empirically specified by the following postulates.[1]

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Postulate 1 (Convexity). If $(X,Y)\in T$ and $(X',Y')\in T$, then $(\lambda X+(1-\lambda)X', \lambda Y+(1-\lambda)Y')\in T$ for all $\lambda\in[0,1]$.

Postulate 2 (Monotonicity). If $(X, Y)\in T$ and $X'\geq X$, $Y'\leq Y$, then $(X', Y')\in T$.

Postulate 3 (Minimum extrapolation). T is the intersection set of all T', satisfying Postulates 1 and 2, and subject to the condition that each of the observed vectors $(X_j, Y_j)\in T'$, $j = 1, \ldots, n$. Production possibility set T can be represented in the algebraical form[1]

$$T=\{(X,Y)/\ X\geq\sum_{j=1}^{n}X_j\lambda_j,\ Y\leq\sum_{j=1}^{n}Y_j\lambda_j,$$
$$\sum_{j=1}^{n}\lambda_j=1,\ \ \lambda_j>0,\ j=1,\ldots,n\}. \tag{1}$$

Following Shepard[9] we define the input possibility set $L(Y)$ and the output possibility set $P(X)$ as follows

$$L(Y)=\{X/(X,Y)\in T\},\qquad P(X)=\{Y/(X,Y)\in T\}.$$

Again, according to Shepard we introduce two appropriate sets. The input isoquant corresponding to $Y\geq 0$ is written as

$$Isoq\ L(Y)=\{X/\ X\in L(Y),\ \lambda X\notin L(Y),\ \text{if}\ \lambda\in[0,1)\}. \tag{2}$$

The output isoquant corresponding to X is defined by

$$Isoq\ P(X)=\{Y/\ Y\in P(X),\ \theta Y\notin P(X),\ \text{if}\ \theta\in(1,+\infty)\}. \tag{3}$$

BCC (Banker, Charnes and Cooper) input-oriented model given below enables us to find some efficient points on the frontier.

$$\min\ \theta-\varepsilon\left\{\sum_{k=1}^{m}s_k^-+\sum_{i=1}^{r}s_i^+\right\}$$

subject to

$$\theta x_{ko}-\sum_{j=1}^{n}x_{kj}\lambda_j-s_k^-=0\ ,\ \ k=1,\ldots,m, \tag{4}$$
$$\sum_{j=1}^{n}y_{ij}\lambda_j-s_i^+=y_{io}\ ,\ \ i=1,\ldots,r,$$
$$\lambda_j,s_k^-,s_i^+\geq 0\ ,$$

where x_{kj} and y_{ij} represent the observed inputs and outputs of production units $j=1,\ldots,n$. Unit (X_o,Y_o) is under investigation in problem (4).

Definition 1 (Pareto-efficiency) Production unit $(X^*,Y^*)\in T$ is efficient if and only if there is no $(X,Y)\in T$ and $(X,Y)\neq(X^*,Y^*)$ such that $X\leq X^*$, $Y\geq Y^*$.

We denote a set of Pareto-efficient points by $Eff_P\ T$.

Definition 2 (Weak Pareto-efficiency) Production unit $(X', Y')\in T$ is weakly efficient if and only if there is no $(X, Y)\in T$ such that $X < X'$, $Y > Y'$.

We denote a set of weakly Pareto-efficient points by $WEff_P\ T$.

There are many optimization models in the DEA framework. In this paper, we dwell mainly on BCC model, without any loss in generality, since the proposed approach can be extended to other DEA models.

3. Parametric optimization algorithms

In this paragraph we develop parametric optimization algorithms for constructing intersections of the frontier with two-dimensional planes.

Let us define the two-dimensional plane in space E^{m+r} as

$$Pl(X_o, Y_o, d_1, d_2) = (X_o, Y_o) + \alpha d_1 + \beta d_2, \tag{5}$$

where $(X_o,Y_o) \in T$, α and β are any real numbers, directions $d_1, d_2 \in E^{m+r}$ and d_1 is not parallel to d_2. The plane is going through point (X_o,Y_o) in E^{m+r} and spanned by vectors d_1 and d_2.

Next, define five intersections of the frontier with two-dimensional planes

$Sec_1(X_o, Y_o)$ = $\{(X, Y) / (X, Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\, T$, *where* $d_1 = (X_o, 0) \in E^{m+r}$, $d_2 = (0, Y_o) \in E^{m+r}\}$, (6)

$Sec_2(X_o, Y_o, p, s)$ = $\{X / (X, Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\, T$, *where* $d_1 = (e_p, 0) \in E^{m+r}$, $d_2 = (e_s, 0) \in E^{m+r}$, e_p *and* e_s *are m-identity vectors with a one in position p and s, respectively*$\}$, (7)

$Sec_3(X_o, Y_o, b)$ = $\{(X, Y) / (X,Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\, T$, *where* $d_1 = (b, 0) \in E^{m+r}$ *and* $b \in E^m$, $d_2 = (0, Y_o) \in E^{m+r}\}$, (8)

$Sec_4(X_o,Y_o,p,s)$ = $\{Y / (X,Y) \in Pl(X_o,Y_o,d_1,d_2) \cap WEff_P\, T$, *where* $d_1=(0, e_p) \in E^{m+r}$, $d_2= (0, e_s) \in E^{m+r}$, e_p *and* e_s *are r-identity vectors with a one in position p and s, respectively* $\}$, (9)

$Sec_5(X_o,Y_o,c)$ = $\{(X,Y) / (X,Y) \in Pl\ (X_o,Y_o,d_1,d_2) \cap WEff_P\, T$, *where* $d_1=(X_o,0) \in E^{m+r}$, $d_2=(0,c) \in E^{m+r}$ *and* $c \in E^r\}$. (10)

We note that components of vectors b (8) and c (10) can take, in principle, any real values. However, we assume that there exist some indices i and k of vector b such that $b_i < 0$ and $b_k > 0$ in order to associate sets (8) and (10) with some functions in economics. Let the same assumption be valid for vector c.

By choosing different directions d_1 and d_2 we can construct various sections going through point (X_o, Y_o) and cutting the frontier. Moreover, we obtain the curves generalizing the well-known functions in macro- and microeconomics: production functions, isoquant, isocost, isoprofit, etc. Thus, we can investigate the structure of the frontier over unit (X_o, Y_o) in the multidimensional space of inputs and outputs.

Now, there are grounds to outline a general scheme of algorithms for building of intersections (6-10).

Step 1 Project unit $Z_o=(X_o ,Y_o) \rightarrow \tilde{Z} = (\tilde{X},\tilde{Y})$ onto the frontier along direction d_1 or d_2 Set $\delta_1 = \delta$, where δ is a small parameter, l=1, $Z'_l = \tilde{Z}$.

Step 2 Determine a direction along the current facet. Solve the following optimization problems.

a) *Problem A*: $\max_{\beta_1} \beta_1$

subject to $(\tilde{Z} + \beta_1 d_2) \in T$.

Determine point $\tilde{Z}_1 = (\tilde{Z} + \beta_1^* d_2) \in T$, where optimal value β_1^* is obtained from solution of Problem A.

b) *Problem B*: $\max_{\beta_2} \beta_2$

subject to $(\tilde{Z} + \delta_1 d_1 + \beta_2 d_2) \in T$.

Determine point $\widetilde{Z}_1 = (\widetilde{Z} + \delta_1 d_1 + \beta_2^* d_2) \in T$. Test stopping criterion of the algorithm. Determine direction $\widetilde{Z}_3 = \widetilde{Z}_2 - \widetilde{Z}_1 = \delta_1 d_1 + (\beta_2^* - \beta_1^*) d_2$.

Step 3 Compute the step length along the chosen direction. Solve the following problem

$$\max_{\beta} \beta$$

subject to $\qquad (\widetilde{Z}_1 + \beta \widetilde{Z}_3) \in T$.

a) If $\beta^* \leq 1$, then set $\beta^* = 1$, go to Step 4.

b) If $1 < \beta^* < K$, where K is a parameter, then set $l = l + 1$, $Z'_l = \widetilde{Z} + \beta^* \widetilde{Z}_3$. Point Z'_l lies on the intersection of the current facets. Go to Step 4.

c) If $\beta^* \geq K$, then $\delta_1 = K_1 \delta_1$, where K_1 is a parameter. Go to Step 2b.

Step 4 Set $\widetilde{Z} = \widetilde{Z} + \beta^* d_1$, $\delta_1 = \delta$. Go to Step 2.

We denote algorithms for constructing curves (6-10) on the basis of general scheme by *Algorithm* 1, …, *Algorithm* 5, respectively.

As a result of Algorithm runs we obtain sequence of points $Z'_l = (X'_l, Y'_l)$, $l = 1, \ldots, M$, that are angular points of piecewise linear curves determined by (6-10).

However, the main movement in the algorithms is accomplished along direction d_1 (Step 4), and angular points of the curves are determined along direction d_2 by solving optimization problem A (Step 2). This tool increases significantly the accuracy of calculations and allows us to avoid constructing "false" vertices on the curve. If a linear segment of the curve turns out to be too long, then the algorithm makes correction and goes to step 2b instead of Step 4. Else, calculation errors would be too large. These observations are valid for all proposed algorithms.

Let us find the form of the curve (6) on the two-dimensional plane, the horizontal axis of this plane is determined by vector X_o, and the vertical axis is associated with vector Y_o.

Substituting $d_1 = (X_o, 0)$ and $d_2 = (0, Y_o)$ in problem A and using (1), we obtain that problem A is transformed into the output BCC model. Consider function $\theta_1^*(\alpha)$, where θ_1^* is an optimum of problem A under condition that $\widetilde{X} = \alpha X_o$, where α is a real number. By the form of problem A, it follows that the feasible region expands with increasing α, so the function does not decrease. Next, by the output constraints of problem A, it follows that function $\theta_1^*(\alpha)$ is limited. Curve of function $\theta_1^*(\alpha)$ is a piecewise linear one, since it is a part of boundary of two-dimensional convex polyhedral set. Hence, the function attains its maximum under $\alpha = \alpha_{max}$. Therefore function $\theta_1^*(\alpha)$ is equal to constant if $\alpha > \alpha_{max}$.

By the form of problem A, it follows that function $\theta_1^*(\alpha)$ attains its minimum $\theta_1^*(\alpha_{\min}) > 0$, if α decreases. Under $\alpha < \alpha_{min}$ problem A is unfeasible, so function $\theta_1^*(\alpha)$ does not exist.

To complete the curve, let us draw a ray on the plane from point $(\alpha_{min}, \theta_1^*(\alpha_{\min}))$ vertically down. This ray is contained in set (6) due to monotonocity of T.

Thus, section (6) represents a concave piecewise linear curve consisting of a number of segments and two rays, horizontal and vertical ones. In addition, DEA approach does not imply negative inputs and outputs, therefore we can regard that this curve consists of a number of segments and of a horizontal ray.

In theoretical economics, the production function is determined in multi-input/one-output production model as maximum output that can be produced for any specific input. Various mathematical models construct the production function in different manners. For a more detailed consideration we refer to Banker.[1] DEA approach extends the production function notion to multi-input/multi-output model, thus production function is transformed into efficient production surface. $Sec_1(X_o, Y_o)$ determines the curve that shows dependence of maximum output according to DEA approach while input is changing along the direction αX_o, $\alpha > 0$, as in the one-input/one-output production model.

So, we can call the curve determined by $Sec_1(X_o, Y_o)$ production function associated with unit (X_o, Y_o).

In a similar way, we can show that section (7) represents a convex piecewise linear curve consisting of a number of segments and of two rays, horizontal and vertical ones. So, we call section $Sec_2(X_o,Y_o, p, s)$ (7) input isoquant associated with directions x_p and x_s, since this curve determines weakly Pareto-efficient points in two-dimensional space of inputs, which produce output Y_o.

Moreover, we shall prove further that $Sec_2(X_o,Y_o, p, s) \subset Isoq\ L(Y_o)$ under some conditions.

The parametric curve obtained with the help of Algorithm 3 has also a visual economic interpretation. Let us draw in the space of inputs a hyperplane P going through point X_o and containing vector b, and let hyperplane P cut every axis of positive orthant in space of inputs. Production units which lie on P have equal sums of inputs. So, hyperplane P determines constraints for a sum of inputs. A family of curves built by Algorithm 3 under different vectors b belonging to P shows production output under certain constraints for resources. So, lines belonging to P are isocost. Hence, a family of curves built by Algorithm 3 enables us to optimize production output under constraints for resources and under a given structure of production output determined by vector Y_o. It can be shown that the section (8) represents a piecewise linear curve consisting of a number of segments.

$Sec_4(X_o,Y_o,p,s)$ (9) shows a part of the frontier in a two-dimensional space of output variables y_p and y_s under given input vector X_o.

In a similar vein, we can show that section (9) represents a concave piecewise linear curve consisting of a number of segments and of two rays going through negative orthants. Since DEA approach does not imply negative outputs, we can regard that this curve consists of a number of segments.

So, we can call the curve (9) output isoquant associated with variables y_p and y_s and input vector X_o.

Now, we consider an economic interpretation of section (10). Let us draw in the space of outputs line L going through point Y_o and determined by vector c. Production units which lie on L have an equal sum of outputs. Since outputs are usually associated in some way or another with profits, especially in bank models, we may think of line L as an isoprofit. Hence the curve (10) shows correspondence between points on the frontier which are obtained by reducing inputs along vector X_o. So, this curve enables us to minimize inputs by moving along isoprofit c.

As we have already noted, the form of the curve (7) is similar to the form of isoquant used in three-dimensional models, see, for example.[5,8] In mathematical economics, a more general notion of isoquant $Isoq\ L(Y)$ is introduced.[9] Now, we prove that section (7) is a part of $Isoq\ L(Y)$ under some conditions.

Theorem 1 Let unit $(X_o, Y_o) \in int\ T$ and $X_j>0, j=1,\dots, n$, then for BCC model the following relation holds $Sec_2(X_o, Y_o, p, s) \subset Isoq\ L(Y)$.

Proof Suppose the contrary. Then some unit $(\widetilde{X},\widetilde{Y}) \in Sec_2(X_o, Y_o, p, s)$ and $(\widetilde{X},\widetilde{Y}) \notin Isoq\ L(Y)$. This means that $0<\theta<1$ and $(X',Y')=(\theta\widetilde{X},\widetilde{Y}) \in T$, hence $x'_p = \theta\widetilde{x}_p < \widetilde{x}_p$ and $x'_s = \theta\widetilde{x}_s < \widetilde{x}_s$. Using these relations and monotonocity of T, we obtain that every input $\widetilde{x}_p$ or $\widetilde{x}_s$ can be reduced separately. For example, unit $(X'', \widetilde{Y}) \in T$, where $x_i''=\widetilde{x}_i$, $i\neq p$, $x_p''=\theta\widetilde{x}_p$. However unit $(\widetilde{X},\widetilde{Y})$ is contained in $Sec_2(X_o, Y_o, p, s)$, this means that this unit belongs to the set of weakly Pareto-efficient points that are contained in two-dimensional polyhedral set $Pl(X_o, Y_o, e_p, e_s) \cap T$. Thus, at least one of inputs $\widetilde{x}_p$ or $\widetilde{x}_s$ cannot be decreased without worsening the other. But this contradicts the assumption, which completes the proof. □

Theorem condition $(X_o, Y_o) \in int\ T$ can be replaced by some other that ensures that the two-dimensional plane goes through the interior of T. Else, set (7) may be two-dimensional polyhedral set, then it is possible to reduce input $\widetilde{x}_p$ or $\widetilde{x}_s$ without worsening the other.

Next, if relations $X_j>0$, $j=1,\ldots,n$ are not observed, then set (7) can include weakly Pareto-efficient points, however these points may not belong to $WEff_I\ T$, hence they do not belong to $Isoq\ L(Y)$.

Theorem 2 Let $(X_o, Y_o) \in int\ T$, then for BCC model the following relation holds $Sec_4(X_o, Y_o, p, s) \subset Isoq\ P(X)$.

The proof of theorem 2 is similar to the previous one.

To substantiate Algorithms 1-5, let us define the following sets

$$W_i = Pl_i(X_o, Y_o, d_1, d_2) \cap T,\ i=1,\ldots,5, \tag{11}$$

here $Pl_i(X_o, Y_o, d_1, d_2)$ are two-dimensional planes used to determine sections (6-10). From (11), it follows that set W_i may be two-dimensional set, one-dimensional set or a point. Suppose that W_i is a two-dimensional set. Using (11), we obtain

$Bound\ W_i = Pl_i(X_o, Y_o, d_1, d_2) \cap WEff_P\ T = Sec_i(X_o, Y_o, d_1, d_2),\quad i=1,\ldots,5.$

Consider the general scheme of Algorithms 1-5.

At Step 1, parameters of Algorithms are initiated. At Step 2, two optimization problems are solved. After solution of problem A, we obtain $\widetilde{Z}_1^* = (\widetilde{Z} + \beta_1^* d_2) \in T$. Since problem A is a linear optimization problem, then $\widetilde{Z}_1^* \in Bound\ W_i$. After solution of problem B we have $\widetilde{Z}_2^* = (\widetilde{Z} + \delta_1 d_1 + \beta_2^* d_2) \in T$. Again, for the same reason, we obtain $\widetilde{Z}_2^* \in Bound\ W_i$.

Next, we determine the direction along the current facet $\widetilde{Z}_3 = \widetilde{Z}_2^* - \widetilde{Z}_1^* = \delta d_1 + (\beta_2^* - \beta_1^*) d_2$. At Step 3, we find a step length along direction $\widetilde{Z}_3$, i.e. we calculate β^*.

At Step 4, we move along direction d_1: $\widetilde{Z} = \widetilde{Z}_1^* + \beta^* d_1$. Point $\widetilde{Z}_1^*$ obtained from problem A at Step 2 is determined as a vertex of set W_i.

So, we can conclude that movement during the solution process takes place on plane $Pl_i(X_o, Y_o, d_1, d_2)$, point $\widetilde{Z}_1^* \in Sec_i(X_o, Y_o, d_1, d_2)$ is a vertex of set W_i. Set of all such vertices determines the curve (6-10).

Earlier, while describing curves (6-10), we established forms of these curves. Stopping criteria of Algorithms follow from these forms.

It may be observed that vertices of parametric curves constructed by Algorithms are calculated within the accuracy of a ball. This means that, if the distance between two angular points is less than the radius of the ball, the Algorithms produce only one angular point. The radius of this ball is regulated by parameter δ. This property can be used under investigation of production units that differ significantly in sizes.

For example, if we analyze small banks, we can take a small radius of the ball. And vice versa, under investigation of large banks we can increase the radius of the ball. We do not dwell on this and similar mathematical subtleties in more detail, since it can overload the exposition.

4. Conclusion

In this paper we present the family of parametric optimization methods which allows us: a) to apply in the DEA the well-known functions in the economic theory such as production function, isoquant, isocost, isoprofit; b) to visualize the frontier in the multi-dimensional space of inputs and outputs; c) to optimize the unit behavior in the multidimensional space of inputs and outputs; d) to calculate various economic notions such as marginal rate of substitution, marginal rate of transformation, marginal product and so on.

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A DEA Approach for Measuring Relative Performance of Saudi Banks

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Abstract

The banking sector in the Kingdom of Saudi Arabia is encountered with a multitude of interlinked factors unique to Islamic countries, influencing its fiscal operations. Therefore it is extremely difficult to measure the performance of the Saudi banking sector in simple terms such as capital structure, volume of business or investments, total assets or share equities, etc. Besides such performance evaluations, generally, do not take into consideration the combined effect of these factors. More often such evaluation is done using pair-wise comparison techniques that do not yield comprehensive results. This paper presents Data Envelopment Analysis (DEA) as a fractional linear programming approach to measure the relative performance efficiencies of Saudi banking sector. The study was conducted on ten banks in the Kingdom. From data collected, the most influential factors were identified and grouped as input and output variables for the DEA model. In addition to this Cluster Analysis is carried out on the data collected to classify the banks on the basis of the multiple criteria in order to improve the confidence in the results of the DEA approach. Recommendations are also made for future possible improvements.

Keywords: Saudi banking sector, Relative efficiency, Data envelopment analysis, MCDM, Cluster analysis

1. Introduction

Commercial banking has undergone tremendous growth during the course of the country's development. There are now ten commercial banks, with branches all over the Kingdom of Saudi Arabia. These banks are considered in this paper and listed in Table 1. The rapid expansion of deposits has allowed the banking system to take on a leading role in marshalling Saudi financial resources to fund the expanding activities of the private sector. Since 1990, some Saudi banks have as much as tripled their domestic loan portfolios, and by the end of 1998, the total amount of bank claims on public and private sectors had reached 71.47 billion U.S. Dollars. The Kingdom's financial and monetary policies have maintained stable domestic prices, and stable exchange rates for the national currency (Riyal). The banking sector continues to enhance its financial ability, with overall capital and reserves increasing by almost five percent in 1999. As for the stock market, the NCFEI share index stood at 22.86 as on December 14, 2000, representing an increase of 13% since the beginning of this year (www.saudiembassy.net, 2002).

In comparison with commercial banks in developed countries, banks in the Kingdom of Saudi Arabia, face a variety of obstacles in expanding their fiscal activities. This is due to various factors including low export financing, lack of adequate security or insurance guarantees, low profile manufacturing and export businesses. Import financing has been the most important

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source of business for Saudi banks. Oil export and Islamic banking in the trade finance sector are unique features of Saudi Banking business. Even though non-oil exports have been on the rise in view of the growing competitive global business environment, they need to revitalize their fiscal activities.

Table 1
The ten banks in the Kingdom of Saudi Arabia.

No. of banks	Legends	Name of the banks
1	RB	Riyadh Bank
2	SAMBA	Saudi American Bank
3	SABB	Saudi British Bank
4	SHB	Saudi Hollandi Bank
5	JB	Al-Jazira Bank
6	BSF	Saudi France Bank
7	ANB	Arab National Bank
8	RJB	Al-Rajhi Bank
9	USB	United Saudi Bank
10	SAIB	Saudi Arabian Investments Bank

Saudi exporters and importers are seeking new forms of trade finance including non-recourse forfeiting, export credit guarantees, Islamic or non-interest bearing financing schemes and various counter-trade arrangements.

Obviously export financing does not yet constitute a large source of business for Saudi commercial banks. Nonetheless, non-oil exports have been on the rise and the Saudi private sector is seeking suitable financing for export contracts. In today's increasingly competitive international business environment, the Saudi private sector feels that export incentive and support from the government are needed when exporting to new risky markets (Henry, 1999).

Saudi banks operate in a highly liquid environment and are eagerly looking to boost their trade finance portfolios. The Kingdom has the potential to significantly increase its non-oil exports with greater utilization of existing manufacturing capacity.

Total private sector imports financed by commercial banks recorded an increase of 6.6% in the first half of 1996 compared to a year ago level. All import categories financed by commercial banks recorded an increase with the exception of appliances and other goods. Data on the composition of imports financed by commercial banks show foodstuffs accounting for 17% of the totaling the first half of 1996, followed by motor vehicles (13.3%), textiles and clothing (8.8%),and appliances (6.9%).

Islamic banking system is unique to Muslim countries. In the Kingdom of Saudi Arabia, Islamic financing deals are becoming increasingly competitive in the trade finance business. Although the Kingdom's banks are providing credit to exporters as part of their trade finance activities, there are no schemes designed specifically to encourage exports of manufactured goods. The availability of finance for exports, in adequate measure and reasonable cost, is essential for exporters of manufactured goods to develop and expand their trade. At present export finance is an underdeveloped function in the Kingdom. Saudi banks do not treat export credit as a separate financial product. Exporters often use working capital facilities provided to them by banks to finance exports. Export financing is therefore not transaction based with no separate accounts being used. It is consequently difficult to assess the volume of outstanding export credit for individual banks or for the sector as a whole.

In addition, Saudi banks face a number of obstacles in expanding their export finance activities, in comparison with banks in developed countries. Firstly, in developed countries, the production and export of manufactured goods constitute an established sector of the economy that is able to offer the commercial banks an attractive business volume. Historically, this has not been the case in Saudi Arabia. The Kingdom's non-oil exports have only recently started to gain importance. Secondly, banks in developed countries can provide cheap financing to exporters in conjunction with government institutions that are supported out of public resources. No such facilities exist in the Kingdom, as the government does not participate, directly or indirectly, in the provision of credit or insurance to exporters. Due to the small volumes involved, most commercial banks look at export finance business only to maintain client relationships with other services provided being more profitable.

In spite of all the odds cited, there has been a remarkable growth in the overall banking transactions in Saudi Arabia. Fig.1 shows this growth during the period 1994 to 1999. The growth of the number and use of Automatic Teller Machines (ATM) are other indicators of growth as shown in Fig.2. Over the last 10 years, the growth has been almost hundred fold. On the other side, Fig.3 presents an idea about the increase in deposits in Saudi banks. As per Saudi Arabian Monetary Agency (SAMA) reports, in comparison with the performance in 1998 there is a remarkable growth in the business (Al-Eqtisadiah, June 2000).

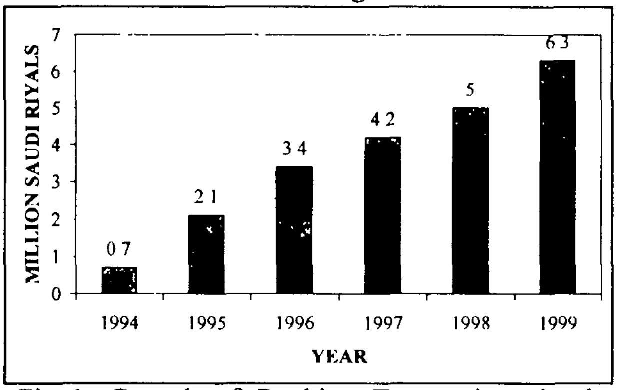


Fig. 1. Growth of Banking Transactions in the Kingdom of Saudi Arabia

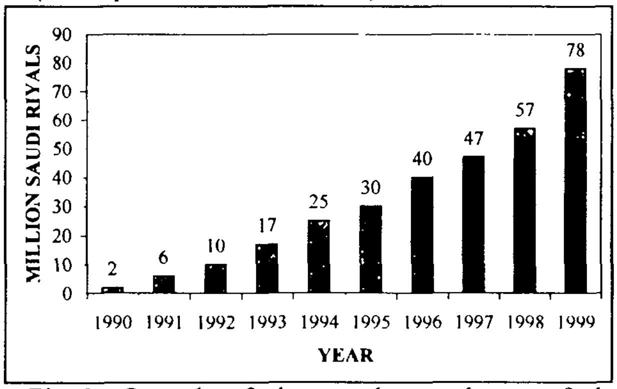


Fig. 2. Growth of the number and use of the Automatic Teller Machines in Saudi Arabian Banks

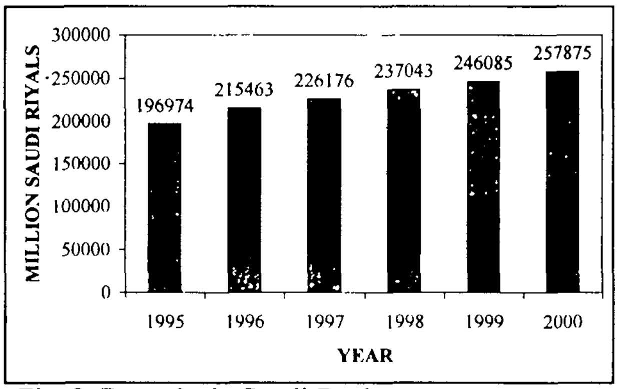


Fig. 3. Deposits in Saudi Banks

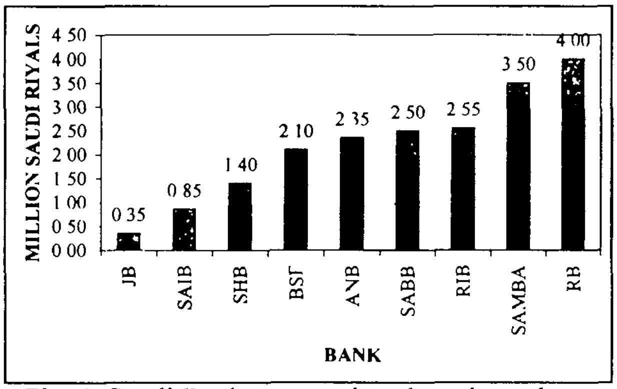


Fig. 4. Saudi Banks comparison by sales volume

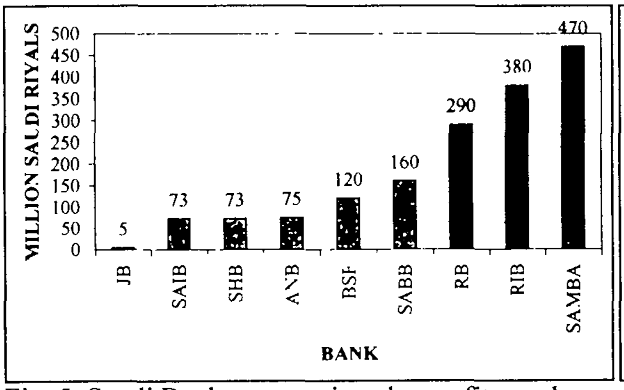


Fig. 5. Saudi Banks comparison by profits made

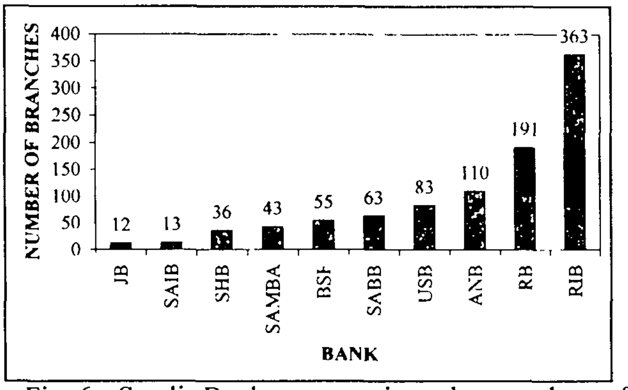


Fig. 6. Saudi Banks comparison by number of branches

2. Traditional ranking approach

Under the circumstances unique to Saudi Arabia performance based appraisal of the Saudi banks often becomes unwieldy and inaccurate. Many attempts have been made by researchers and financial analysts for assessing and ranking Saudi banks. However such analyses most often are based on pair-wise comparison based on single criterion taken at a time. It is possible to get a distinct ranking order for these banks from the figures 4, 5, and 6 presented (Al-Eqtisadiah, May 1999). Fig.4 shows the sales volume of Saudi banks in the year 1999 while Fig.5 presents the profits made by different Saudi Arabian banks in the same year. In addition, Fig. 6 gives the number of branches of the ten Saudi banks.

Obviously these results are obtained by ranking the banks on a linear composite scale, such as Likert's Scale (Myron and Kruskall, 1987), which gives different ranks according to the criteria choosen. In fact, this approach is not adequate for ranking the banks, since the performance of any bank bases on multiple criteria interrelated together. Therefore, an alternative approach based on Data Envelopment Analysis (DEA) will be considered, in this paper, to rank the Saudi banks.

3. DEA as a MCDM approach

A variety of scaling techniques are available for rating products, organizations, employees, services etc. Multivariate Analysis techniques such as cluster analysis, discriminate analysis, and multidimensional scaling provide efficient methods for such assessments. Similarly many techniques have been used to study the efficiency of organizations.

In the case of banks the technique build up depends on how the system is viewed. Some researchers view banks as producers of loans and deposit accounts (Sherman and Gold, 1985) and measure output either by the number of transactions or by the number of accounts serviced. This is known as Production Approach. In the Intermediation Approach (Piyu Yue, 1992) the output of banks are measured in terms of value of loans and inputs in terms of various costs of labor, capital, operations, deposits and other resources. Unlike the Production Approach, which focuses on operating cost and ignores interest expense, in the Intermediation Approach both operating and interest expenses are included in the analysis (Berger et al., 1993).

Data Envelopment Analysis (DEA) computes the efficiency of a bank in transforming inputs into outputs in relation to its peer group. Originally Charnes et al., (1978) (CCR) developed the DEA approach for the purpose of evaluating the relative efficiency of similar economic production system. The technique aroused great interest as the development of several variants of the classic CCR model and their applications demonstrate. There are many alternative DEA models with different characteristics such as the BCC model (Banker et al, 1984), the Multiplicative models (Charnes et. al, 1982), the Additive model (Charnes et. al, 1985), the FDH model (Tulkens, 1993), and radial DEA models (Knox Lovell and Pastor, 1999). Since the choice of a particular DEA model determines consequences on the study, careful considerations should precede the selection of the model to solve any evaluation problem.

Stewart (1996) has compared and contrasted the traditional goals of DEA and Multiple Criteria Decision Making (MCDM). DEA arises from situations where the goal is to determine the productive efficiency of a system or Decision Making Unit (DMU) by comparing how well these units convert inputs into outputs, while MCDM models have arisen from problems of ranking and selecting from a set of alternatives that have conflicting criteria. A methodological connection between MCDM is to define maximizing criteria (benefits) as outputs and minimizing criteria (costs) as inputs. Doyle and Green (1993) have also made this methodological connection apparent in an example of applying DEA as an MCDM model. Another example can be found in Sarkis (2000). Khouja (1995) also adopted this methodological connection in his DEA evaluation model for a robot selection problem.

Identifying whether a criteria is minimizing or maximizing, as is part of the practice for most outranking techniques, aids in determining whether the criteria could be considered an input or output in the DEA model. The results of this methodological relationship, which make DEA suitable for discrete alternative MCDM problems, is what we investigate in this paper.

4. Applying the DEA technique

DEA is a fractional linear programming technique that converts multiple inputs and outputs into a scalar measure of efficiency. This conversion is accomplished by comparing the mix and services provided and the resources used by each bank with all other banks. Each bank is evaluated against a hypothetical bank with an identical output mix that is constructed as a combination of efficient banks.

In DEA the model identities the most efficient banks assigning a value (score) of unity to it and attributes a measure of inefficiency for all others. These less efficient institutions are assigned scores between zero and one. Thus DEA does not measure optimal efficiency of banks. Instead, it differentiates the least efficient banks from among the set of all banks.

Asish Saha and T.S. Ravisankar (2000) have analyzed Indian commercial banks using DEA approach. They considered 25 Indian commercial banks for measurement of efficiency and proved that DEA could be an appropriate tool for such analysis. Duffua S.O, et.al (1999) applied DEA approach to measure the relative efficiency of educational institutions.

In general Data Envelopment Analysis have gained more acceptability in recent years for evaluation and measurement of relative efficiency of any type of systems with an input and output, organizations, educational institutions, industrial organizations etc; provided quality data is available.

4. 1. Formulation of DEA model

The mathematical formulation is simple and follows the rules of LP model formulation. Let us assume that there are *p* banks in the group and that there are *n* output variables and *m* input variables for a bank. Let Y_{jk} and X_{ik} respectively denote the *j*th output and the *i*th input for the *k*th bank (*j*=1,2,3... n; *i*=1,2...m; *k*=1,2...p). The relative efficiency of the *k*th bank is then defined as:

$$E_k = \frac{\sum_{j=1}^{n} V_{jk} Y_{jk}}{\sum_{i=1}^{m} U_{ik} X_{ik}}$$

where, V_{jk} is the weight placed on jth output and U_{ik} is the weight placed on ith input of the kth bank and $\sum_j V_{jk} = \sum_i U_{ik}$ for all k.

According to conventional ranking procedures, the weights are assigned to variables subjectively. The best examples are Uni-Dimensional Scaling approach (Shoukath Ali and Ibrahim Jomoah, 1997) and GE-Matrix approach (Philip K., 1999). But by formulation of the objective function, that is the efficiency function formulation, DEA model selects the weights that maximizes each bank's efficiency score under the model constraints such as i) no weight is negative, ii) any bank should be able to use the same set of weights to evaluate its own efficiency ratio, and iii) efficiency ratio must not exceed one.

The DEA model for a specific bank can be formulated as a linear programming problem, which can be solved if it is transformed into an equivalent linear form in which the bank's input and output weights are treated as the decision variables. A complete DEA solution would require one such linear program to be solved for each bank. In this paper covering 10 banks, for the kth bank (k=1,2...10), the problem corresponding to maximization of E_k ,as defined in the equation before, can be transformed into the following equivalent LP problem:

Maximize $E_k = \sum_{j=1}^{n} V_{jk} Y_{jk}$

subject to the constraints,

a) $\sum_{i=1}^{m} U_{ik} X_{ik} = 1,$

b) $\sum_{j=1}^{n} V_{jk} Y_{jk} - \sum_{i=1}^{m} U_{ik} X_{ik} \le 0,$

c) $U_{ik} \ge 0,$ for $i = 1, 2, 3 \ldots m$

d) $V_{jk} \ge 0,$ for $j = 1,2,3 \ldots n$

e) $\sum_{i=1}^{m} U_{ik} = \sum_{j=1}^{n} V_{jk}.$

4. 2. Identifying Input/Output Variables

The choice of input/output variables for the DEA model is crucial. Results may vary according to the variables chosen. Two researchers may obtain different results depending on the choice of variables. So extreme care should be exercised in selecting the variables. Obviously such a choice would depend on the objectives of the analysis. In fact there are differences of opinion among researchers on this criterion for choice of variables (Brown and Gardner, 1995), (Resti Andrea, 1997), and (Humphrey, 1991). The choice of input and output variables would necessarily depend on the nature and the thrust areas of banking in the country concerned as the role played by the banking system is dictated by the needs of the society and the state of the economy and the expectations of the Governments. So, the choice of the input and output variables in this paper are primarily guided by these considerations.

There were four input and six output variables identified during the data collection stage. They include outstanding shares, general and administration expenses, provisions for doubtful debts and capital as input variables and gross income, return on assets (%), investments, deposits, loans/deposits (%) and equity/assets (%) as output variables. Data on these variables for ten years from 1989 to 1998 were collected. The final variables chosen from among the initially identified set is based on the consideration of parity in the units of measurement of the variables and to ensure uniqueness in the representation. Thus three output variables are considered for analysis that in turn restricts the choice of number of input variables into two. From an initial set of data, outstanding shares (X_1) and general & administrative expenditure (X_2) were chosen as input variables and gross income (Y_1), investments (Y_2), and deposits

(Y_3) were chosen as output variables. These variables are given in Table 2 for the year 1989. Though capital is a very important input variable to be considered, it is expected that the combined effect of the choice on investments, general & administrative expenditure and gross income take care of its influence on the results.

5. Analysis and results

DEA analysis was carried out in two stages. At the first stage the model was considered to quantify the relative efficiency of banks in the form of a total weighted output by total weighted input. In the second stage an attempt was made for one input X_2 (general & administrative expenditure) and one output Y_1 (gross income). The results from the two stages represent the elements of the Relative Efficiency Matrix (REM). The REM provides information on the relative efficiency between the banks. Table 3 summarizes a typical REM. The *k*th row and the *s*th column represent the relative efficiency measure between bank *k* and bank *s* (E_{ks}, $k \neq s$) based on stage I. The diagonal elements (E_{kk}) represent the relative efficiency between bank *k* with respect to all other banks based on stage II.

Table 2
Two-input three-output variables for 10 Saudi Banks for Year 1989.

	X_1	X_2	Y_1	Y_2	Y_3
RB	2.00	0.45	1.17	5.56	23.16
JB	1.00	0.06	0.04	0.09	4.54
SAIB	0.90	0.02	0.12	0.32	2.36
SHB	2.10	0.11	0.33	0.38	7.46
BSF	4.00	0.27	0.51	1.17	13.17
SABB	4.00	0.16	0.34	2.60	8.38
ANB	3.00	0.26	0.73	1.48	13.10
SAMBA	6.00	0.26	0.89	5.13	20.74
RIB	7.50	0.31	1.43	14.42	13.18
USB	2.50	0.05	0.19	0.52	4.69

Table 3
Generalized Relative Efficiency Matrix

	Bank s				
Bank k	1	2	3	...	p
1	E_{11}	E_{12}	E_{13}	...	E_{1p}
2	E_{21}	E_{22}	E_{23}	...	E_{2p}
3	E_{31}	E_{32}	E_{33}	...	E_{3p}
:	:	:	:		:
:	:	:	:		:
p	E_{p1}	E_{p2}	E_{p3}	...	E_{pp}

Table 4
The relative efficiency matrix for 10 Saudi banks - 1989

	RB	JB	SAIB	SHB	BSF	SABB	ANB	SAMBA	RIB	USB
RB	**1.00**	1.00	0.43	0.87	1.00	1.00	0.93	0.76	0.56	0.68
JB	0.26	**1.00**	0.11	0.22	0.35	0.31	0.24	0.19	0.14	0.17
SAIB	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SHB	1.00	1.00	0.50	**0.89**	1.00	1.00	1.00	0.88	0.65	0.79
BSF	0.73	1.00	0.31	0.63	**0.70**	0.89	0.67	0.55	0.41	0.50
SABB	0.82	1.00	0.35	0.71	1.00	**0.68**	0.76	0.62	0.46	0.56
ANB	1.00	1.00	0.47	0.93	1.00	1.00	**0.87**	0.82	0.61	0.74
SAMBA	1.00	1.00	0.57	1.00	1.00	1.00	1.00	**1.00**	0.74	0.90
RIB	1.00	1.00	0.77	1.00	1.00	1.00	1.00	1.00	**1.00**	1.00
USB	1.00	1.00	0.63	1.00	1.00	1.00	1.00	1.00	0.82	**0.79**

Table 5

The relative efficiency matrix for 10 Saudi banks - 1998

	RB	JB	SAIB	SHB	BSF	SABB	ANB	SAMBA	RIB	USB
RB	**0.71**	1.00	0.63	1.00	0.70	0.91	1.00	0.81	0.65	0.62
JB	0.70	**0.44**	0.44	0.76	0.49	0.64	0.78	0.57	0.46	0.44
SAIB	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	0.99
SHB	0.92	1.00	0.58	**1.00**	0.64	0.84	1.00	0.74	0.60	0.57
BSF	1.00	1.00	0.90	1.00	**0.99**	1.00	1.00	1.00	0.93	0.89
SABB	1.00	1.00	0.69	1.00	0.76	**0.99**	1.00	0.89	0.73	0.68
ANB	0.89	1.00	0.56	0.97	0.62	0.81	**0.89**	0.72	0.58	0.56
SAMBA	1.00	1.00	0.77	1.00	0.86	1.00	1.00	**1.00**	0.80	0.77
RIB	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00	**1.00**	0.96
USB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**

As there were 10 Saudi banks included in this study, 100 linear programs were solved using 'DEASP' for each year from 1989 to 1998. DEASP is a software designed by the authors for the basic DEA model. The windows based software has a capability to construct the REM for as many as 100 banks in one computer run. Any other software for solution of linear programming such as LINDO or solver module of Microsoft Excel may also be use.

Thus for the *k*th bank the set of equations (as specified earlier in this paper) would yield the input and output weights that maximizes the efficiency score of that bank with respect to other banks for the entire time horizon. This procedure was followed for the remaining banks leading to the construction of the REM. Table 4 and Table 5 show the REM obtained for year 1989 and year 1998 respectively. Taking the example of REM in 1998 (Table 5), the values in this table can be read as follows: when the total weighted output by total weighted input was considered the relative efficiency of bank RB with respect to all other banks was 0.71, bank JB with respect to all other banks was 0.44, bank SAIB with respect to all other banks was 1.00 and so on. On the other side, when one weighted input X_2 and one weighted output Y_1 were taken, the relative efficiency between bank RB and bank JB was 1.00, bank RB and SAIB was 0.63, bank RB and SHB was 1.00 and so on. Also, for the same situation, the relative efficiencies of other banks namely JB, SAIB, SHB, BSF, SABB, ANB, SAMBA, RIB, and USB with respect to bank JB were 0.70, 1.00, 0.92, 1.00, 1.00, 0.89, 1.00, 1.00, and 1.00 respectively

5. 1. Stage I

From the diagonal elements in Table 4 and Table 5, one can find that the performance of the banks: SHB, BSF, SABB, ANB and USB is increased by 11%, 29%, 31%, 2%, and 21% respectively during the period 1989-1998. In contrast to these five banks, the performance of another two banks, namely RB and JB, is decreased by 29% and 56% respectively for the same period. On the other side, the performance of the remaining three banks (SAIB, SAMBA, and RIB) is kept constant with efficiency 100% in both of 1989 and 1998.

For more analysis, a comparative study was made to find the average performance of *k*th bank with the average performance of all other banks within the period of study (1989-1998). Fig. 7 gives a graphical representation of the results obtained. As shown, the performance of JB bank was decreased gradually, by 21% on average, over the period from 1989 to 1992, compared with RB bank in which its performance was efficient by 100% and then decreased suddenly by 46% at year 1992. Also, the performance of JB and RB banks were inefficient by 21% and 51% compared with the average performance of the other banks in year 1998. For example, the percentage improvement for each input and output that the bank JB would need to make in order to become efficient, for year 1998, is as follows:

$X_1 = -55\%$ $Y_1 = 12\%$

$X_2 = -55\%$

From Fig. 7, it can be, also, shown that there were six banks (SAIB, SHB, SABB, SAMBA, RIB, and USB) which have achieved higher efficiency score when they compared individually with the average efficiency score. The banks SAIB, RIB, and USB were consistently efficient over the ten years. The banks BSF and ANB were trying up to maintain a performance level near to the total average.

5. 2. Stage II

Another comparative analysis was carried out with one input X_2 (general & administrative expenditure) and one output Y_1 (gross income) only. The analysis based on the off-diagonal elements of the REMs over the ten years from 1989 to 1998. Two cases in this stage were studied. In the first case, the performance of *k*th bank relative to the performance of all other banks was determined by dividing the average efficiency of this bank, over the ten years, on the average efficiency of all other banks. The second case is evaluating the performance of all other banks relative to the performance of *k*th bank. Fig. 8 shows the results obtained. Taking an example of RB bank, it may be observed that the relative performance of RB with respect to other banks was 80% in 1989, 83% in 1990, 95% in 1991, and so on. On the other hand, the relative performance of other banks with respect RB bank was 87% in 1989, 85% in 1990, 95% in 1991, and so on. It can be, also, shown that the performance of the RB, SHB, SABB, and ANB banks was very close to the average performance of all other banks. This is in contrast to the performance of JB bank which appeared far away from the total average. However, JB bank is started to improve its performance from 1994 onward. The same was for BSF bank. Other banks such as SAIB, SAMBA, RIB, and USB achieved higher performance when they compared individually with other banks.

5.3. Confidence of results – A clustering approach

In order to improve the confidence in the results obtained from DEA approach, cluster analysis was conducted on the ten Saudi banks in order to classify them into 5 groups. Hierarchical Clustering technique was applied using SPSS, Version 10.0 for this purpose. This procedure attempts to identify relatively homogeneous groups of cases (or variables) based on selected characteristics, using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left. Raw variables can be analyzed or may be chosen from a variety of standardizing transformations. Distance or similarity measures are generated by the Proximities procedure. Statistics are displayed at each stage to help selection of the best solution. Dendrograms are used to assess the cohesiveness of the clusters formed and can provide information about the appropriate number of clusters to keep. They are visual representations of the steps in hierarchical clustering solution that show the clusters being combined and the values of the distance coefficients at each step. The dendrogram rescales the actual distances to numbers between 0 and 25, preserving the ratio of the distances between steps.

In this study the cluster method used was 'nearest neighbor' and the interval measure used was 'Squared Euclidean Distance' using agglomeration schedule. This is a method for creating clusters in which each case starts out as a cluster. At every step, clusters are combined until all cases are members of a single cluster. Once a cluster is formed it cannot be split, it can only be combined with other clusters.

The dendrograms were obtained for each year from 1989 to 1998. Figures 9, 10 and 11, the example charts, indicate that SAIB, USB, and SHB banks are forming a group consistently over the years 1990, 1996, and 1998. This is in agreement with the DEA results given in sections 5.1 and 5.2 where these three banks are consistently efficient over the ten years.

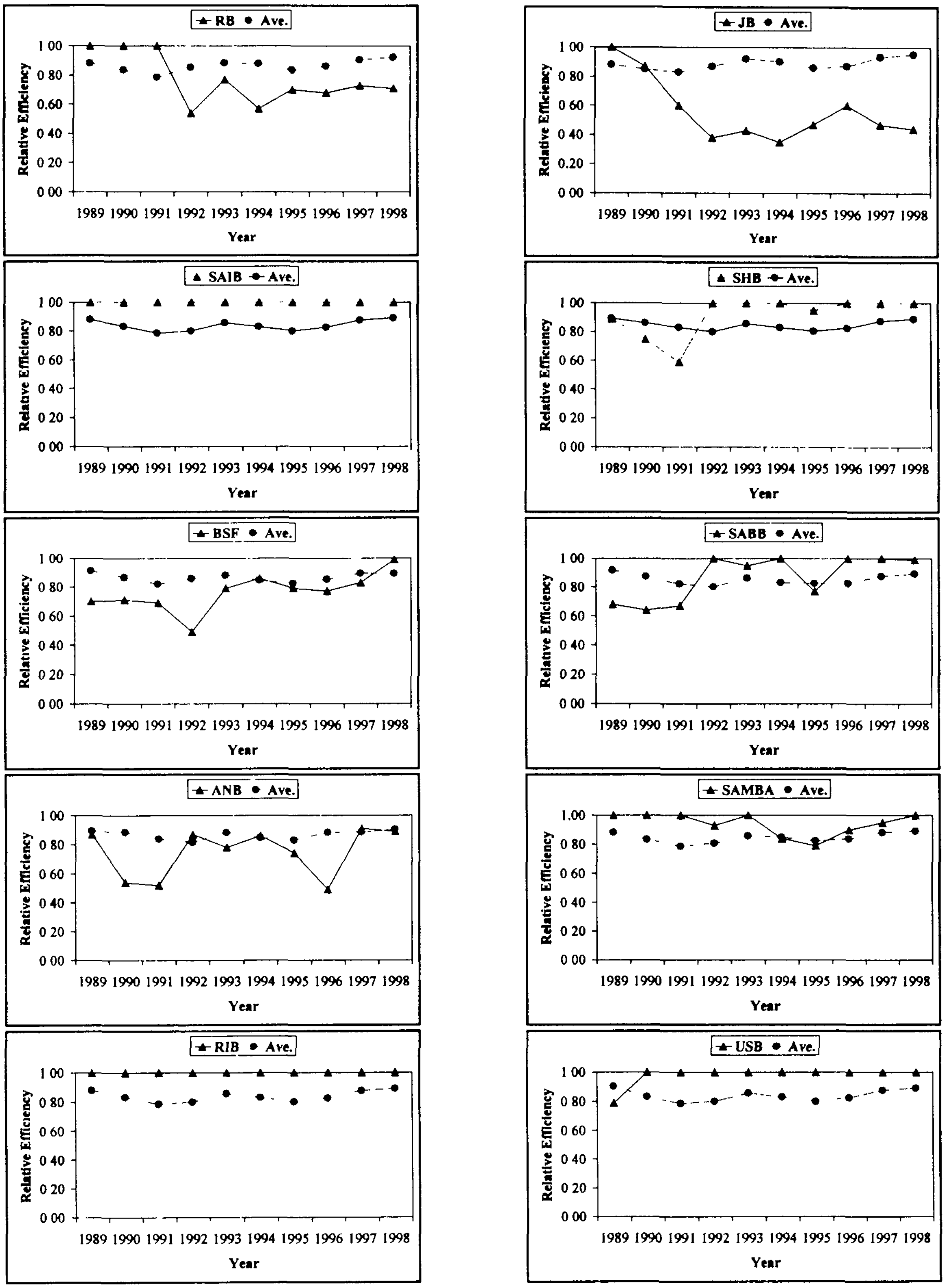


Fig. 7. A graphical representation of the relative performance between *k*th bank and all other banks with total input and total output over ten years from 1989 to 1998.

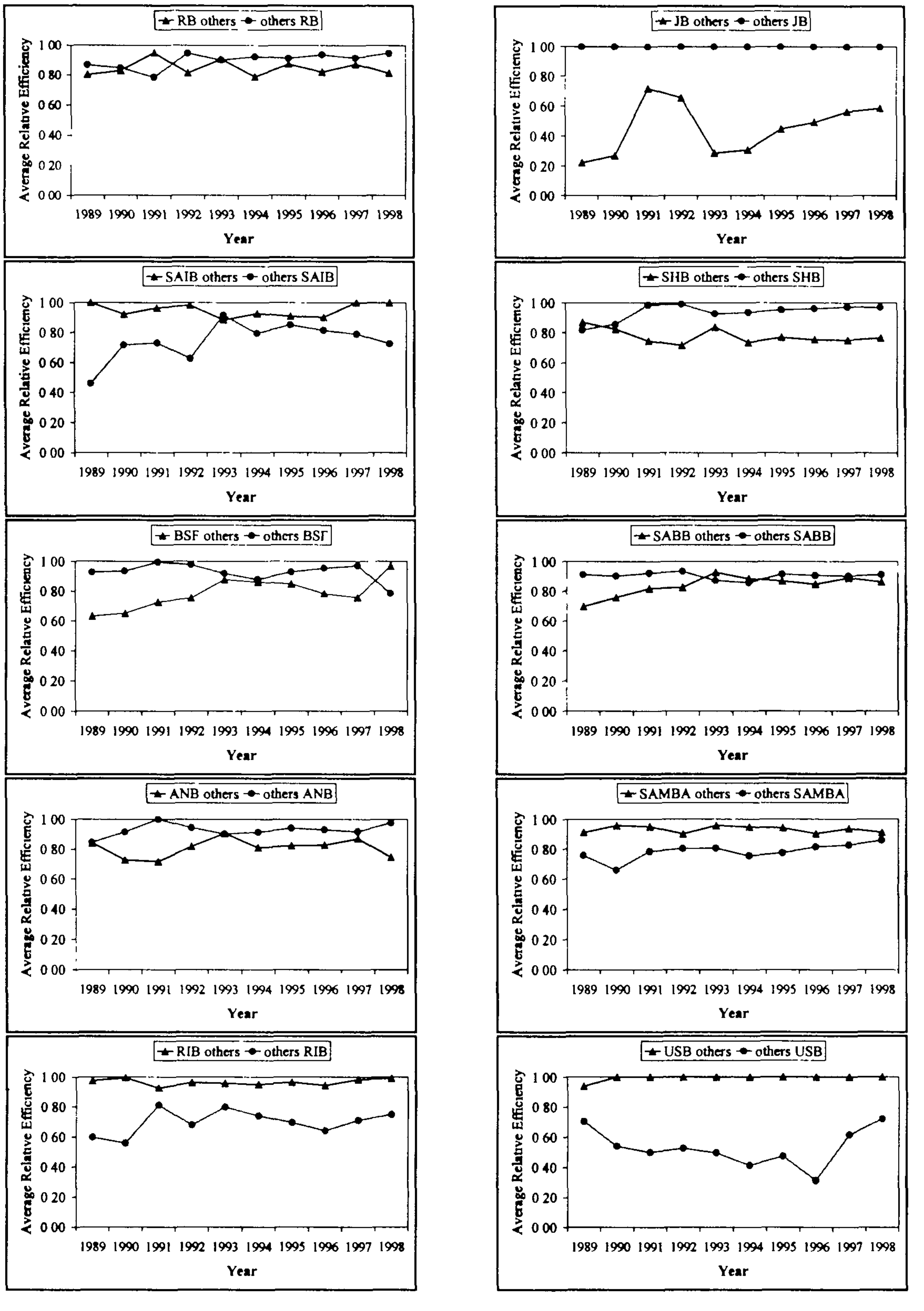
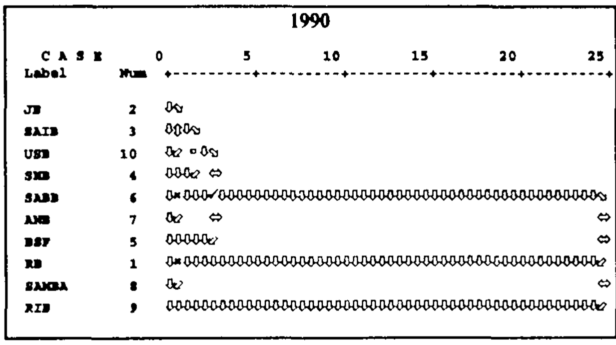


Fig. 8. A graphical representation of the performance of *k*th bank relative to other banks (*k*th:others) and other banks relative to *k*th bank (others: *k*th) with one input and one output over ten years.



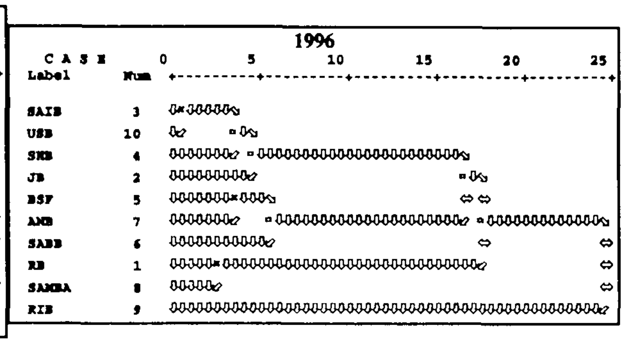


Fig. 9. Hierarchical Cluster Analysis for 10 Saudi Banks at year 1990.

Fig. 10. Hierarchical Cluster Analysis for 10 Saudi Banks at year 1996.

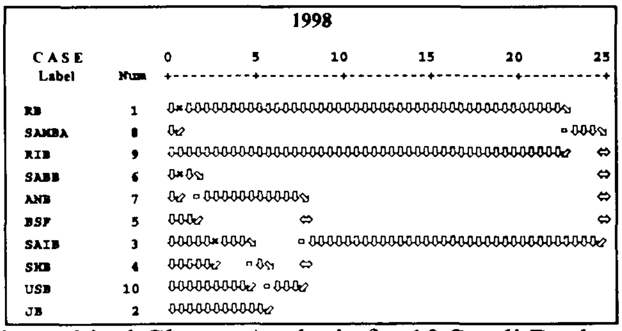


Fig. 11. Hierarchical Cluster Analysis for 10 Saudi Banks at year 1998.

6. Conclusions

In view of globalization and liberalization the Saudi banking system has undergone tremendous changes during the past few years. As is happening elsewhere in the world Saudi banking sector is gradually coming out of a veiled secrecy in terms of disclosures of balance sheets and profit and loss accounts.

Though the entry of foreign banks has aggravated the field of competition it has resulted in better customer services and competitive rendering of products. Overall picture is that efficiency issue is going to assume greater significance at individual bank's level so as to gain better understanding of the various facets of the new banking business.

This paper attempted to address the above issue in the Saudi banking context and had advocated the use of DEA approach in evaluating the relative efficiency of the top ten banks in the Kingdom. The results of the analysis indicated that, barring few exceptions the banks have in general improved their efficiency scores over the years 1989 to 1998. According to a report released in year 2001, by the ministry of finance and national economy on the state of the economy in 2000, Saudi banka deposit grew 4.3% during the first ten months of 2000 capital and the resources grew by 2.3% and reached to 43.3 billion Riyal (equivalent to 11.54 billion U.S. Dollars) (www.saudiembassy.net, 2002). This is in agreement with the results obtained by the authors. In spite of this there were a few banks that continue to be at the lower end of the relative efficiency scales during the study period. Similarly some banks have consistently been among the relatively more efficient banks.

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Assessing Program and Managerial Efficiencies: With an Application to Bank Branches

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Abstract:
This paper develops a method, based on the Malmquist index, for the identification of differences in decision making units (DMUs) performance that can be attributed to their association with certain programs (or groups). The new performance index comparing two groups of DMUs can be multiplicatively decomposed into an index comparing the efficiency spread within each group, and an index reflecting the productivity gap between the "best-practice" frontiers. The applicability of the method is illustrated in the context of the comparison of regional performance of bank branches within a country.

Keywords: Data Envelopment Analysis, Efficiency, Banking, Malmquist Index

1. Introduction

The recent developments in the banking industry, such as deregulation, globalisation and technological evolution, have made the attainment of efficiency an essential requirement to retain competitiveness and economic viability. This challenging and more hostile banking environment has called for sophisticated techniques that can objectively assess organisational performance and contribute to its improvement.

This paper uses the Data Envelopment Analysis (DEA) methodology to assess the performance of branches from a Portuguese commercial bank. DEA is a linear programming based technique for measuring the relative efficiency of a fairly homogeneous set of decision making units (DMUs) in their use of multiple inputs to produce multiple outputs. In most DEA applications, although the DMUs' activity exhibits a large degree of homogeneity, it is often important to explore the profile of groups of DMUs from the set under analysis which face similar exogenous conditions (e.g., demographics, economic development) or operational characteristics (e.g., managerial policies). Charnes *et al.* (1981) introduced this analysis by group, rather than by individual DMUs, (called "program evaluation"), shortly after the publication of the seminal paper introducing the DEA models, Charnes *et al.* (1978). This paper develops an enhanced method for program evaluation based on the construction of an index.

The new index developed in this paper is based on the Malmquist index, introduced by Caves *et al.* (1982), and developed further by Fare *et al.* (1994) in the context of performance assessments. The Malmquist index is usually applied to the measurement of productivity change over time, and can be multiplicatively decomposed into an efficiency change index and a technological change index. Similarly, the performance index developed in this paper can be multiplicatively decomposed into an index comparing the within-program efficiency spreads, and an index reflecting the productivity gap between the "best-practice" frontiers of the different programs at a given moment in time. Whilst the first index resulting from this decomposition reflects the managerial efficiencies within the programs, the latter index

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reflects productivity differences between the programs, attributable to their policies or exogenous conditions.

In relation to the performance of the bank branch network analysed in this paper, the assessment was conducted considering four different clusters of branches, corresponding to the regions where they operate. This enabled the identification of the relative strengths and weaknesses of the different regions, distinguishing the inefficiencies that can be attributable to poor management at the individual branches from those that come with the market and the managerial policies defined centrally for the branches in a given region.

This paper unfolds as follows. Next section develops the new performance index for the comparison of groups of DMUs operating under different conditions. Section 3 illustrates the use of the index in the assessment of bank branches' performance. The final section summarises and concludes.

2. Methodology

In recent years the Malmquist index has become the standard approach to productivity measurement within the non-parametric literature. The Malmquist index was first developed by Caves *et al.* (1982) and was only treated theoretically until its enhancement by Fare *et al.* (1994). A major contribution of the Fare *et al.* paper was to account for the existence of inefficiency in DMUs' activity and to provide DEA models for the calculation of the distance function underlying the construction of the index. Also, it showed how to decompose the Malmquist productivity index into a part capturing technological change and a part capturing technical efficiency change between time periods *t* and *t+1*. For a review of the literature on the theoretical developments and applications of the Malmquist index see Fare *et al.* (1998).
This section develops an index for the comparison of performance of groups of DMUs operating under different programs. The new index consists of an adaptation to the Malmquist index such that it no longer measures the productivity change between two time periods. The new index corresponds to a cross-sectional comparison of performance of groups of DMUs operating in different conditions, at a certain moment in time. This index can be multiplicatively decomposed into an index comparing the efficiency spread of DMUs in different groups, and an index reflecting the differences in productivity between the best-practice frontiers.

To illustrate the derivation of this new index (with an input orientation), consider α DMUs in group A, using inputs $x^A \in \Re_+^m$ to produce outputs $y^A \in \Re_+^s$, and β DMUs in region B, using inputs $x^B \in \Re_+^m$ to produce outputs $y^B \in \Re_+^s$. The DMUs operating in group A are represented by their input-output vector as $(y_{j_a}^A, x_{j_a}^A)$ for $j_a = 1,\ldots,\alpha$. A similar notation is used for group B. $D_i^A(y_{j_b}^B, x_{j_b}^B)$ represents the input distance function for a DMU in group B with respect to the frontier of group A. Both within-group and between-group distance functions are needed for the calculation of the index.
The index that compares the within-group efficiency spread is given by the ratio of the geometric means of the distance of the DMUs to their group-specific frontier, as follows:

$$IE_i^{AB} = \frac{\left[\prod_{j_a=1}^{\alpha} D_i^A(y_{j_a}^A, x_{j_a}^A)\right]^{1/\alpha}}{\left[\prod_{j_b=1}^{\beta} D_i^B(y_{j_b}^B, x_{j_b}^B)\right]^{1/\beta}} \qquad [1]$$

A value of IE_i^{AB} less than one indicates that the efficiency spread is smaller (i.e., there is greater homogeneity) in DMUs of group A than in group B. Note that the distance function is the reciprocal to Farrell's (1957) measure of technical efficiency.

Note that the aggregation of the efficiency scores of the DMUs with respect to their group-specific frontier is in line with the notion of a structural efficiency score, described in Farrell (1957), which "measures the extent to which an industry keeps up with the performance of its own best firms". In the context of the program comparison discussed in this paper, the industry may be regarded as a group of DMUs operating under similar conditions. In this case, the index IE_i^{AB} above can be interpreted as a comparison of efficiency levels between two industries.

The other component of the index that compares frontier productivity evaluates the distance between the two frontiers (A and B) at the input-output mixes of all DMUs in both groups. The values of these distance functions are then aggregated using the geometric mean to obtain the frontier productivity index:

$$IF_i^{AB} = \left[\prod_{j_a=1}^{\alpha} \frac{D_i^B(y_{j_a}^A, x_{j_a}^A)}{D_i^A(y_{j_a}^A, x_{j_a}^A)} \cdot \prod_{j_b=1}^{\beta} \frac{D_i^B(y_{j_b}^B, x_{j_b}^B)}{D_i^A(y_{j_b}^B, x_{j_b}^B)} \right]^{1/(\alpha+\beta)} \qquad [2]$$

A value of IF_i^{AB} less than one indicates greater productivity (or dominance) of the frontier of group A with respect to the frontier of group B.

The product of the two indices in [1] and [2] gives the overall index (I_i^{AB}) for the comparison of performance of groups of DMUs associated with different programs, as follows:

$$I_i^{AB} = \frac{\left[\prod_{j_a=1}^{\alpha} D_i^A(y_{j_a}^A, x_{j_a}^A) \right]^{1/\alpha}}{\left[\prod_{j_b=1}^{\beta} D_i^B(y_{j_b}^B, x_{j_b}^B) \right]^{1/\beta}} \cdot \left[\prod_{j_a=1}^{\alpha} \frac{D_i^B(y_{j_a}^A, x_{j_a}^A)}{D_i^A(y_{j_a}^A, x_{j_a}^A)} \cdot \prod_{j_b=1}^{\beta} \frac{D_i^B(y_{j_b}^B, x_{j_b}^B)}{D_i^A(y_{j_b}^B, x_{j_b}^B)} \right]^{1/(\alpha+\beta)} \qquad [3]$$

A value less than unity indicates better performance in group A than in group B. This may be due to two causes: less dispersion in efficiency levels of DMUs in group A than in group B, or the dominance of the best-practice frontier of group A with respect to the frontier of group B.

An approach related to the index [3] developed in this paper, which can also be used to compare the performance of groups of DMUs, was described by Berg *et al.* (1993) and used by Pastor *et al.* (1997). This method is based on the specification of a "typical" DMU for each group, represented by (X_{typ}^A, Y_{typ}^A) and (X_{typ}^B, Y_{typ}^B), such that it is possible to use an index with a similar structure to the usual formulation of the Malmquist index, as follows:

$$I_i^{AB(typ)} = \frac{D_i^A(X_{typ}^A, Y_{typ}^A)}{D_i^B(X_{typ}^B, Y_{typ}^B)} \cdot \left[\frac{D_i^B(X_{typ}^A, Y_{typ}^A)}{D_i^A(X_{typ}^A, Y_{typ}^A)} \cdot \frac{D_i^B(X_{typ}^B, Y_{typ}^B)}{D_i^A(X_{typ}^B, Y_{typ}^B)} \right]^{1/2} \qquad [4]$$

Note that if the DMUs from group A were associated with time period *t+1*, and the DMUs from group B associated with time period *t*, such that (X_{typ}^A, Y_{typ}^A) and (X_{typ}^B, Y_{typ}^B) corresponded to the same DMU at time period *t+1* and *t*, respectively, the expression in [4] would become identical to the Malmquist index for productivity assessment (see Fare *et al.*, 1994):

$$M_i^{t,t+1} = \frac{D_i^{t+1}(X^{t+1},Y^{t+1})}{D_i^t(X^t,Y^t)} \cdot \left[\frac{D_i^t(X^{t+1},Y^{t+1})}{D_i^{t+1}(X^{t+1},Y^{t+1})} \cdot \frac{D_i^t(X^t,Y^t)}{D_i^{t+1}(X^t,Y^t)} \right]^{1/2} \quad [5]$$

Based on the Malmquist-type index in [4], Berg et al. (1993) reported comparisons of productivity across banks in the Nordic countries. The comparisons were made between the largest bank of each country and between the average banks (i.e., defined as the total group values divided by the number of banks in the country). Pastor *et al.* (1997) compared the relative efficiency and productivity of several European and the US banking systems. They reported the results for alternative definitions of a "typical" bank, based on the median bank, the simple average of banks and the weighted (by assets) average of banks.

The calculation of Malmquist indices for the analysis of productivity growth of an industry has been frequently based on the use of average units (e.g., Berg et al., 1992; Forsund, 1993; Odeck, 2000). However, there are some problems associated with this aggregation of the input-output values of all DMUs prior to the construction of the index. First, the definition of a "typical" DMU that can represent all DMUs in a group is subjective, and it not clear which measure should be used (e.g., a simple average, a weighted average, or the median). Also, Ylvinger (2000) demonstrated that the use of average units biases the assessment of industry (or structural) efficiency. Thus, the aggregation of the input-output values of all DMUs to construct a "typical" DMU to represent the group should be avoided. These arguments discourage the use of average units in the construction of a Malmquist index. The advantage of the new index developed in this paper is that it does not require a subjective definition of a "typical" DMU, as it can handle directly all the observations corresponding to individual DMUs within a group.

3. Data and Empirical Results

The analysis reported in this paper is primarily focused on bank branches' commercial and operational activities. Staff is the key resource used and was separated into three categories for this analysis: number of branch and account managers, administrative/commercial staff and tellers. The other input considered refers to operational costs (excluding staff costs). The outputs reflect branches' business levels in terms of revenue related variables (i.e., value of deposits, value of loans, value of off-balance sheet business), and services provided to customers (proxied by the number of general service transactions). The empirical results reported in this paper are based on the analysis of 144 bank branches located in 4 regions within Portugal, with the following number of branches: North: 34, Centre-South: 47, Porto: 24 and Lisbon: 39.

The component of the index corresponding to the comparison of within-region efficiency spread (IE_i^{AB}) is shown in Table 1. The results are reported such that a value smaller than unity indicates that the region listed in the row heading has a better performance status (i.e., less efficiency spread) than the region listed in the column heading. Note that the elements below the diagonal of the matrix are the inverse of the associated value in the upper part of the matrix. Figure 1 pictorially illustrates the comparison of regional efficiency spread considering Lisbon as the reference region (i.e., data from the first row in Table 1, where the efficiency spread index for Lisbon is 1). It is concluded that Porto has the smallest efficiency spread (i.e., it is 'super-efficient' in relation to the spread observed in Lisbon, considered as the reference), followed by Lisbon, the North and finally the Centre-South (CS), which has the largest efficiency spread.

Table 1 – Within-region efficiency spread index

A \ B	Lisbon	Porto	CS	North
Lisbon	1	1.072	0.948	0.998
Porto	0.933	1	0.885	0.931
CS	1.054	1.130	1	1.052
North	1.002	1.074	0.950	1

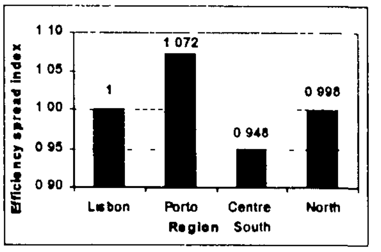

Figure 1 – Within-region efficiency spread index (using Lisbon as the reference region).

Table 2 reports the results of the index for the comparison of productivity between regional frontiers (IF_i^{AB}). The results are reported such that a value smaller than unity indicates that the region listed in the row heading has a frontier with greater productivity than the region listed in the column heading.

Table 2 – Frontier productivity index

A \ B	Lisbon	Porto	CS	North
Lisbon	1	0.817	0.948	0.942
Porto	1.224	1	1.123	1.123
CS	1.062	0.890	1	1.054
North	1.062	0.891	0.949	1

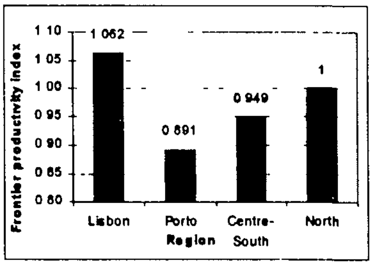

Figure 2 – Frontier productivity index (using the North as the reference region)

The information provided in Table 2 can be very useful for pair-wise comparisons of frontier productivity, leading to the identification of suitable benchmarks for a certain region. For example, the manager in charge of the Northern region can explore the relative productivity of its regional frontier using the data reported in the last column of Table 2, and pictorially illustrated in Figure 2. From Figure 2 can be concluded that the Northern region should direct a benchmarking effort to the branches in Lisbon, in order to identify the procedures that can improve the productivity of the best-practice branches in the North.

In a more general setting, where it is important to obtain a ranking of more than two groups, it is desirable that the index used satisfies the circular relation of Frisch (1936), as follows:

$$I_i^{AB} \times I_i^{BC} = I_i^{AC} \qquad [6]$$

This relation implies that the index for the comparison of performance between two groups A and C (I_i^{AC}) can be obtained by comparing these groups to any other group considered as the reference underlying the comparison (group B in formula [6]). This property ensures that the ranking of group performance is independent of the reference underlying the comparison.

In relation to the indices developed in this paper, only the within-group efficiency spread index [1] satisfies this property. However, since a robust performance ranking is only attainable if the index comparing frontier productivity also satisfies the circular relation, we propose the use of an adjusted index as an alternative to [2] when the performance comparison involves more than two groups. This adjusted index involves evaluating the distance between any two frontiers at the input-output mixes of all DMUs in the groups under comparison. For example, for the comparison of the frontiers of Lisbon (L) and Porto (P), the adjusted index would consider the input-output mixes of the all branches in the four regions (L, P, CS and N, with a number of branches α, β, χ, δ, respectively):

$$IF(adj)_i^{LP} = \left[\prod_{j_a=1}^{\alpha} \frac{D_i^P(y_{j_a}^L, x_{j_a}^L)}{D_i^L(y_{j_a}^L, x_{j_a}^L)} \cdot \prod_{j_b=1}^{\beta} \frac{D_i^P(y_{j_b}^P, x_{j_b}^P)}{D_i^L(y_{j_b}^P, x_{j_b}^P)} \cdot \prod_{j_c=1}^{\chi} \frac{D_i^P(y_{j_c}^{CS}, x_{j_c}^{CS})}{D_i^L(y_{j_c}^{CS}, x_{j_c}^{CS})} \cdot \prod_{j_d=1}^{\delta} \frac{D_i^P(y_{j_d}^N, x_{j_d}^N)}{D_i^L(y_{j_d}^N, x_{j_d}^N)} \right]^{1/(\alpha+\beta+\chi+\delta)} \quad [7]$$

The results of the adjusted index ($IF(adj)_i^{AB}$) are shown in Table 3. Figure 3 pictorially illustrates the ranking of frontier productivity, using Lisbon as the reference (i.e., data from the first row in Table 3, where Lisbon has a reference value of frontier productivity equal to 1).

Table 3 – Adjusted frontier productivity index

A \ B	Lisbon	Porto	CS	North
Lisbon	1	0.877	0.937	0.978
Porto	1.141	1	1.069	1.115
CS	1.067	0.935	1	1.043
North	1.023	0.897	0.959	1

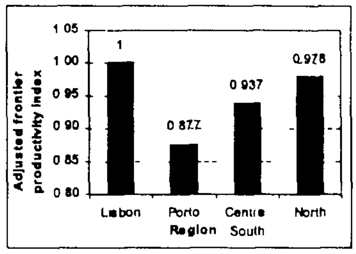

Figure 3 – Adjusted frontier productivity index (using Lisbon as the reference region).

In terms of the managerial implication of the results obtained, it was found that Porto has the frontier with the lowest productivity (see Figure 3), although all its branches operate very close to the regional best-practice frontier (see Figure 1). This may be interpreted as an indication that the targets set for these branches are relatively easy to achieve, and thus most branches operate close to the regional best-practice levels. The market potential of Porto should be carefully analysed to verify if these branches can be set more demanding targets, in order to close their productivity gap with respect to other regions. The Centre-South region has a rather different performance status. Its frontier is closer to the most productive frontier, corresponding to Lisbon. However, there is a significant variability in the efficiency levels of the CS branches, which indicates that the performance improvements should be directed to increase the homogeneity of within-region efficiency. In relation to the North, improvements to within-region efficiency levels and frontier productivity are attainable, although it is close to the best performing levels in both performance dimensions. Finally, Lisbon should focus on increasing the homogeneity of branches' efficiency levels. Its frontier is the most productive among the four regions considered. In terms of the overall performance ranking of the four regions, based on the use of an adjusted index $I(adj)_i = IE_i \times IF(adj)_i$, it was found that Lisbon is the best performing region, followed by the North, Porto and the Centre-South, respectively.

4. Conclusions

This paper developed a method for the comparison of performance of groups of DMUs operating under different conditions. The method is based on an adaptation to the Malmquist productivity index. In contrast with the general use of the Malmquist index, which evaluates the productivity change of individual DMUs over a given time period, the new index focuses on the comparison of performance of groups of DMUs operating under different conditions at the same moment in time. One important property of this new index is that it does not require a subjective aggregation of data on individual DMUs prior to the construction of the index comparing the groups' performance. Also, it was developed an adjusted index satisfying the circular relation of Frisch (1936) that can be used for performance rankings involving more than two groups.

The applicability of the index developed in this paper was illustrated in the context of a comparison of regional performance of bank branches within a country. Attributing the measured performance differences to its sources is a very important issue in any managerial context. This issue was addressed by decomposing the performance index into a part comparing the efficiency spread of the DMUs operating in different groups (reflecting within-region managerial efficiency), and a part capturing the difference in frontier productivity between the groups (reflecting the impact of environmental factors and regional managerial policies on branches' productivity).

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Calculations of Marginal Rates in DEA Using Parametric Optimization Methods

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Abstract
The proposed family of parametric optimization methods allows one to construct an intersection of the frontier with a two-dimensional plane determined by any pair of given directions. We also develop constructive methods to calculate marginal rates of substitution, marginal rates of transformation and so on.

Keywords: DEA, parametric optimization algorithms.

1. Introduction

Data Envelopment Analysis (DEA) appears to be highly efficient for investigation of production units, see Banker, Charnes and Cooper;[1] Cooper, Seiford and Tone.[2] Many scientific publications are devoted to DEA applications in the financial area, see, for instance, Thompson et al.[3]

A family of parametric optimization methods developed by our group allows one to construct an intersection of the frontier with a two-dimensional plane determined by any pair of given directions. This approach reduces the efficiency analysis of production units to the investigation of well-known functions in economics, see, for instance, Varian,[4] such as production function, isoquant, isocost, isoprofit, etc.

From the very beginning, DEA classics touched on the problem of calculations of partial derivatives employed in mathematical economics, using optimal dual variables for this purpose.[5-7]

It was also noted that the partial derivatives are not defined at the points of the intersection of two or more of the bounding surface segments. In this paper, we show that the one-side directional derivatives exist at any point and in any direction. We propose a constructive technique that allows us to calculate such partial derivatives.

This paper develops the results that were presented at the 16th IMACS World Congress 2000 on Scientific Computation, Applied Mathematics and Simulation, Lausanne[8] and at the International DEA Symposium 2000, Brisbane, see Krivonozhko et al.[9]

2. Background

Consider a set of n observations of actual production units (X_j, Y_j), $j=1, \dots, n$, where the vector of outputs $Y_j=(y_{1j},\dots,y_{rj}) \geq 0$ is produced from the vector of inputs $X_j=(x_{1j},\dots,x_{mj}) \geq 0$. The production possibility set T is the set $\{(X,Y) \mid$ *the outputs* $Y \geq 0$ *can be produced from the inputs* $X \geq 0\}$.

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Production possibility set T can be represented in the algebraical form[1]

$$T = \{(X,Y) / \ X \ge \sum_{j=1}^{n} X_j\lambda_j,\ Y \le \sum_{j=1}^{n} Y_j\lambda_j, \quad \sum_{j=1}^{n}\lambda_j = 1,\ \ \lambda_j > 0,\ j = 1,\dots,n\}. \tag{1}$$

BCC (Banker, Charnes and Cooper) input-oriented model given below enables us to find some efficient points on the frontier.

$$\min\ \theta - \varepsilon\left\{\sum_{k=1}^{m} s_k^- + \sum_{i=1}^{r} s_i^+\right\}$$

subject to

$$\theta x_{ko} - \sum_{j=1}^{n} x_{kj}\lambda_j - s_k^- = 0\ ,\ \ k=1,\dots,m, \tag{2}$$

$$\sum_{j=1}^{n} y_{ij}\lambda_j - s_i^+ = y_{io}\ ,\ \ i=1,\dots,r,$$

$$\lambda_j, s_k^-, s_i^+ \ge 0\ ,$$

where x_{kj} and y_{ij} represent the observed inputs and outputs of production units $j=1,\dots,n$. Unit (X_o,Y_o) is under investigation in problem (2).

Definition 1 (Pareto-efficiency) Production unit $(X^*,Y^*)\in T$ is efficient if and only if there is no $(X,Y)\in T$ and $(X,Y)\neq(X^*,Y^*)$ such that $X\le X^*$, $Y\ge Y^*$.
We denote a set of Pareto-efficient points by $Eff_P\ T$.

Definition 2 (Weak Pareto-efficiency) Production unit $(X', Y') \in T$ is weakly efficient if and only if there is no $(X, Y)\in T$ such that $X < X'$, $Y > Y'$.
We denote a set of weakly Pareto-efficient points by $WEff_P\ T$.

There are many optimization models in the DEA framework. In this paper, we dwell mainly on BCC model, without any loss in generality, since the proposed approach can be extended to other DEA models.

Next, we describe parametric optimization algorithms for constructing intersections of the frontier with two-dimensional planes.

Let us define the two-dimensional plane in space E^{m+r} as

$$Pl(X_o, Y_o, d_1, d_2) = (X_o, Y_o) + \alpha d_1 + \beta d_2, \tag{3}$$

where $(X_o,Y_o) \in T$, α and β are any real numbers, directions $d_1, d_2 \in E^{m+r}$ and d_1 is not parallel to d_2. The plane is going through point (X_o,Y_o) in E^{m+r} and spanned by vectors d_1 and d_2.

Next, define five intersections of the frontier with two-dimensional planes

$$Sec_1(X_o, Y_o) = \{(X, Y) / (X, Y)\in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\ T, \text{ where } d_1 = (X_o, 0) \in E^{m+r}, d_2 = (0, Y_o) \in E^{m+r}\}, \tag{4}$$

$$Sec_2(X_o, Y_o, p, s) = \{X / (X, Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\ T, \text{ where } d_1 = (e_p, 0) \in E^{m+r}, d_2 = (e_s, 0) \in E^{m+r}, e_p \text{ and } e_s \text{ are } m\text{-identity vectors with a one in position } p \text{ and } s, \text{ respectively}\}, \tag{5}$$

$$Sec_3(X_o, Y_o, b) = \{(X, Y) \,/\, (X,Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\, T, \text{ where } d_1 = (b, 0) \in E^{m+r} \text{ and } b \in E^m, d_2 = (0, Y_o) \in E^{m+r}\}, \quad (6)$$

$$Sec_4(X_o, Y_o, p, s) = \{Y \,/\, (X,Y) \in Pl(X_o, Y_o, d_1, d_2) \cap WEff_P\, T, \text{ where } d_1 = (0, e_p) \in E^{m+r},\ d_2 = (0, e_s) \in E^{m+r}, e_p \text{ and } e_s \text{ are r-identity vectors with a one in position } p \text{ and } s, \text{ respectively}\}, \quad (7)$$

$$Sec_5(X_o, Y_o, c) = \{(X,Y) \,/\, (X,Y) \in Pl\ (X_o, Y_o, d_1, d_2) \cap WEff_P\, T, \text{ where } d_1 = (X_o, 0) \in E^{m+r}, d_2 = (0, c) \in E^{m+r} \text{ and } c \in E^r\}. \quad (8)$$

By choosing different directions d_1 and d_2 we can construct various sections going through point (X_o, Y_o) and cutting the frontier. Moreover, we obtain the curves generalizing the well-known functions in macro- and microeconomics: production functions, isoquant, isocost, isoprofit, etc. Thus, we can investigate the structure of the frontier over unit (X_o, Y_o) in the multidimensional space of inputs and outputs.

Now, there are grounds to outline a general scheme of algorithms for building of intersections (4-8).

Step 1 Project unit $Z_o=(X_o, Y_o) \rightarrow \widetilde{Z} = (\widetilde{X}, \widetilde{Y})$ onto the frontier along direction d_1 or d_2. Initiate the start values of the algorithm.

Step 2 Determine a direction along the current facet. Test stopping criterion of the algorithm.

Step 3 Compute the step length along the chosen direction. Determine a point on the intersection on the frontier with two-dimensional plane.

Step 4 Set Move the along one of the two vectors determining the two-dimensional plane. Modify variables of the algorithms. Go to Step 2.

We denote algorithms for constructing curves (4-8) on the basis of general scheme by *Algorithm* 1, ..., *Algorithm* 5, respectively.

As a result of Algorithm runs we obtain sequence of points $Z'_l = (X'_l, Y'_l)$, $l = 1,\ldots, M$, that are angular points of piecewise linear curves determined by (4-8).

3. Calculations of partial derivatives

In DEA approach, serious efforts have been made to elaborate methods for estimation of partial derivatives (marginal rate of substitution, marginal rate of transformation, marginal product). Most proposed methods indicate how to evaluate these rates when production unit belongs to the relative interior of the facet, using optimal dual variables, see, for example, Charnes et al,[6] Banker and Maindiratta.[7]

In this section, we consider a technique that enables one to calculate partial derivatives at any point on the frontier on the basis of parametric optimization methods.

From (1), it follows that set T is a convex polyhedral set. Therefore, it can be written in the following form

$$L_1(X,Y) \leq 0, \quad \ldots \quad L_q(X,Y) \leq 0, \quad (9)$$

here $L_i(X,Y)$ is a linear function from variables $(X,Y) \in E^{m+k}$, q is a number of inequalities in system (9).

Define function

$$\Phi(X,Y) = \max_i \{ L_i(X,Y)\}, \quad i=1,\ldots, q. \tag{10}$$

Function $\Phi(X,Y)$ is not differentiable everywhere. However, it can be shown that this is a continuous convex function that takes on finite value at any finite point $(\widetilde{X},\widetilde{Y})$. Hence, as it follows from convex analysis,[10] the one-side directional derivatives of $\Phi(X,Y)$ exist at every point (X,Y) and in any direction. We denote the right-side directional derivative of $\Phi(X,Y)$ at (X,Y) in the direction of $V\in E^{m+r}$ by $\Phi'(X,Y;V^+)$.

Lemma Production unit $(X, Y) \in$ *Bound T*, where *Bound T* stands for the boundary of T, if and only if the following relation holds

$$\Phi(X, Y) = 0. \tag{11}$$

Proof Suppose that $(\widetilde{X},\widetilde{Y})\in$ *Bound T*. Hence relations $L_i(\widetilde{X},\widetilde{Y}) \le 0$ hold for all $i=1,\ldots, q$, and some of these relations hold as equalities. Then from (9), we obtain (11).

Conversely, let relation (11) hold at unit $(\widetilde{X},\widetilde{Y})$. From (10), if follows that relations (9) hold. And some of these relations hold as equalities. Hence $(\widetilde{X},\widetilde{Y})\in$ *Bound T*. □

Thus, according to lemma equation (11) determines a hypersurface that is a boundary of T.

However, function $\Phi(X,Y)$ describes boundary of T implicitly, since linear functions $L_i(X,Y)$, $i=1,\ldots,q$, can be found only with the help of computational procedures by solving BCC optimization problems and taking optimal dual variables as coefficients for these linear functions. Actually, we do not to need calculate functions $L_i(X,Y)$. We employ relation (11) to develop and substantiate the technique that enables us to compute partial derivatives that are widely used in mathematical economics. Moreover, as it turns out, most of computational work has been already accomplished during the run of parametric optimization algorithms.

Let unit $(X_o, Y_o) \in$ *Bound T*. Using (11), we obtain

$$\begin{aligned} &\frac{\partial\Phi(X_o,Y_o;x_p^+)}{\partial x_p}dx_p + \frac{\partial\Phi(X_o,Y_o;x_s^+)}{\partial x_s}dx_s = 0, \\ &\frac{\partial\Phi(X_o,Y_o;y_p^+)}{\partial y_p}dy_p + \frac{\partial\Phi(X_o,Y_o;y_s^+)}{\partial y_s}dy_s = 0, \\ &\frac{\partial\Phi(X_o,Y_o;y_p^+)}{\partial y_p}dy_p + \frac{\partial\Phi(X_o,Y_o;x_s^+)}{\partial x_s}dx_s = 0. \end{aligned} \tag{12}$$

We stress again that function $\Phi(X,Y)$ is not differentiable everywhere. However, the one-side directional derivatives of $\Phi(X,Y)$ exist at every point (X,Y) and in any direction. Hence, the one-side partial derivatives of $\Phi(X, Y)$ do exist. In what follows, the sign plus designates the right-side partial derivative.

By virtue of (12), we obtain

$$\left(\frac{dx_p}{dx_s}\right)^+ = -\Phi'(X_o,Y_o;x_s^+)/\Phi'(X_o,Y_o;x_p^+),$$

$$\left(\frac{dy_p}{dy_s}\right)^+ = -\Phi'(X_o,Y_o;y_s^+)/\Phi'(X_o,Y_o;y_p^+), \tag{13}$$

$$\left(\frac{dy_p}{dx_s}\right)^+ = -\Phi'(X_o,Y_o;x_s^+)/\Phi'(X_o,Y_o;y_p^+).$$

The right-side partial derivatives are computed at point (X_o, Y_o). In a similar vein, we can consider the left-side partial derivatives at boundary points.

Thus, relations (13) give us partial derivatives that are widely used in mathematical economics: marginal rate of substitution, marginal rate of transformation, marginal product. Partial derivatives exist at every boundary point of T. However, they may take on values $\pm\infty$ at some boundary points as distinct from function $\Phi(X,Y)$.
Now, we proceed to constructive technique of partial derivative computations.

Using expressions of two-dimensional planes that are exploited for section constructions (4-8) and substituting them in equation (11), we obtain

$$\begin{aligned}
&\Phi(\alpha X_o, \beta Y_o) = \tilde{\Phi}_1(\alpha,\beta) = 0,\\
&\Phi(x_{1o},\ldots, x_p,\ldots, x_s,\ldots, x_{mo}, Y_o) = \tilde{\Phi}_2(x_p, x_s) = 0,\\
&\Phi(X_o, y_{1o},\ldots, y_p,\ldots, y_s,\ldots, y_{ro}) = \tilde{\Phi}_4(y_p, y_s) = 0,\\
&\Phi(x_{1o},\ldots, x_s,\ldots, x_{mo}, y_{1o},\ldots, y_p,\ldots, y_{ro}) = \tilde{\Phi}_6(x_s, y_p) = 0.
\end{aligned} \tag{14}$$

Relations (14), excluding the last one, are other forms of representations of sections (4), (5), (7). Hence, curves described by equations (14) can be constructed by the parametric optimization algorithms that are considered in the previous paragraph. The last equation of (14) is obtained if we take in relation (3) the following two directions: one is along the axes x_s, another direction is along the axes y_p.
From relations (14), we obtain

$$\begin{aligned}
&\left(\frac{d\beta}{d\alpha}\right)^+ = -\tilde{\Phi}'_1(\alpha,\beta;\alpha^+)/\tilde{\Phi}'_1(\alpha,\beta;\beta^+),\\
&\left(\frac{dx_p}{dx_s}\right)^+ = -\tilde{\Phi}'_2(x_p,x_s;x_s^+)/\tilde{\Phi}'_2(x_p,x_s;x_p^+),\\
&\left(\frac{dy_p}{dy_s}\right)^+ = -\tilde{\Phi}'_4(y_p,y_s;y_s^+)/\tilde{\Phi}'_4(y_p,y_s;y_p^+),\\
&\left(\frac{dy_p}{dx_s}\right)^+ = -\tilde{\Phi}'_6(x_s,y_p;x_s^+)/\tilde{\Phi}'_6(x_s,y_p;y_p^+).
\end{aligned} \tag{15}$$

The first derivative in (15) indicates the rate of relative change of inputs along vector Y_o with respect to relative change of inputs along vector X_o. The second derivative (15) represents the rate of substitution of input s for input p (marginal rate of substitution). The third derivative (15) is the rate of transformation of output s for output p (marginal rate of transformation). The forth derivative (15) is the marginal product of input s for output p.

As we have already observed, equations (14) describe curves implicitly. However, they can be constructed by parametric optimization algorithms presented in the previous paragraph.

Therefore, every partial derivative (15) can be evaluated as slope of appropriate curve at given point (X_o, Y_o). Since curves determined by (14) are piecewise linear, it is not difficult to calculate slopes if we have already constructed these curves as a result of parametric algorithm runs.

As we have already noted, in many papers on DEA it is observed that the partial derivatives are not defined at the points of the intersection of two or more of the bounding surface segments.[6,7] However, this is not a shortage of DEA models. In our opinion, this is a specific feature of DEA approach. What is more important, the one-side directional derivative exists at every point of the frontier and in any direction. Moreover, we can compute these one-side derivatives on the basis of parametric optimization methods. Thus, we can study the production unit behaviour under movement in any direction.

4. Visualisation of modelling results

Now, we apply our methods to the efficiency analysis of Russian banks. We used the following input and output parameters for our bank model.

Inputs: x_{1j} – total assets, in ths rubles; x_{2j} – interest expense, in ths rubles; x_{3j} – non-interest expense, in ths rubles.

Outputs: y_{1j} – interest income, in ths rubles; y_{2j} – non-interest income, in ths rubles, y_{3j} – profit, in ths rubles, where $j=1, \dots, 150$.

The data was taken from financial accounts for September 1998 for 150 banks, just after the August default in Russia.

Figure 1 shows an intersection of the frontier in six-dimensional space with two-dimensional plane for Vneshtorgbank. In the figure, the horizontal line is determined by input vector X_o, and the vertical line corresponds to output vector Y_o. The scale of lines is expressed in units of production object (X_o, Y_o), that is point (1, 1) denoted by A corresponds to Vneshtorgbank. Line AB shows the classical radial path of the bank state improvement. And point C designates a projection onto the frontier in accordance with output-oriented model. So, the curve in the figure may be visualized as a production function. Light points in the figure denote other banks under study with their registration numbers.

Using analogy with three-dimensional space, this section is a side-view of a frontier or production function in two-dimensional space. Actually, line AB, that indicates expense decrease for the bank, consists of a large number of possible directions for decreasing bank expenses. To see this, let us turn to a "top view" of the frontier or isoquant in the next figure.

Figure 2 represents an intersection of the frontier with two-dimensional plane for Vneshtorgbank where the directions of the plane are determined by the following inputs: non-interest expense and total assets. Again, point A denotes Vneshtorgbank, and point B designates a projection of the production unit onto the frontier. Line AB indicates the conventional radial path of the bank state improvement when the two inputs decrease proportionally. Directions AC and AD are other possible ways of the bank state improvement. While moving along line AC, the bank decreases its non-interest expense while keeping total assets at the same level. On the contrary, along path AD the bank diminishes its total assets and keeps its non-interest expense constant.

In Figure 2, the partial derivative does not exist at point G. However, according to the previous results the right-side partial derivative can be calculated as $\left(\frac{dx_2}{dx_3}\right)^{+} = -k\,tg\,b$, where coefficient k reflects the fact that the scale of axes is expressed in units of production object (X_o, Y_o). This partial derivative shows the marginal rate of substitution of non-interest expense for interest expense, if non-interest expense increases for bank G.

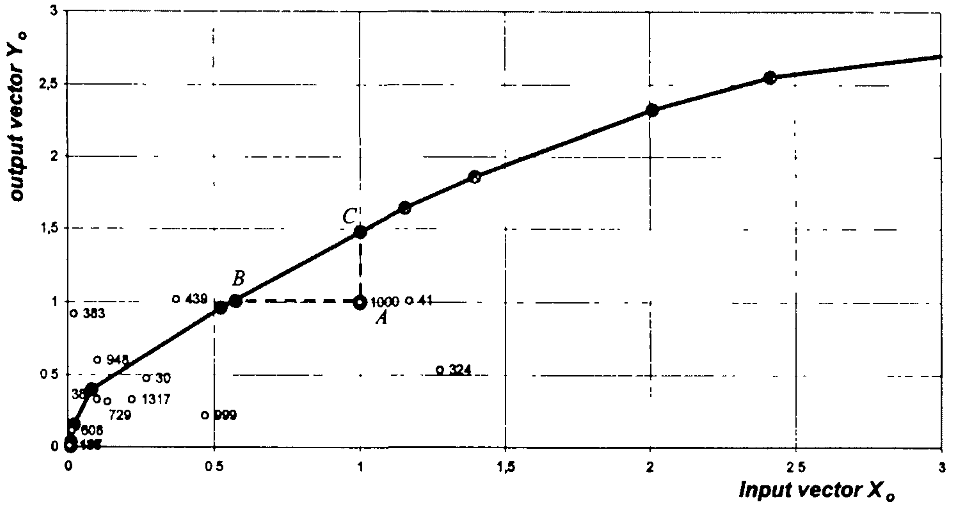

Figure 1 Production function for Vneshtorgbank

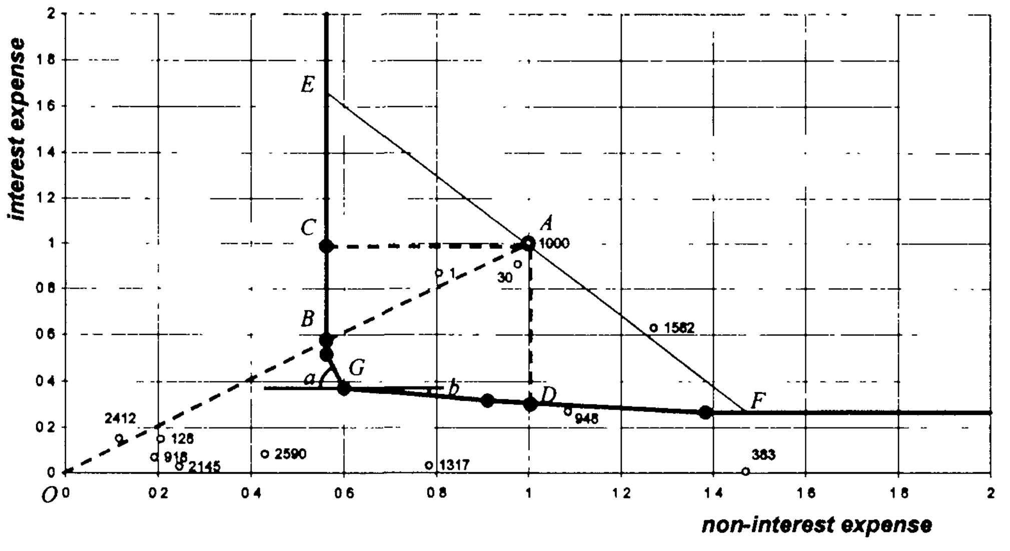

Figure 2 Input isoquant for Vneshtorgbank

In a similar way, the left-side partial derivative is evaluated by relation $\left(\frac{dx_2}{dx_3}\right)^- = -k\,tg\,a$. From this relation, we obtain the marginal rate of substitution of non-interest expense for interest expense, if non-interest expense decreases for bank *G*.

5. Conclusion

In this paper we demonstrate how the proposed family of parametric optimization methods can be used to calculate various economic notions such as marginal rate of substitution, marginal rate of transformation, marginal product and so on.

Our research is based on the published data and all examples are merely illustrative.

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Bank Efficiency and Liberalisation: A Case Study of Egyptian Commercial Banks

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Abstract

Financial institutions face today a fast-paced, dynamic, and competitive environment at a global scale. Within such a competitive environment, financial institutions are required to examine their performance because their survival will depend on their productive efficiencies. For the last 20 years, many countries liberalised their financial sector through deregulation in order to improve performance efficiency. Egypt, similar to other countries has undergone a number of major important policy changes in terms of bank deregulation. The country's banking sector within the financial system has been a target of heavy regulatory interventions till 1991. Deregulation covered a number of areas such as pricing on loans and deposits, exchange rates, import regulations, restrictions on foreign branches operating in local currency, and limitation on foreign equity ownership in Egyptian commercial banks. The study aims to quantify and compare the efficiency of Egyptian commercial banks pre and post liberalisation, and to identify the sources of inefficiencies using a non-parametric technique, namely, a two-stage data envelopment approach (DEA) for each year from 1988 to 2000. The two-stage DEA methodology facilitates the investigation of both production, and intermediation functions of the banks to determine the relationship of these two components to bank operations.

1. Introduction

The Egyptian banking environment changed drastically starting 1991, when Egypt introduced an extensive economic reform and structural adjustment program (ERSAP) to transform the economy from an inward-centrally planned one dominated by the public sector to an outward looking economy led by the private sector. Liberalisation and privatisation of the financial sector in general, and the banking system in particular were crucial to the intended transformation of the economy.

Egypt's move towards this transformation process of the economy was in response to the general globalisation move. Within the context of globalisation, liberalisation of financial markets worldwide has led to deeper integration of financial institutions (Ragunathan, 1999). As a result, financial institutions face today a fast-paced, dynamic, and competitive environment at a global scale. Given such competitive environment, financial sector supervisors, as well as, financial institutions themselves are required to examine their performance because their survival will depend on their productive efficiencies. Some earlier studies (Berger and Humphrey, 1991 and Berger, Hunter and Timme, 1993) demonstrated that, particularly in banking sector, inefficiencies are more important than scale and scope issues. Hence, as a result, firms have been trying to adapt and adjust themselves to improve their productive efficiencies in this changing environment (Harker and Zenios, 2000).

The Egyptian banking sector has undergone several stages in terms of deregulation. The country's banking sector within the financial system has been a target of heavy regulatory interventions till 1974. Some relaxations have been introduced since then when Egypt adopted its open door policy. However, since 1991 there has been a sharp move to liberalise the banking activity in order to improve the efficiency of its financial system.

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In fact, prior to 1974, four commercial public sector banks and four specialised banks served the banking needs of the Egyptian economy. After 1974, and following the introduction of "Open Door Policy", private local and foreign investors started establishing banks in the country. Between 1975 and 1983 a large number of local and foreign banks entered the Egyptian banking arena. Since 1983, no licenses have been issued for the establishment of new banks. There are currently 62 banks operating in Egypt under the supervision of the Central Bank of Egypt "CBE". Those are classified into three main categories: commercial banks, business and investment banks, and specialised banks.

Despite of the open door policy in 1974, the banking sector was highly regulated until the liberalisation in 1991, with evident intervention from the CBE in all aspects of banks' policies (H.C. Securities and Investment, 1999). The CBE set for the banking sector deposit and lending rates and banking services fees and charges. Exchange rate for the Egyptian pound was also set by the CBE. Not withstanding, the Egyptian financial sector was dominated by the banking system, and while liberalisation in the spirit of open door policy tended to increase the number of private and joint venture banks (private and joint ventures were 75 out of 101 bank), yet as mentioned by El Refaie (1997), the banking sector activity was dominated by the public sector banks (virtually 80% of the activities were carried out by public banks). Other financial intermediaries (such as mutual funds, finance companies, leasing companies, brokerage firms, money changers, portfolio managers, etc.) were lacking.

Starting 1991, the banking sector in Egypt has experienced vast changes due to its deregulation to be in accordance with international norms. Deregulation covered a number of areas such as interest on loans and deposits, exchange rates, credit ceilings, allowing foreign branches to operate in local currency, and allowing foreign ownership in Egyptian public sector banks. Changes included other areas such as the classification of and provisioning for non-performing loans, capital adequacy, financial reporting, and divestiture of public sector bank's interest in joint venture banks.

According to Mohieldin (2000), the reform of the banking sector during the 1990s took three forms. First, liberalisation of financial variables. The interest rate ceilings were eliminated, the required reserve ratio was modified, liquidity ratio decreased and the government lifted out the regulation-governing public sector borrowings and therefore bank credit was liberalised.

Second, applications of new prudential measures were introduced for capital adequacy and asset classification and provisioning in 1991, setting bank liquidity requirements for domestic and foreign currencies took place in 1990. Other regulatory measured followed: international concentration limits were introduced and domestic concentration limits were further strengthened consecutively in 1992 and 1993. Banks were required to produce periodic financial statements based on international accounting standards since 1997.

Third, inclusion in the privatisation program, which took the form of the privatisation of public sector shares in joint venture and private banks, which were the majority in joint venture banks. During the 1990s there was a reduction of the public sector shares in joint venture banks. In 1994, the four public banks were requested to reduce their shares in joint venture banks to less than 51%, and in early 1996 they were requested to further reduce their shares to a maximum of 20%. Moreover, majority foreign ownership was permitted in joint venture banks through Law 97of 1996. As a result, a number of foreign banks took a controlling interest in their local subsidiaries, such as Societe Generale Bank in National Societe General Bank (1996) Banque National de Paris in Banque Du Caire et De Paris (1997) and Barclays Bank in Cairo Barclays International Bank (1998).

One of the aims of privatising the public sector shares in joint venture banks is to lessen the interdependence between different banks and to improve competition in the market, Moheildin (2000). No major activity in the privatisation of joint venture banks occurred until early 1996 and despite, several divestitures of public shares in joint venture banks, privatisation of the public banks' shares in joint venture banks has not been completed. As declared in IBTCI 1996, 27 banks were subject to privatisation.

In June 1998, the parliament passed Law 155, which allows for private sector (foreign or local) participation in the ownership of the public sector banks. However, no action has been taken regarding the privatisation of any of the four public sector banks.

In the light of the liberalisation of the economy and, in particular, the deregulation of the banking sector, it is useful to assess and quantify the impact of liberalisation on the efficiency of commercial banking sector in Egypt. In order, to see whether there are any further steps that needs to be taken to enhance the banking sector efficiency. The population under study includes all locally incorporated commercial banks (excluding foreign bank branches). Our investigation covers the period from 1988 to 2000. The analysis is further broken-down in three consecutive time frames. These are identified as follows: Pre-liberalisation from 1988 to 1990; Liberalisation phase from 1991 to 1997; and Post-liberalisation, which covers the period from 1998 to 2000.

2. Research Design

The main purpose of the quasi-experimental time series study that we will adopt is to test the hypothesis that the overall level of efficiency of Egyptian commercial banks has improved following the liberalisation of the economy and the deregulation of the banking sector that took place in 1991.

Deregulation is typically undertaken to improve the performance of the industry being deregulated. If efficiency is raised, the improvement in resource allocation will benefit society and may lead to price reductions and/or service expansion for consumers if the market environment is sufficiently competitive. Given that a primary goal of deregulation has been to improve efficiency, the results have been mixed. Berger and Humphrey (1997) report that Norwegian banks experienced improved efficiency and productivity after deregulation. In contrast, banking efficiency in the U.S. was relatively unchanged by the deregulation of the early 1980s (Bauer, Berger, and Humphrey, 1993).

The population under study comprises all locally incorporated banks (excluding foreign bank branches and specialised banks)[1]. We define commercial banks as all those labelled commercial and investment banks (based on the CBE classification). This is because although investment banks are registered to function as "investment" banks, in reality they tend to perform the same tasks as those registered as "commercial" banks. Table 2.1 shows key figures of the Egyptian banking system while figure 2.2 displays the structure and market share of the various banking sector sub- groups.

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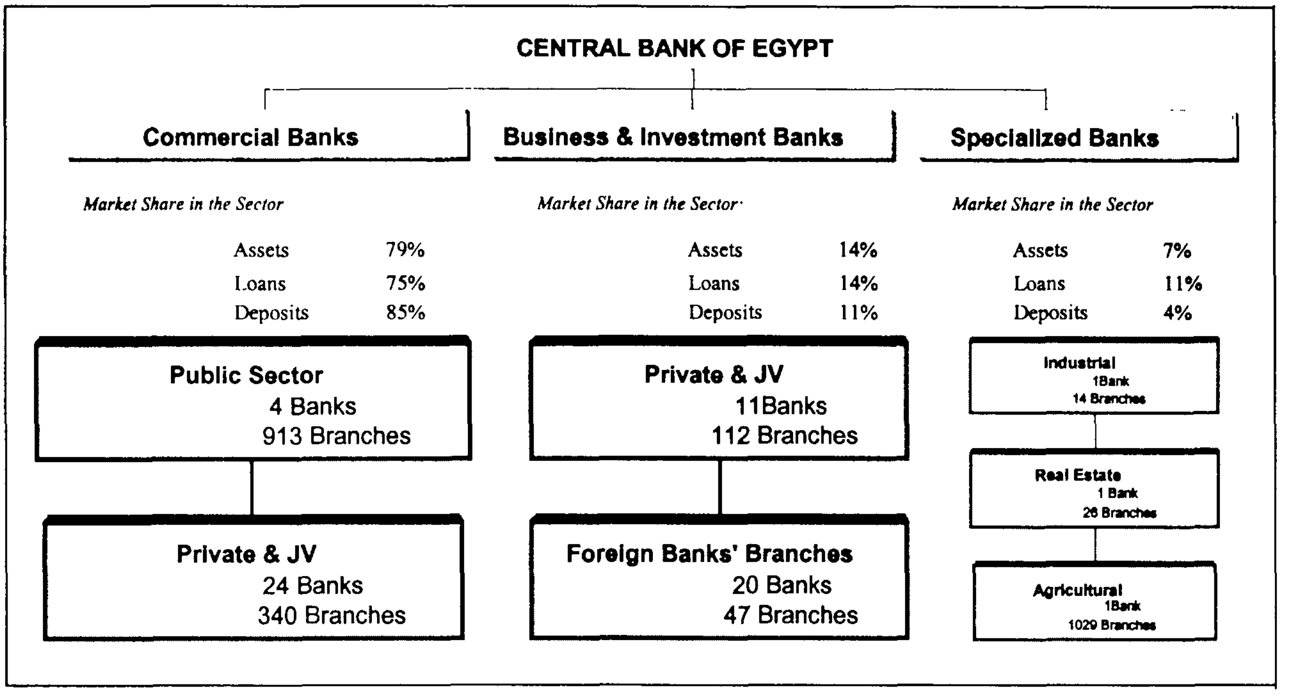
[1] Foreign Banks Branches were not included as they have their own regulations and reporting measures. Similarly, Specialized banks have not been included as they have defined functions that relates to specific activity such as agricultural credit..etc.

Table 2.1 Key Figures of the Egyptian Banking System

Key Indicators	June 2000
Total N. of Banks	62
Total N. of Branches	2481
Asset Size of the Sector (in LE million)	382,338
Total Deposits (in LE million)	260,429
Loan Book of the Sector (in LE million)	226,776

Source: CBE, Economic Review 1999/2000

Figure 2.2 Structure of the Egyptian Banking Sector and Market Shares of Sub-groups



Notes: The population under investigation market's share in the sector exceeds 75% of total banking assets, loans and deposits.
Source: CBE, Economic Review 1999/2000 and own calculations.

As displayed in figure 2.1, the population comprises a total of 39 locally incorporated commercial banks. Out of which four are public sector banks, while the remainder are private and joint venture banks. The total number of Decision Making Units (DMUs) is 39 (4 public and 35 private and joint ventures). The total number of observations is 507 (i.e. 39 DMU x 13 yrs). The use of a relatively speaking large number of observations would lead to better results. As the use of a limited number of observations close to or less than the total number of variables, would lead to a large number of efficient DMUs, and the discriminant power of the data envelopment technique would be weak.

The period of investigation is from 1988 to 2000. This time frame is subdivided according to deregulation (intervention) to three consecutive periods. Figure 2.3 portrays the three periods in light of the quasi-experimental design adopted. The time series design is considered a quasi-experiment as stated by Campbell and Stanley (1963), because there is no randomisation of test units to treatments and the timing of treatment is not within our control.

Figure 2.3 Time Series- Single Case Design

$B_1 B_2 B_3$	X X X X X X X	$A_1 A_2 A_3$
↓	↓	↓
Pre-liberalisation	liberalisation	Post-liberalisation
(1988-1990)	(1991-1997)	(1998-2000)

Notes: B refers to before intervention, X refers to intervention and A refers to post intervention.

In order to measure efficiency we will use a two-stage non-parametric mathematical programming model, Data Envelopment Analysis (DEA), for each year from 1988 to 2000 to determine whether or not the liberalisation program improved the efficiency of Egyptian commercial banks by function and by ownership. We will also identify the sources of observed inefficiencies. The two-stage DEA methodology facilitates investigation of both production and intermediation functions of the banks to determine the relationship between these two components of bank operations. This will allow us to examine the banks' efficiency in separate dimensions without one biasing the other. Although these two components are two discrete analyses, they complete a continuum in presenting a more comprehensive picture of the system. Taking a relatively long time series of data will improve the chances of identifying the long-term policy implications. It is hypothesized that after liberalisation and relaxed regulation competition will intensify and, in turn, discipline banks in resource management, forcing them to be more efficient.

One of the benefits of adopting the DEA technique is that the resulting average banking efficiency and banks rating are based on the banks included in that year. Consequently, both sector related and macroeconomic variables are considered within the group. The frontier analysis is formulated by measuring the efficiency of each bank to the whole set of banks during each year. As they operate under the same macroeconomic environment, if one bank is efficient then another bank can replicate what that bank is doing and aim to reach the same level of efficiency. In theory, lots of factors intervene and have an unquantifiable effect such as human dealings and management techniques. Yet looking at the banking sector as a whole, by identifying the overall efficiency of the banking sector through the stated periods, one can examine the impact of liberalisation on efficiency.

Furthermore, DEA has proven to be a popular technique for performance analysis in general and in the banking sector in particular. In this regard, the banking sector has a series of characteristics that make it particularly suitable for study through DEA: its multiple-input and multiple-output nature, the non-linearity of its input-output relationships, the non-physical nature of some resources and products, and the impossibility of drawing on market price mechanism for some of them.

3. Variables Selection

The choice of variables in efficiency studies affects the expected results significantly. A number of studies have presented results that differ due to variable selection (Favore and Pappi, 1995; Hunter and Timme, 1995). There are, however, certain limitations on variable selection due to reliability of the data.

Definition of commercial bank's function:

The definition of a bank's function is one of the complications in bank efficiency studies that affects variable selection and associated results. In order to provide guidelines fcr variable selection and application, it is useful to define the banking process.

The role of a commercial bank is generally defined as collecting savings of households and other agents to finance the investment needs of firms and individuals. Three approaches in the banking literature discuss the activities of banks: the production approach, the intermediation approach and the modern approach (Denizer, Dinc, and Tarimcilar, 2000). The first two approaches apply the traditional microeconomic theory of the firm to banking and differ only in the specification of banking activities. The third approach goes one step further to incorporate some specific activities of banking into the classical economic theory and thereby modifies it.

In the production approach, banking activities are described in terms of production of services to depositors and borrowers. Traditional production factors such as labour and capital are used as inputs to produce desired outputs. Although this approach recognizes the multi-product nature of banking activities, earlier studies ignored this aspect, mainly because the techniques to deal with scope and scale issues were not well developed (Denizer, Dinc, and Tarimcilar, 2000). The production approach suffers from a basic problem of measurement of outputs. Is it the number of accounts, the number of operations on these accounts, or the value amounts? The generally accepted approach is to use value amounts because of availability of such data. Yet the number of accounts and the number of operations could also be used.

The intermediation approach is complementary to the production approach. It describes banking activities as transforming the money borrowed from depositors into the money lent to borrowers. This transformation activity originates from the different characteristics of deposits and loans. Deposits are typically liquid and riskless, while loans, on the other hand, are regarded as illiquid and risky. In this approach, the deposits collected and funds borrowed from financial markets constitute inputs while outputs are measured by the volume of outstanding loans and investments.

The modern approach has the novelty of integrating risk-management and information processing with the classical theory of the firm. One of the most innovative parts of this approach is the introduction of the quality of banks' assets and the probability of banks' failure in the estimation of costs. This third approach, perhaps, can be best represented through Capital adequacy, Asset quality, and Management, Earnings and Liquidity (CAMEL) rule. Under this rule, Capital adequacy, Asset quality, Management, Earnings and Liquidity are derived from the financial tables of the bank and are used as variables in the performance analysis.

The modern approach is the best of the three, as it accounts for differences in risk, which is an integral part of banking operations. Banking can be looked at as a junction of financial functions and real activities, with risk determining the "quality" of the former and possibly affecting the quantity of the latter. For instance, extending a commercial loan to a firm with S & P – AAA rating should demand much less effort in risk evaluation and monitoring than lending to a local partnership. This approach, in addition, takes into account the off balance sheet activities, such as loan securitization and derivative contracts).

Although we acknowledge the importance of risk management aspects and that of off-balance sheet activities, the non-availability of comprehensive data, combined with the fact that the banking sector in Egypt is not highly sophisticated; and that so far derivatives are non-existent in the Egyptian case, we will restrict our discussion to the use of the first and second approaches conjunctively.

We will use both the production and intermediation approaches complementarily in the analysis of the efficiency of Egyptian commercial banks. We assume banking as a simultaneous two-stage process. During the production stage, banks collect deposits using their resources[2], labour and physical capital. Banks use their managerial and marketing skills in the intermediation stage to transform these deposits into loans and investments.

Following the above-discussed framework, three variables were selected as inputs for production stage of the banking: total own resources of the bank, total personnel expenses, and the interests and fees paid by the bank. At this stage a bank produces two outputs: total deposits and income from charges and commissions collected. The outputs of the previous stage (production stage) may be seen as inputs for the intermediation process, and hence total deposits will be input. In addition, operating expenses, excluding personnel expenses, will be the other input in this stage.

Since personnel expenses are used as an input in the previous stage in order to avoid double counting, this variable is not included into the operating expenses in the intermediation stage as an input. The outputs of this stage are total loans and banking related income (interest and commission collected, and charges and commission for banking). All input and output variables are normalized by dividing them by the number of branches.

The list of variables that we will adopt to measure efficiency employing a two stage DEA can be portrayed in table 3.1.

Table 3.1. Selected Variables for the Two-Stage Data Envelopment Approach

First Stage		**Second Stage**	
Production Stage		**Intermediation Process**	
Inputs	**Outputs**	**Inputs**	**Outputs**
x Total own resources of the bank	x Total deposits	x Total Deposits	x Total loans & banking related Income (Interest & commission collected, and charges & commission for banking)
x Total personnel expenses	x Income from Charges & commissions collected	x Operating expenditure (excluding personnel expenses)	
x Interests & fees paid by the bank			

Notes:

- All input and output variables will be normalized by dividing them by the number of branches.
- The outputs of the production stage may be seen as inputs for the intermediation process.
- In the intermediation process, personnel expenses are excluded from operating expenditures, since personnel expenses are used as an input in the production stage in order to avoid double counting.

4. Data Processing

We will use the Warwick Windows DEA software in data processing. We will solve input oriented models for both constant returns to scale (CCR) and variable returns to scale (BCC) for every year from 1988 to 2000 for commercial banks in Egypt. These models identify efficiency in two stages; the intermediate point is first obtained and then the subsequent projection point is found by solving the second stage. We adopt the same formulations used by (Denizer, A., Dinc, M., and Tarimcilar, M., 2000).

5. Methodology

The two approaches used to assess productive efficiency of an entity, parametric (or econometric) and non-parametric (mathematical programming), employ different techniques to envelop a data set with different assumptions for random noise and for the structure of the production technology. These assumptions, in fact, generate the strengths and weaknesses of both approaches. The essential differences and the sources of (dis) advantages of these approaches can be grouped under two categories:

[2] By own resources we mean equity capital.

1-The econometric approach is stochastic and attempts to distinguish the effects of noise from the effects of inefficiency; it is based on sampling theory for the interpretation of statistical results. The programming approach is non-stochastic, and hence groups noise and inefficiency together and calls this combination "inefficiency". It is built on the findings and observation of population and assesses efficiency relative to other observed units.

2-The econometric approach is parametric and confounds the effects of misspecification of functional form with inefficiency. The programming model is non-parametric and population-based and hence less prone to this type of specification error (Lovell, 1993).

We will use the non-parametric frontier approach to estimate the relative efficiency of commercial banks in Egypt. This approach, also known as Data Envelopment Analysis (DEA), is a mathematical programming technique that measures the efficiency of a decision-making unit (DMU) relative to other similar DMUs with the simple restriction that all DMUs lie on or below the efficiency frontier (Sieford and Thrall, 1990). It was first introduced by Charnes, Cooper and Rhodes in 1978. Since then its utilization and development have grown rapidly to include many banking-related applications.

This analysis is concerned with how each DMU is performing relative to others, the causes of inefficiency, and how a DMU can improve its performance to become efficient. In that sense, the focus of the methodology should be on each individual DMU rather than on the averages of the whole body of DMUs. DEA calculates the relative efficiency of each DMU in relation to all other DMUs by using the actual observed values for the inputs and outputs of each DMU. It also identifies, for inefficient DMUs, the sources and level of inefficiency for each inputs and outputs (Charnes, Cooper, Lewin and Seiford, 1994).

Basic DEA Models

DEA begins with a relatively simple fractional programming formulation. Assume that there are n DMUs to be evaluated. Each consumes different amounts of **i** inputs and produces **r** different outputs, i.e.DMUj consumes $\mathbf{x_{ij}}$ amounts of input to produce $\mathbf{y_{rj}}$ amounts of output. It is assumed that these inputs, $\mathbf{x_{ij}}$ and outputs, $\mathbf{y_{rj}}$, are non-negative, and each DMU has at least one positive input and output value. The productivity of a DMU can be written as:

$$h_j = \frac{\sum_{r=1}^{s} U_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad (1)$$

Where h refers to the efficiency, j is the DMU under study, xij are the amounts of input consumed by DMUj to produce yrj amounts of output. U and V are weights assigned to each input and output.

In this formulation, *u* and *v* are the weights assigned to each input and output. By using mathematical programming techniques, DEA optimally assigns the weights subject to respectively two constraints, namely:

1- The weights for each DMU are assigned subject to the constraint that no other DMU has an efficiency greater than 1 if it uses the same weights, implying that efficient DMUs will have a ratio value of 1.
2- The derived weights, u and v are not negative.

The objective function of DMUK is the ratio of the total weighted output divided by the total weighted input:

$$\text{Maximize } h_k = \frac{\sum_{r=1}^{s} U_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \tag{2}$$

$$\text{Subject to } \frac{\sum_{r=1}^{s} U_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad \text{for j=1..n}$$

$v_i \geq 0$ for i=1...m, and $u_r \geq 0$ for r =1...s

This is a simple presentation of basic DEA model.
According to Denizer, et. al., Charnes, Cooper and Rhodes (1978) employed the optimisation method of mathematical programming to generalize the Farrel (1957) single-output/input technical-efficiency measure to multiple-output/multiple-input case. The characteristic of the Charnes, Cooper and Rhodes (CCR) ratio model is the reduction of the multiple-output/multiple-input situation for each DMU to a single virtual output and a single virtual input ratio. This ratio provides a measure of efficiency for a given DMU, which is a function of multipliers. The objective is to find the largest sum of weighted outputs of DMUk, while keeping the sum of its weighted inputs at the unit value, thereby forcing the ratio of the weighted output to the weighted input for any DMU to be less than one. The CCR model is also known as the constant return to scale model, and it identifies inefficient units regardless of their scale size. In the CCR models, both technical and scale inefficiency are present.

Banker, Charnes and Cooper (1984) take into account the effect of returns to scale within the group of DMUs to be analysed. The purpose here is to point out the most efficient scale size for each DMU and at the same time to identify its technical efficiency. To do so, the Banker, Charnes and Cooper (BCC) model introduces another restriction, convexity, to the envelopment requirements. This model requires that the reference point on the production function for DMUk will be a convex combination of the observed efficient DMUs. The BCC model, known as variable returns to scale model, gives the technical efficiency of DMUs under investigation without any scale effect.

It is possible to use models that provide input-oriented or output-oriented projections for both CCR (constant returns to scale) and BCC (variable returns to scale) envelopment. An input-oriented model attempts to maximize the proportional decrease in input variables while remaining within the envelopment space. On the other hand, an output-oriented model maximizes the proportional increase in the output variables, while remaining within the envelopment space.

Application

We will utilize a two-stage DEA analysis. In the first stage, the relative efficiency of the production process of banking will be assessed. In the second stage the efficiency of intermediation process of banking will be examined. The underlying reason is that a bank may perform relatively better in collecting deposits by using less resources than its competitors, compensating its losses in the intermediation process or vice versa. The performance matrix shows that a bank may be in four different positions regarding its performance in the production and intermediation processes.

Figure 5.1 Performance Matrix

Efficiency	Production	Intermediation
	+	+
	+	-
	-	-
	-	+

It is obvious from the performance matrix that the most desirable position is the first row where a bank performs well in both the production and intermediation processes. However, these institutions are for-profit-entities, depending on the gains from each process, a bank may intentionally choose either the second or the fourth raw to accomplish some short-term objectives i.e. market share growth or introduction of a new financial product.

Scale Issue

Although commercial banks are homogeneous with respect to their organizational structure and objectives, they vary significantly in size and production level. Even after normalizing the data, this suggests that the scale of banks plays an important role in their relative efficiency or inefficiency. As previously stated, the CCR model comprehends both technical and scale efficiency. The BCC model, introduced by Banker, Charnes and Cooper (1984), separates technical efficiency and scale efficiency. BCC also modified the original CCR linear programming formulation by adding a convexity constraint for the production possibility set to estimate not only technical efficiency, but also returns to scale.

Banker, Charnes and Cooper (1984) showed that the CCR measure captures not only the productive inefficiency of a DMU at its actual scale size, but also any inefficiency resulting from its actual scale size being different from the most productive scale size. A most productive scale size maximizes average productivity in the long run. In order to maximize average productivity, a DMU would have to increase its scale size if increasing returns to scale were prevailing, and decrease the scale size if decreasing returns to scale were prevailing. It follows that a technically efficient and scale efficient DMU will be in the most productive scale size.

Given that the CCR efficiency score is a product of technical and scale efficiency, and BCC measures pure technical efficiency, then the ratio of the efficiency scores

$$S_k = \frac{q_k, CCR}{q_k, BCC} \tag{3}$$

Yields a measure of the relative scale efficiency of bank k. If S=1 it is said that bank k is operating at the most efficient scale size. If it is less than unity, this means there is scale inefficiency for bank k. Thus, (1-S) represents the relative scale inefficiency of a bank (Banker et al., 1984). The units that are CCR efficient will also be scale efficient, since scale was already factored in the CCR model. Thus, the two are equal. The units that are BCC efficient, but inefficient based on the CCR model, have a scale inefficiency. Since they were technically efficient, all of the inefficiencies picked by CCR are due to scale. Those units that are CCR efficient are considered most productive scale sizes, as the average productivity of each of those units is maximized.

This can serve as a useful diagnostic tool for decision makers and bank directors. Once technical and scale efficiencies are isolated, the next step is to determine the share of the overall inefficiency that is attributable to technical inefficiency and scale inefficiency.

6. Interpretation of Results

The study will report the average efficiency scores of Egyptian commercial banks by year and by model CCR versus BCC for both stages of banking process, namely production and intermediation. The scores will be presented as annual simple averages of banks under investigation for the whole Egyptian banking system. If our main hypothesis holds, i.e. if the liberalisation had a positive impact on the overall efficiency of the Egyptian commercial banking system, it is expected that the annual simple average efficiency score would increase over time.

Where there are major year-to-year fluctuations in the results, we will try to eliminate the effect of shocks to the system by comparing normal years pre and post liberalisations. The results obtained will be related to the overall macroeconomic environment and the ownership of banks.

Average efficiency scores by ownership

As the responses for the partial liberalisation may differ across banks depending on the ownership structure, we will report the average efficiency scores by ownership.

Percentage of efficient banks

The decline/ increase in efficiency scores may be due to a few very inefficient/efficient banks rather than an overall trend. We will calculate the percentage of efficient banks to analyse this hypothesis.

Sources of inefficiency

In case of inefficiency, we will analyse its sources (i.e. whether it is due to an excess use of resources, output shortfalls, or some combination of the two).

Once we obtained the results of our main model (DEA) and conducted basic data analysis, we can further examine and verify our results by examining the correlation between efficiency and its various potentially influential variables. Potential influential variables include size as proxied by total assets and/or deposits, total non-performing loans as proxied by non-performing loans provision, ownership structure (private versus public) and time. We will construct a correlation matrix of all the influential variables and then test their significance at both 5% and 1% levels to reach substantive conclusions. We will use Pearson's r in testing for correlation. Pearson's r measures how much of one time changes in one variable correspond with equivalent changes in the other variables. It can also be used as a measure of association between an ordinal variable and an interval or between an interval and a dummy variable. Once we obtain the correlation results, we can further test the significance of the hypothesized relationship between efficiency and its various potentially influential variables through the use of regression analysis. We will run a multiple regression model in which the dependent variable is the efficiency score and the independent variables are potential proxies (e.g a potential proxy for size could be reflected by total assets or deposits). We will test the significance of our results at both 5% and 1% significance levels.

Moreover, we can examine the relation between efficiency scores obtained and other performance indicators that are widely used in the banking industry such as Return on Equity (ROE) and Return on Assets (ROA), which are among the most accepted performance indicators in banking, whereas these indicators seem to be unrelated with operational efficiency as operational efficiency does not guarantee profitability.

7. Limitations

On the basis of careful examination of the data that we will gather and while measuring efficiency, we might be faced with problems regarding the quality of data, which would negatively impact the robustness of results. The methodology we use assumes that the input-output variables of the firms are measured accurately and in addition give a good representation of the complete production process. In practice, data are almost contaminated by errors in variables. Since efficiency analysis relies on comparisons with extreme observations, the results are extremely sensitive to errors. A single outlier can substantially affect the outcomes for the entire sample.

In order to minimize such error, we preferred to take the whole commercial banking population. The use of a relatively speaking large number of observations (39 x 13) would lead to better results. As the use of a limited number of observations close to or less than the total number of variables, would lead to a large number of efficient DMUs, and the descriminant power of the model would be weak.

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Productivity Differences Across OECD Countries In The Presence Of Environmental Constraints

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Abstract

The purpose of this paper is to perform a computational analysis of the tradeoffs between a good output and the CO_2 emissions or bad output, often created as a by-product of the production process. One considers the strategy of minimising the pollution level produced for the generation of a given good-output level. Another seeks the maximum good-output production for a set bad-output level. A mixed strategy looks for simultaneous increases in the good output and decreases in CO_2 emissions. A final option ignores the pollution issue altogether and concentrates on optimising the efficiency of the production of the good output.

1. Introduction

Bad or undesirable outputs, such as CO_2 emissions, represent an unavoidable part of most production technologies used for the generation of good or desirable outputs. Curtailing the production of a bad output is not costless. Its elimination requires a decrease in the production of good outputs and/or an additional resource commitment to pay pollution fines. Estimating the productive efficiency costs of CO_2 abatement programs is also hampered by the lack of price information related to bad outputs and by differences in emission standards worldwide and across the various sectors of the economy. A way around this problem is to develop tradeoffs between the jointly produced outputs so as to determine the maximum production of good outputs with the minimum production of undesirable components. In this way, tradeoffs are represented strictly in the form of unit exchanges among the various outputs. It is the purpose of this paper to model the computations of these tradeoffs, in order to provide estimates of productive efficiency losses incurred by OECD countries due to the regulation of CO_2 emissions.

To that effect, section 2 of the present paper considers a non-price-based alternative to the problem of the computation of the tradeoffs between good and bad outputs. It describes the characteristics of a production process, built upon the distance-function concept and uses Data Envelopment Analysis (DEA) methodology (Cooper, Seiford & Tone 2000). The model combines the approaches developed in Chung, Färe & Grosskopf (1997), Färe & Grosskopf (1998) and Färe et.al. (1993). The basic feature is the asymmetric treatment of the inputs and the outputs, on the basis of whether they are labelled as good or bad. Section 3 uses a simple example to introduce possible scenarios that will characterize the interaction between the two outputs. The resulting methodology is then applied in section 4 to analyse the data collected for a set of 14 OECD countries. Some concluding comments complete the paper. The primary advantage of using DEA over that of its traditional production-function counterpart lies in that the modelling of the relationship between the inputs and outputs does not require the assignment of predetermined weights, based upon a single optimised mean-performance index. Rather, these weights vary with each observation and the determination of the

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magnitude of those weights forms an integral part of the efficiency measurement process. With this approach, the productive efficiency of a decision-making unit or DMU can simultaneously increase with a rise in the generation of the good output and decrease with the production of higher levels of bad outputs. It is also possible to construct the production frontier composed of benchmarking countries and to estimate the changes in the production of the good and bad outputs that non-efficient countries need to reach the efficient frontier. Lastly, the approach allows for the estimation of the decrease in efficiency associated with the fact that the bad output is not freely disposable and thus not costless.

2. Characteristics of the Production Process

This section describes the characteristics of a production process, whose main feature is the asymmetric treatment of the link between the production of a desired or good output and the level of pollution or bad output that is necessarily created as a by-product of the process itself. The starting point of the analysis is the construction of the efficient production frontier, formed by the "best practice" benchmarking countries. For this purpose, the DEA formulation of the paper includes a set of *c* decision-making units (DMUs) or countries. Each consumes x_1 and x_2 units of L and K, respectively, for the production of *g* units of the good output, jointly with *b* units of the bad output, as a by-product. This feature of the relationship between the two outputs, *b* and *g*, implies that a production level of zero units of *b* would of necessity be associated with zero units of *g*, whereas the opposite is not necessarily so. For a fixed level of inputs, each DMU would like to produce as many units of *g* as possible, while simultaneously generating the fewest possible number of units of *b* as feasible. The best practice or reference technology of the production process is defined through the Output Possibility Set, which includes the set of all possible outputs that can be produced with a given level of inputs.

In addition, the production process possesses three characteristics of interest, related to the concepts of efficiency, disposability of outputs and scale of operations (Coelli, Rao & Battese, 2000; Fāre, Grosskopf & Lovell, 1994). The efficiency of each DMU is measured relative to the best practice frontier, on the basis of the Pareto-Koopmans efficiency concept of economics. "A DMU is said to be fully efficient, if and only if it is not possible to improve any input or output without worsening some other input or output (Cooper, Seiford & Tone 2000, p. 45). The second characteristic of the production process relates to output disposability. Reducing the bad output is costly, in that it requires additional inputs and/or a decrease in the production of the good output and/or extra resources to pay the fines. Further, reducing the production of the good output does not necessarily lead to reduction of the level of CO_2 produced. Under these conditions, the production process is said to exhibit weak disposability of the bad output and strong disposability of the good output. In addition, weak (strong) disposability of outputs, *W* (*S*), indicates the presence (absence) of congestion, another source of production inefficiency. "Evidence of congestion is present when reductions in one or more inputs can be associated with increases in one or more outputs - or, proceeding in reverse, when increases in one or more inputs can be associated with decreases in one or more outputs - without worsening any other input or output." (Cooper, Seiford & Tone 2000, p.2]. Congestion represents a measure of the potential success or failure of CO_2 abatement programs. If there is no congestion in the generation of the bad output, it is freely disposable. That is to say, the good in question is costless and regulation is ineffective. Another characteristic of the production process is the scale of the operations of the reference technology. It is defined as the change in output generated by a given change in inputs. Constant (variable) returns to scale, *CRS* (*VRS*), are said to occur when inputs and outputs change in value at the same (a different) rate. On the basis of the evidence presented in (Arcelus & Arocena, 2000), this paper only considers the less restrictive VRS technology.

3. Analysis of the Results for the Fourteen OECD Countries

This section describes the nature of the data collected and evaluates the evidence obtained from 14 OECD countries, subject of this study. The study uses two OECD databases. The first is the International Sectoral Database (ISBD, 1999). Its compilation is part of the OECD's ongoing project to study the industrial structure and economic performance of its members. The database covers 14 "Annex I" countries of the Kyoto Protocol, namely Austria, Belgium, Canada, Denmark, Finland, France, Germany, Great Britain, Italy, Japan, Netherlands, Norway, Sweden and USA. Data are not yet available in the desired detail for the other countries. Details from an earlier but still valid version of this database appear in Meyer-zu-Schlochtern & Meyer-zu-Schlochtern (1994). From there we extract three standard variables in a production function. The inputs are labour and capital, denoted by L and K, respectively. The number of employees and the gross capital stock (1990 prices and PPPs, US$ equivalents) are the measures of L and K, respectively. The good output is the value added, VA, measured by the gross domestic product (1990 prices and PPPs, US$ equivalents). The second database is IEA (2000), from which we can obtain the undesirable output, i.e. the CO_2 emissions from fuel combustion, measured in millions of tons emitted. The economic sector selected is the "all industries", in order to obtain the main economic agents that are, at the same time, CO_2 producers.

Simple descriptive statistics for the inputs, L and K, the outputs, VA and CO_2 highlight the overwhelming scale dominance of the USA, in terms of input usage and in the generation of both good and bad outputs. Japan, Germany follows this from very far. However, on the all-important productivity of good output per ton of CO_2, USA and Germany, along with Canada and Australia rank at the bottom of the list and Italy, Japan, Norway, Sweden and France at the top. From one decade to the next, there was approximately a 30% improvement in this measure, going on average from $9.90 to 12.68 per ton of CO_2. The highest % changes correspond to France (75.43%), Japan (46.45%), Belgium (44.76%) and he U.K. (38.83%). The lowest are associated with Australia (4.71%), Denmark (5.91%) and Netherlands (9.47%). As for the partial labour productivities, both value added and capital also experienced important increases. This is especially true of K/L, which increased in value an average of 31.50% (167/127-1), with VA/L, a more modest 23.33% increase. Alternatively, VA/K decreased on average 7.5%. Only Norway experienced a slight increase of 2.9%.

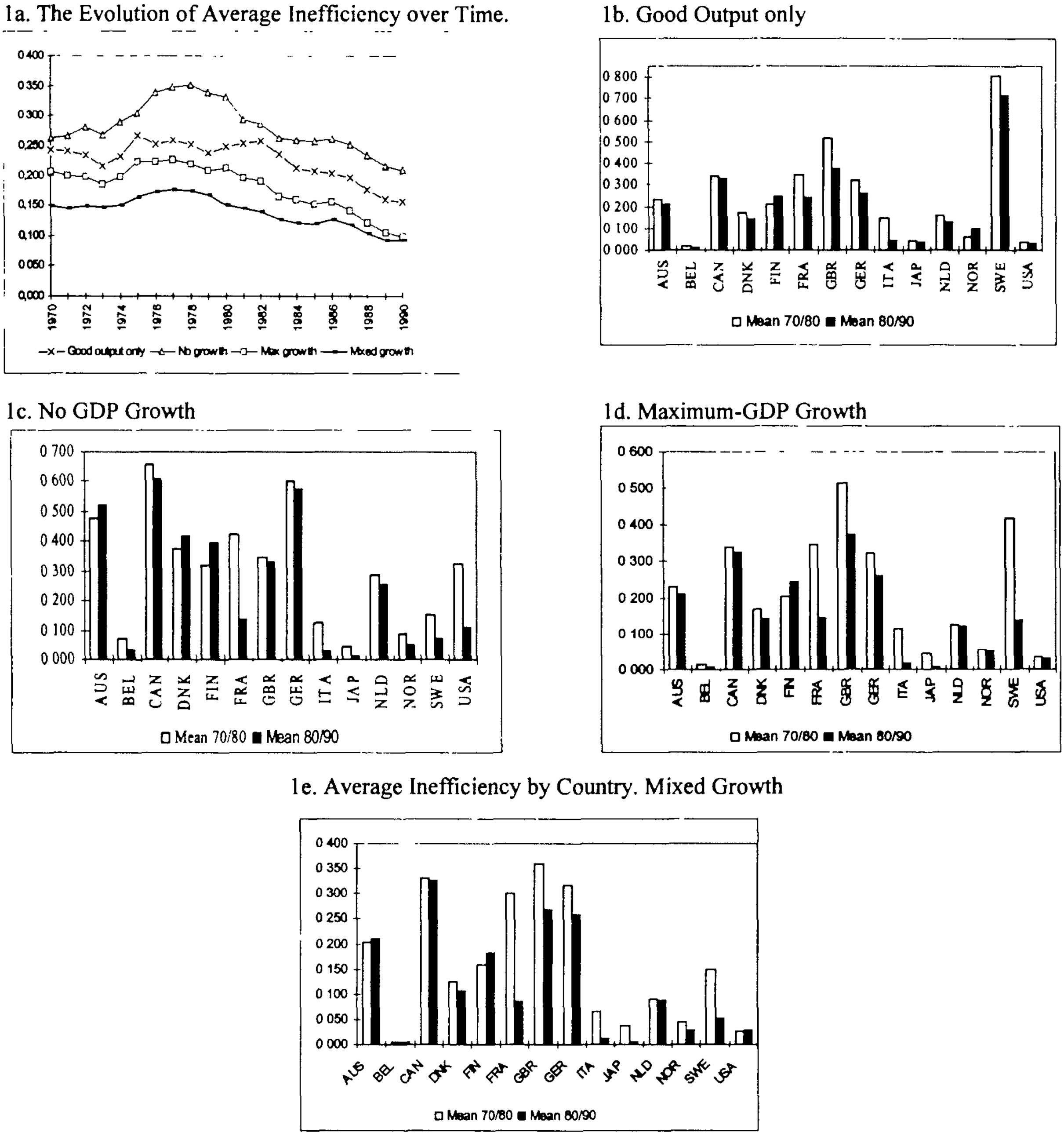
This analysis of the efficiency results for the 14 OECD countries subject of the present study is based on four DEA formulations. They represent the No-GDP Growth, the Maximum-GDP Growth, the Mixed Growth and the Good-Output-Only strategies. The basic information is presented in terms of inefficiencies, i.e. in terms of how far each observation is from the efficient frontier. The efficiency indexes are computed on the basis of an intertemporal reference frontier (Tulkens & Vanden Eeckaut, 1995). It includes the 294 observations of the 14-country, 21-year panel data set used in this study. This approach is analogous to assuming a cross-country study with 294 observations. Further, each country is compared against the performance of same-year observations from other countries and against equivalent observations of the same country across the years. The end result is a stable reference frontier, which permits the identification of the time and/or country factors that can account for efficiency differences. An example of the use of the intertemporal frontiers for efficiency analysis appears in Arcelus & Arocena (2000). Figure 1 depicts graphically summary results in the form of the average country inefficiencies for the periods 1970-1980 and 1980-1990 and the average yearly inefficiencies for the 14 countries combined.

Even a cursory look at the data suggests the following observations. First, the evidence on productive efficiency clearly illustrates the pernicious effects of CO_2. Only the modicum of control over emissions envisioned in the Mixed-Growth Strategy yields a more efficient system than the maximum-output policy of the Good-Output-only Strategy. The joint production effect appears to have an adverse effect on the marginal rate of substitution between the two outputs. Further, as expected, the other two are more inefficient, with the No-GDP-Growth Strategy, as the least desirable option. Second, production appears to be getting "cleaner" with time. With very few exceptions, notably Finland and Australia, the average inefficiency indexes were lower in the decade of the 80's than their counterparts of the 70's. Some countries, especially Sweden and France, experienced a substantial increase in efficiency. This statement should be tempered with the observation that these technological advances may generate other types of bad outputs. For example, switches to nuclear power consumption may cause increases in the production of other bad outputs. Third, there seems to be wide variability in the degree of productive efficiency across countries and that variability does not seem to decrease with time. The changes in the coefficients of variations from one decade to the next do not move in the same direction for all countries. This indicates different degrees of success or failure in the different CO_2 abatement programs. Further, the coefficient of variation for 1990 is at its highest point of the two decades under study. Altogether, these changes in variability reflect a potential two-way split among the 14 countries, in terms of the degree of success in their abatement programs. By 1990, half (Belgium, France, Italy, Japan, Norway, Sweden and USA) are efficient and the other half is still quite far from reaching that goal.

Fourth, a comparison of the No-GDP-Growth versus the Maximum-GDP-Growth results provides an indication of the type of strategy each country has favored throughout the years. Even though no country follows a fully coordinated policy among its economic agents for the control of CO_2 emissions, it is possible to assess the final results by comparing them to those achievable had the strategies described in this paper been followed in their entirely. Australia, Great Britain and Germany appear to have followed a Maximum GDP-Growth Strategy. Evidence to that effect includes the observations that (i) their No-GDP-Growth inefficiencies have remained relatively high and constant throughout the years; and that (ii) their Maximum GDP-Growth inefficiencies have decreased substantially. Finland and Italy seem to have followed a similar strategy, even though their No-GDP-Growth inefficiencies were almost non-existent. Canada and Denmark do not exhibit any consistent pattern either way. Their inefficiencies for either strategy are quite high. The rest of the countries, except for the USA, seem to have followed a mixed strategy in moving towards the efficient frontier. Further, these countries experienced a clear downturn in inefficiency from the late 70's and early 80's.on. A testable explanation for this behavior may be found in the energy crisis and the economy downturn of the era. Finally, the case of the USA is different. It shows evidence of efficiency all throughout the period under consideration in terms of GDP Growth and of substantial improvement in pollution control.

This paper has endeavored to carry out a computational analysis of the tradeoffs between a good output and the CO_2 emissions or bad output that is often created as a by-product of the production process. The efficiency of this process is computed through a series of DEA formulations, related to the two outputs. One considers the strategy of minimising the pollution level produced for the generation of a given good-output level. Another seeks the maximum good-output production for a set bad-output level. A mixed strategy looks for simultaneous increases in the good output and decreases in CO_2 emissions. A final option ignores the pollution issue altogether and concentrates on optimising the efficiency of the production of the good output. The empirical analysis illustrates the feasibility of achieving productivity growth and pollution decreases. It also identifies country trends in the production of good and bad outputs of 14 OECD countries that resemble quite closely the strategies described in the paper.

FIGURE 1. Average Inefficiency by Years and Countries



Finally, with respect to the Kyoto controversy, Table 1 presents some simple statistics as to the actual and estimated emissions, as well as the quantitative CO_2-reduction guidelines from Annex B of the Kyoto Agreement, for the 14 countries considered in this study. It becomes quite clear that the inefficient countries for the No-GDP-Growth strategy do not require technical change to lower their CO_2 emission levels. Thus, for these countries, growth and decreases in pollution are quite feasible. For the others, technical change is required, even if the level of compliance is quite high in all cases. The totals at the end of Table 1 also provide suggestive hints as to possible negotiation strategies for the various countries in their effort to reach a pollution control agreement. Our model estimates that even a mixed-growth strategy leads quite closely to the desired Kyoto limitations. This is true, even if only non-efficient countries attempt to control further their emissions. The modeling of the costs and of the tradeoffs needed to reach these objectives falls outside the scope of this paper and justifies additional research.

TABLE 1. Actual and estimated CO_2 emissions (Mt)

	Actual CO_2 emissions (IEA, 2000)		Estimated CO_2 emissions			
			No GDP Growth	Mixed Growth	Kyoto protocol emissions limitations	
	1990	**1997**	**1990**	**1990**	**%** *	**Mt** **
Australia	253	295	119	202	1,08	273
Belgium	88	95	88	88	0,92	81
Canada	388	445	162	259	0,94	365
Denmark	45	55	29	39	0,92	42
Finland	48	56	29	41	0,92	45
France	297	307	297	297	0,92	273
Great Britain	474	428	327	369	0,92	436
Germany	825	727	401	679	0,92	759
Italy	332	348	332	332	0,92	306
Japan	955	1051	955	955	0,94	897
Netherlands	129	146	100	119	0,92	119
Norway	27	34	27	27	1,01	27
Sweden	46	48	46	46	0,92	42
USA	4483	5038	4483	4483	0,93	4169
Total	8390	9072	7395	7936	(0.93)	7834

* From Annex B of the Kyoto Protocol
** Actual 1990 emissions times % Kyoto limitations

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Efficiency evaluation in the Urban Solid Waste Systems of Portugal using Data Envelopment Analysis

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Abstract

The present work evaluates the efficiency of collection, separation, valorisation and treatment of urban solid waste in the Urban Solid Waste Systems of Portugal by applying an econometric non-parametric technique: technical efficiency and cost minimisation of input needs were reached by the application of Data Envelopment Analysis. The data was obtained by requesting financial information for the year 2000. The sample covered almost 40% of the total population. This research aims to make a contribution to the evaluation of efficiency in the Urban Solid Waste Systems of Portugal.

Keywords: Urban Solid Waste, Data Envelopment Analysis, efficiency analysis

1. Introduction

Citizens make more demands on economy, efficiency and effectiveness in the management of public resources; so, it is the State's concern to establish measuring systems that facilitate the evaluation of the rationality and the results of management decisions, which are mainly related to restrictions of a budgetary nature or changes in legislation.

The evaluation of organisations that offer services of a public nature is a difficult task to carry out, as firstly, they pursue multiple objectives, which are sometimes ambiguous and contradictory, and secondly, there is the difficulty in measuring their outputs in quantitative terms. Those aspects make it difficult to choose indicators, which can offer an adjusted vision of the activity and performance of those organisations, instead of the use of profit as a measure, as happens in private companies.

The present work tries to evaluate efficiency in Urban Solid Waste Systems (collection, separation, valorisation and treatment services of Urban Solid Waste - USW), being motivated by the non-existence of empirical evidence regarding management performance in the sector, and trying in this way to identify efficient and inefficient USW Systems, besides the establishment of a relative order of merit.

The efficiency evaluation will be done using the Data Envelopment Analysis (DEA) method that enables the establishment of a relative efficiency indicator when comparing homogeneous Decision Making Units (DMU) that are characterised by the non-existence of previous suppositions regarding a production function and that obtain multiple outputs due to the contribution of multiple inputs.

Over the last two decades diverse studies have been published on the use of DEA in the public sector, mainly in the sectors of health, education, transport and local public services and more recently in the private sector as can be observed in the extensive bibliographical summary of articles, working papers and thesis carried out by Emrouznejad and Thanassoulis (1996). In particular, Ancarani (2000) applied the model to the water supply and residual water collection services in Sicily (Italy) and Prior et al (1993) have applied it in the evaluation of management efficiency in the urban solid waste collection services in a sample of municipalities in Catalonia (Spain).

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This paper has been structured in the following way: in the second section the Urban Solid Waste sector is characterised. The following point (section 3) describes the Data Envelopment Analysis method. In section 4, the methodology used is presented, proceeding to the determination of the characteristics of the sample, and, in the following section, the main results are presented. Finally, conclusions and references are presented.

2. The Systems of Urban Solid Waste in Portugal

In 1995, Urban Solid Waste (USW) management in Portugal related almost solely to garbage collection and deposit without differentiation, in the more than 300 non-controlled drains, making up the existing municipal systems (INR, 1999). Following Directive 94/62/CE of the European Commission, which imposed goals related to waste valorisation, and Directive 1991/31/CE, related to the norms of drain management, the reform process of USW management started, leading to the Strategic Plan of Urban Solid Waste (SPUSW).

The main objectives of the Plan's first phase, such as the closing of non-controlled drains and provision of USW management infrastructures, have already been reached. In the second phase, it is sought to optimise management of the existing systems through technical and legislative measures, in order to implement a model that assures the quality of the service and self-sustain the systems in the long term, in economic-financial terms.

That strategy presumes the rationalisation and optimisation of the available resources through the introduction of integrated management procedures, the creation of USW analysis methodologies and the establishment of performance indicators, which facilitate efficiency and effectiveness in performance and the evaluation of management results.

Urban Solid Waste management as an economic activity is not accessible to private companies or other entities of the same nature, except under concession and managed through USW Systems. At the present time, exploitation and management of USW Systems, in terms of Act nº 379/93, of November 5, concerns:

- Multimunicipal Systems (MS) are characterised by their strategic nature and for investment rely predominantly on the State due to reasons of national interest. In general, their management and exploitation is made by concession to a company whose capital is distributed in 51% of a State holding and the remainder to all the municipalities of the System's affected area;
- Municipal Systems (MS) which make up all the others, whose management and exploitation can be made by the municipalities or municipality associations or attributed, by concession, to public or private companies of an entrepreneurial nature. When the company owner of the System is an association of municipalities, whatever its management model, we call it, Intermunicipal System (IS).

3. The Data Envelopment Analysis (DEA) Method

The use of primary indicators and performance or productivity ratios in the evaluation of USW Systems presents some limitations. Besides giving an incomplete picture of the companies' activity, resulting in aggregation problems, they hinder the clarification of the real explanatory factors of efficiency and especially of inefficiency.

However, bearing in mind the difficulty in determining and valuing the output and the lack of knowledge of each input participation level in obtaining the observed activity levels, it is impossible to determine a production function and consequently, to use deterministic models in efficiency measurement (Norman and Stoker, 1991). Consequently, the existence of other indicator categories of a synthetic nature that summarise a series of data regarding the multiple dimensions of the same output, elaborated from functional relationship or economical models (Pina Martinez and Torres Pradas, 1999) will allow an integral visualisation of the companies.

The Data Envelopment Analysis (DEA) method of Charnes, Cooper and Rhodes (1978), later referred to as CCR, based on studies of Farell in 1957, has tried to summarize, in relative terms, the global efficiency of the activities developed by non-profit units (Decision Making Units - DMU) using a numeric indicator that includes, besides the internal aspects, environmental variables outside its control which affect efficiency.

The DEA is framed in the set of the non parametric frontier production function models, which are particularly useful in evaluating public service activities, by building an efficient frontier starting from empirical observations, avoiding "the necessity to establish ponderability a priori and making previous presumptions on the form of the production function" (Prior et al.: 1993, 276). In the initial formulation of the problem CCR (1978) each segment of the efficiency frontier presumed that the average and marginal productivity are the same (constant returns to scale) (1).

The DEA methodology synthesises the group of efficient DMUs in a lineal production frontier; the efficient DMUs define a production limit that, in an economic sense, represent the maximum output that some DMUs can obtain from the combinations of their current input levels, or the minimum level of necessary inputs to maintain an established level of services (SDC, 1995).

The determination of relative efficiency indicators in the DEA formulation problem presumes the application of fractional lineal programming techniques that consist of maximising the efficiency ratio of each evaluated DMU that is characterised by the use of multiple inputs, independent of arbitrary ponderation, in obtaining or producing multiple outputs. Either the inputs or the outputs can adopt a great variety of forms and be expressed in any unit of measure, as long as they maintain their homogeneity in all the DMUs, that is to say, they should present common characteristics to be comparable.

The solution of the problem leads to a relative order of efficiency among the evaluated units, ensuring the highest valuation possible to each DMU, which does not mean that the DMU with the best classification has obtained its maximum possibilities, but rather those that are under can improve their level. This means that the optimal DMU requires less input to obtain the same output or, with the same input, obtains more output. That order only remains while the elected DMUs, the elected input and output variables and respective assumed values are constant, which presumes that this DEA generates optimal DMUs in those conditions; a change in one of these, presumes a change in the relative order produced.

For Pina Martínez and Torres Pradas (1995) the information facilitated by the DEA presents 4 components:

- the relative efficiency indicator, that is to say, a total productivity ratio of the factors which compares the productive activity of each evaluated DMU with the other technologically homogeneous ones (Lozano Chavarría and Mancebón Torrubia, 1999);
- the range that indicates the quantities of input and output to diminish and to increase respectively to make each evaluated DMU efficient, that is to say, the excess of consumed resources or the insufficient output production which is determined by subtracting the current values of inputs/outputs of the DMU from the ideal values of the optimal DMU (Al-Shammari, 1999);
- the DMUs that are taken as a reference point;

- the coefficients that point out the importance of each indicator in the determination of efficiency.

Therefore, the model facilitates information on "the input and output levels that could be reached in an efficient situation and the services level that could be made if they decreased the available resources, or contrarily, the resources that would be necessary to assist to an increment in the demand" (Pina Martínez and Torres Pradas: 1995, 184). The DEA is in this way a benchmarking technique that is gaining importance due to the possibility that it offers establish improvements in the inputs consumption or outputs production (Soteriou and Stavrinides, 2000) and in consequence in efficiency by the improvement in organisations' productivity indicators.

The initial formulation of the problem that presents a more direct relationship with the ratio analysis is

$$Máx h_0 = \frac{\sum_{r=1}^{s} u_{r0} y_{r0}}{\sum_{i=1}^{m} v_{i0} x_{i0}}$$

$$\text{s. a. } \frac{\sum_{r=1}^{s} u_{r0} y_{rj}}{\sum_{i=1}^{m} v_{i0} x_{ij}} \leq 1$$

$$j = 1, ..., n \qquad u_{r0} \geq 0, r = 1, ..., s \qquad v_{i0} \geq 0, i = 1, ..., m$$

The unit whose efficiency is to be evaluated is denoted by the subindex 0; y_{rj} and x_{ij} represent, respectively, the quantities of output *r* and of input *i* of the DMU *j*; y_{r0} and x_{i0} represent the values of the DMU that we evaluate; and finally u_{r0} and v_{i0} reflect, respectively, the ponderability coefficients attributed to the output *r* and to the input *i* corresponding to the DMU whose efficiency is sought to evaluate. The value of h_0 indicates the pondered relation between the inputs and outputs of the efficient units and that employed by the evaluated unit.

When the estimated efficiency of a DMU is inferior to one it means that it is inefficient in relation to the subset of units, which it is compared with and constitutes its reference set (Prior et al., 1993). The optimal values u^*_{ro} e v^*_{io} obtained from the solution of the problem provide the evaluated unit with the highest possible estimate of efficiency (h_0) that can vary for each evaluated DMU. The set of values u^*_{ro} e v^*_{io} constitute the coefficients of the unitary isoquant segments in which the distinct units are situated, and their relation indicates the marginal productivity of the inputs of each DMU or DMUs located in the same segment.

It is important to observe that the organisation whose efficiency is sought to determine appears as much in the objective function as in the restrictions, always guaranteeing the existence of a solution for the fractional problem with a value for the objective function between 0 and 1 (Lozano Chavarría and Mancebón Torrubia, 1999).
As CCR have demonstrated, the initial problem can be linearized

$$Máx h_0 = \sum_{r=1}^{s} u_{r0} y_{r0}$$

s. a. $\sum_{r=1}^{s} u_{r0} y_{rj} - \sum_{i=1}^{m} v_{i0} x_{ij} \leq 0$

j = 1, ..., n $\quad \sum_{i=1}^{m} v_{i0} x_{i0} \geq 1 \quad u_{r0} \geq 0$, r = 1, ..., s $\quad u_{r0} \geq 0$, r = 1, ..., s

The dual problem offers a lineal approach to the optimal production function, by the minimisation of the *m* input quantities for the given production levels of the *s* outputs.

4. Methodology and Characteristic of the Sample

The operation of the USW sector in Portugal is carried out by 14 Multimunicipal Systems (MS) that are characterised by having organisational structures of identical operation, in spite of having different dimensions and consequently different infrastructures, by 16 Intermunicipal Systems (IS) property of the Associations of Municipalities and one Municipal System.

The MS are located mainly on the coast and in regions with greater population density, while the IS are located mainly in the interior and in the south, mainly in the regions with lower population density. The management and exploitation of the IS, in most cases, is in the hands of private companies, depending on concession or provision of services contracts and on the management and exploitation model adopted by the owner.

Although all the USW Systems are legally constituted, the management infrastructures are not completely implanted, that is to say, some work in an appropriate and full way, others work partially, and the remainder are in the phase of infrastructure construction.

Concerning the procedure used in obtaining data, the annual accounts were asked for from the Multimunicipal Systems concessionaire companies' managers through the State holding, from the Associations of Municipalities and from the concessionaire or service provider companies that manage them under contract.

As for the concessionaire companies who manage Multimunicipal Systems, the balance sheet and the profit and loss sheet of the year 2000 was obtained, organised according to the accounting system for the private sector (Accounting Official Plan).

In relation to information from management organisations that run the Intermunicipal Systems, acquiring data presented some difficulties, mainly due to its confidential character.

Concerning the characteristics of the collected USW, the information was obtained from the available data in the Waste Institute.

The initial sample of USW Systems was characterised like this:

Table 1 – Initial sample of Urban Solid Waste management Systems

System	Nº	%	Sample	%	% of the group
Multimunicipal	14	45,2	10	62,5	71,4
Intermunicipal	16	51,6	6	37,5	37,5
Municipal	1	3,2	0	–	–
Total	31	100,0	16	100,0	51,6

Source: Own elaboration

Answers from companies that manage MS were obtained through the holding company, concerning 62,5% of the universe. With relation to the 4 companies that have not responded, 3 of them were formed at the end of 2000 and at the beginning of 2001. With relation to the IS, for the reasons already mentioned, the rate of response was less.

It should be mentioned that the financial data obtained from the companies that run the Intermunicipal Systems presents several limitations. Concerning the Systems managed by the Municipalities' Associations, these have their accounting organised according to public accounting rules, making their records on a cash basis (receipts and expenses), which limits the possibility of establishing comparisons with respect to the activity costs. As for the Intermunicipal Systems managed under concession or a provision of services contract, each Municipal Association possesses its own management model for the USW System, implying the existence of different contract modalities and different types of service given by the companies involved, resulting in different cost structures.

In addition, although the companies have their accounting organised according to the rules of managerial accounting, their economic-financial states may not reflect exclusively the aspects of the System's management, nor the personnel employed by them, for which it was necessary to obtain these data by asking those responsible directly.

The selection of the final group of Systems to analyse was made according solely to the availability and reliability of the information. Therefore, keeping in mind the lack of consistency and homogeneity of the data, 3 IS and one MS, which was in the phase of infrastructure construction, were eliminated. The sample to consider and which constitutes the database for the application of the DEA is the following.

Table 2 – Final Sample of Urban Solid Waste management Systems

System	N°	%	Sample	%	% of the group
Multimunicipal	14	45,2	9	75,0	64,3
Intermunicipal	16	51,6	3	25,0	18,8
Municipal	1	3,2	0	–	–
Total	31	100,0	12	100,0	38,7

Source: Own elaboration

As can be observed, the data concern almost two thirds of the universe of Multimunicipal Systems and 19% of Intermunicipal Systems, corresponding to 38,7% of the total existing USW Systems in Portugal.

5. Analyses and Discussion of the Results

The implementation of the DEA method begins by establishing the most representative indicator group of the productive and the activity factors that best define the basic objectives and the performance of the USW Systems, as Prior et al (1993) referred to, although for Pina Martínez and Torres Pradas (1999, 182) "the results show that, habitually, a reduced number of indicators is enough to explain the behaviour of the evaluated units", so the less outstanding ones should be eliminated.

Regarding the inputs the following indicators were chosen:

- current costs of the service, that is to say, operational costs and financial costs (in euros);
- personnel costs (in euros);
- number of USW Systems employees, which, in spite of also being a variable, is a non financial indicator.

In relation to outputs, the indicators are the following:

- total USW production in the area attached to each System (in tons);
- quantity of selective collection, that is to say, waste collected separately for later recycling (in tons);
- USW Systems' beneficiaries, or in other words, the number of people resident in its geographical area.

The selection of the variables was kept as in Prior's et al (1993) study, who chose the beneficiaries of the service and the USW production as outputs and the cost of the service and the employed personnel in relation to the inputs, as this was found to be appropriate to our study.

In this work, we have added only two more variables, one of input and another of output for two reasons. Firstly, the limitation of the data obtained concerning availability, comparability and reliability. Secondly, for the DEA to operate more powerfully, the number of DMUs needs to be at least double the sum of the input and output variables (Drake and Howcroft, 1994) or even triple as Stern et al (1994) refer to, mentioned in Avkiran (1999). However, Avkiran (1999) considers that the DEA, to discriminate effectively between efficient and inefficient DMUs, hardly needs the sample to be superior to the product of the variable input by the variable output, that is, the ratio $\frac{N^{o}\,DMU's}{N^{o}\,inputs * N^{o}\,outputs}$ should be superior to the unit. In this study, the ratio assumes a minimum of 1,33 and a maximum of 3,00 meeting the requirement established by the author.

In aggregated terms, we have chosen a series of 6 DEA models, defined from different combinations of input and output indicators, through which efficiency is evaluated.

Table 3 – DEA Models applied in the USW Systems

		DEA 1	DEA 2	DEA 3	DEA 4	DEA 5	DEA 6
Outputs	USW production	X	X	X	X	X	X
	Selective collection		X		X		X
	Beneficiaries	X	X	X	X	X	X
Inputs	N° employees	X	X			X	X
	Personnel costs			X	X	X	X
	Operative costs	X	X	X	X	X	X

The difference between the models is centred on the use, alternatively, of the personnel variable in terms of operative cost or the number of operatives in the service, and another model with the combination of the two variables. Another aspect was to observe what is the specific impact of the selective collection output variable.

The development of the DEA technique resorted to the Frontier Analyst software, through the dual formulation of the problem, which consists of minimizing the consumption of resources given a set of fixed outputs, as Prior et al (1993) did, bearing in mind that USW management is a service to the population with some standard characteristics. The results obtained are shown in table 4.

Table 4 – Estimated efficiency of DEA Models

SYSTEM	DEA 1	DEA 2	DEA 3	DEA 4	DEA 5	DEA 6	AVERAGE
MS-A	0,63	0,63	0,55	0,55	0,63	0,63	0,60
MS-B	1,00	1,00	0,99	1,00	1,00	1,00	1,00
MS-C	1,00	1,00	1,00	1,00	1,00	1,00	1,00
MS-D	0,73	0,87	0,74	0,85	0,75	0,87	0,80
MS-E	0,83	0,84	0,78	0,80	0,83	0,84	0,82
MS-F	0,75	0,75	0,69	0,70	0,75	0,75	0,73
MS-G	0,87	1,00	0,69	0,70	0,87	1,00	0,86
MS-H	0,94	1,00	1,00	1,00	1,00	1,00	0,99
MS-I	0,47	0,47	0,56	0,56	0,56	0,56	0,53
IS-J	1,00	1,00	1,00	1,00	1,00	1,00	1,00
IS-K	0,60	0,60	0,74	0,74	0,74	0,74	0,69
IS-L	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Own elaboration

The most efficient DMU is the one that needs lowest input quantities to produce an output unit, observing that the inefficient units are always the same in all the models, with the exception of the MS-G unit that is efficient in the DEA 2 and 6 and the MS-H unit that is inefficient only in the DEA 1.

With the purpose of reinforcing the extracted conclusions of the 6 models, from the variable data used in the DEA and the data regarding the population of the area served by each unit, the input and output indicators shown below were elaborated.

Table 5 – Output indicators of USW systems

SYSTEM	USW production/ inhabitant (Kg)	Selective collection/ inhabitant (Kg)	Recycling rate	USW collection (2)/ employee (Kg)
MS-A	346	9,8	2,8%	1.967
MS-B	322	13,0	4,0%	2.619
MS-C	348	8,3	2,4%	2.809
MS-D	390	19,3	4,9%	2.504
MS-E	365	12,5	3,4%	2.504
MS-F	355	9,8	2,7%	2.327
MS-G	551	24,1	4,4%	4.702
MS-H	574	28,7	5,0%	2.950
MS-I	723	19,4	2,7%	1.666
IS-J	301	5,9	2,0%	18.277
IS-K	372	6,4	1,7%	1.943
IS-L	513	16,4	3,2%	3.681

Source: Own elaboration

Table 6 – Input indicators of USW systems

SYSTEM	Operative costs/ USW collection (€)	Operative costs/ inhabitant (€)	Personnel costs/ USW collection (€)	Productivity (VAB/ Nº employees) (€)
MS-A	22,5	7,8	8,6	82.839
MS-B	13,4	4,3	5,5	59.348
MS-C	12,3	4,3	4,5	53.321
MS-D	18,0	7,0	5,5	61.712
MS-E	15,2	5,5	6,7	63.288
MS-F	18,1	6,4	6,5	64.715
MS-G	21,0	11,6	5,3	216.766
MS-H	9,9	5,7	4,5	53.442
MS-I	20,0	14,4	7,6	55.351
IS-J	31,7	9,5	0,3	36.829
IS-K	22,2	8,3	4,7	9.787
IS-L	9,3	4,8	5,0	26.330

Source: Own elaboration

It is observed that the input variable of personnel costs has a negative impact on the DMUs MS-A, MS-E, MS-F and MS-G that is explained by having the highest personnel cost per collected ton. On the contrary, the variable number of employees has a negative impact on the DMUs MS-I and IS-K.

In general terms, we can affirm that the selective collection variable does not produce outstanding effects in the analysis, except in the systems managed by units MS-D and MS-G, bearing in mind the USW recycling rate and the quantities of selective collection per inhabitant, as can be observed in table 5.

Another conclusion refers to the Systems managed by units MS-A, MS-I and IS-K being the most inefficient in average terms, mainly due to the low population of its area of influence when compared to the remaining systems, so the number of collected tons by employee is significantly smaller. In addition, this is also due to the fact that operative and personnel costs per collected ton, in general terms, are the highest in the sample, as is demonstrated in table 6.

Therefore, it can be seen that models 5 and 6 which include all the input variables, are those that register the highest coefficients of efficiency, keeping in mind that they show the best aspects in each DMU. Considering the unit MS-I result in DEA 6 (0,56) which is relatively the most inefficient DMU, this means that the efficient DMUs (MS-B, MS-C, MS-G, MS-H, IS-J and IS-L) can obtain at least the level of each output of DMU MS-I using as a maximum 56% of the resources (inputs) used by the latter. Or then that the DMU MS-I should produce its current output level with 56% of the available resources, or using 44% less consumption.

In tables 7 and 8, the optimal values associated with each variable of the DEA 6 are shown in both output and input terms, as well as the positive or negative variation, in absolute and relative terms.

Table 7 – Increase in the output variable values for relatively inefficient DMUs

	Production of USW				Selective collection				Beneficiaries			
	Real value	Optimal Value	Vari-ation	%	Real value	Optimal Value	Vari-ation	%	Real value	Optimal Value	Vari-ation	%
MS-A	27.537	27.537	0	0,0	779	779	0	0,0	79.480	79.480	0	0,0
MS-D	165.276	187 446	22.170	13,4	8.167	8.167	0	0,0	423.538	423.538	0	0,0
MS-E	107.692	107.692	0	0,0	3.691	3.691	0	0,0	295.087	295.087	0	0,0
MS-F	344.390	344.390	0	0,0	9.466	9.466	0	0,0	969.803	969.803	0	0,0
MS-I	283.166	283 166	0	0,0	7 619	13.660	6.041	79,3	391.819	519.697	127.878	32,6
IS-K	79.653	79.653	0	0,0	1.365	2.377	1.012	74,1	213.984	213.984	0	0,0

Source: Own elaboration

In spite of the DEA model being guided towards the minimisation of inputs, bearing in mind some fixed outputs, it still determines what is the possible increment regarding each one of the DMU variables. It is observed that it is possible to register a 32,6% population increase in the geographical area of the MS-I unit. As for selective collection, very significant increases of 79,3% and 74,1% can be registered, in the geographical area of units MS-I and IS-K.

Table 8 - Decrease in the output variable values for relatively inefficient DMUs

	N° employees				Personnel costs				Current costs			
	Real value	Optimal Value	Vari-ation	%	Real value	Optimal Value	Variation	%	Real value	Optimal Value	Variation	%
MS-A	14	9	-5	-35,7	237.932	119.996	-117.936	-49,6	620.111	393.596	-226.514	-36,5
MS-D	66	57	-9	-13,6	916.656	772 528	-144.128	-15,7	2.977.724	2.593.420	-384.304	-12,9
MS-E	43	36	-7	-16,3	718.084	535 719	-182.365	-25,4	1.633.164	1.366 103	-267.061	-16,4
MS-F	148	111	-37	-25,0	2.231.103	1.514.041	-717.062	-32,1	6.250.421	4.702.023	-1.548.398	-24,8
MS-I	170	91	-79	-46,5	2.165.152	1.215.486	-949.666	-43,9	5 658.274	3.176.470	-2.481.804	-43,9
IS-K	41	22	-19	-46,3	371 724	276.783	-94 941	-25,5	1.769.156	1.317.305	-451.851	-25,5

Source: Own elaboration

As for the inputs, the possibility of having reductions is observed both in operational and personnel costs, as well as in the number of employees, which always show very significant values as is the case of the number of employees in units MS-I and IS-K, with respectively, 46,5% and 46,3%, the personnel costs in units MS-A and MS-I, of 49,6% and 43,9% and current costs in the case of the companies MS-I and MS-A, of 43,9% and 36,5%.

Finally, based on the average of the models, the following table was also obtained:

Table 9 – Resumed table of average efficiency of DEA Models

Systems	Efficiency		Inefficiency				Total
			> 0,8		< 0,8		
	Nº	%	Nº	%	Nº	%	
Multimunicipal	2	22,2	4	44,5	3	33,5	9
Intermunicipal	2	66,7	0	–	1	33,3	3
Total	4	33,3	4	33,3	4	33,3	12

Source: Own elaboration

Regarding the average of the sample, 33,3% of the companies that manage USW Systems are efficient and 33,3% have an inefficiency index superior to 0,8. As for Multimunicipal Systems, which represent 75% of the total sample, only 2 are efficient, in spite of the System MS-H having an average of 0,99, meaning that 44,5% of the companies that manage the MS possess inefficiency superior to 0,8.

Conclusions

The good function of USW Systems supposes that the citizens have means that facilitate the correct garbage collection, maximising selective collection, with the appropriate periodicity and with minimum costs. So for that to happen, infrastructures and equipment should be adapted and managed in a rational way, assuring the effectiveness and self-sustainability of the Systems.

The establishment of a widely accepted set of indicators for the activity and quality evaluation of the services provided to the population will allow to compare and evaluate the most outstanding aspects over time.

This work has tried to give a first approach to efficiency evaluation in USW Systems in Portugal using the DEA method that contemplates the multiple dimensions of companies when evaluating the influence of the diverse factors on efficiency, providing a relative efficiency valuation for each DMU and suggesting lines of action for a better use of resources in the inefficient Systems, while still being of use as a complementary indicator of other indicators.

In conclusion, in spite of the established indicators showing that a third of the companies that run USW Systems are efficient, these data can be influenced regarding the Intermunicipal Systems, bearing in mind the reliability of the economic-financial data. In fact, according to Avkiran (1999) one of the main disadvantages of the DEA method, is that, when the integrity of the data is breached, information cannot be interpreted with trust. However, we believe that the fact that most Systems have not finished their investments can influence negatively their efficiency evaluation.

In spite of the pioneering nature of this work, in the use of the DEA method in Portugal, where we do not know of any other study that makes use of this methodology, as well as in the novel character of the analysis in the USW sector, this work presents diverse limitations that allow for further investigation in this area.

The establishment of mechanisms that allow the comparability of efficiency indicators of Multimunicipal Systems and Intermunicipal Systems, can be resolved with the implantation of the Accounting Plan for the Local Municipalities in Portugal in the Intermunicipal Systems.

Furthermore, the non existence of reliable data could be solved through the compulsory delivery of the annual accounts to the Waste Institute, leading in consequence, to the publication of annual indicators, to the dissemination of those indicators in the companies and to the widespread implementation of standard systems of management accounts.

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(1) The initial position has evolved for the model of Banker, Charnes and Cooper (BCC, 1994), based on variable returns to scale, that is to say, the growth of the outputs related to the inputs is more than proportional, although this methodology will not be developed here.

(2) The variable USW production is the same as the variable USW collection, once all the produced waste is collected. The reason for the change is the fact that they are aspects of different analyses.

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Productivity Assessment of Indian Textile Mill Industry through DEA

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Abstract

Based on the time series data for the year 1973-74 to 1997-98, the paper examines the growth rates, factor productivities, and relative efficiency trends for Indian Textile Mill Industry. Using one output and three input measures, the BCC-DEA model has been applied to compute year-wise efficiency scores. The study finds that the reforms in 1985-86 have shown significant improvement in performance of the industry. It also evinces that the labour productivity has increased at the annual rate of 5.78%, while capital productivity has declined at the annual rate of 3.75%. The relative efficiency of the industry has exhibited mixed trends in pre-reform period, but post-deregulated period witnessed deterioration in performance of the industry.

Keywords: Annual Growth Rates, Single Factor Productivities, Data Envelopment Analysis, Relative Efficiency, Input/output slacks

1. Introduction

The Textile Mill Industry in India today constitutes a major sector in terms of its contribution to total industrial production, exports, and employment. However, since the dawn of independence, the industry has been subjected to various restrictions on its growth designed to encourage the production base of the handloom, powerloom sector. The aftermath has been a sluggish growth of demand for mill cloth, lack of drive for modernization and emergence of sickness in the mill sector [5]. With its general problem of obsolete machinery, low utilization of spindles and looms, uncertain profitability due to agro-nature and government regulation, the Textile Mill Industry in India merits a careful analysis of its performance over the years.

With deregulation programme initiated in June 1991, the situation had expected to change substantially because in the new economic policy regime, the significant technology upgradation and efficiency improvement was expected to meet the challenges of competition and globalization. According to Basant, R. [1], the reforms have expedited significant quality upgradation, non-price rivalry, product differentiation, restructuring, and consolidation in the corporate sector. Moreover, the benefits of reforms are not evenly distributed among the various regions, sectors and industries. Some sectors such as information technology, telecommunication, electronics, automobile have extracted largest gains from new economic policy of globalisation and liberalisation. The Textile Mill Industry, who is the largest source of employment and has high backward and forward linkages in the economy, could not avail the fruits of economic reforms as much as it was expected. Researchers have conducted studies on various aspects of economic reforms, their impact on productivity and efficiency of various industries, but no significant studies so far have reported on this sector especially after the initiation of new economic reforms. Moreover, studies conducted so far on this sector have used either total factor productivity indices or financial ratio analysis to analyse the productivity trends [7,8]. These tools cannot handle multiple output variables and multiple input variables together. Too many productivity indices and ratio coefficients make comparison difficult. In order to overcome these difficulties, the present paper attempts to

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apply DEA for assessing the performance of the Textile Mill Industry for the last twenty-five years. This technique has been widely applied to study various industries such as: Defence Industry [2], Textile, Chemical, Metallurgy [4], Indian Industry [6], Chinese Industry [9] and Textile Industry [10] etc.

2. Methodology

The basic data for the analysis has been obtained from regular publications of the Annual Survey Industries-factory sector (ASI) and Center for Monitoring Indian Economy (CMIE) reports. Data are transformed at constant prices (base year 1981). To obtain more insights on performance of the industry annual compound growth rates, single factor productivity ratios have been computed. Multiple regression equations are fitted to choose best determinants of efficiency. Data Envelopment Analysis (DEA) has been used to measure the relative efficiency of the Textile Mill Industry during 1973-74 to 1997-98.

3. Empirical Results

3.1 Trends In Gross Output, Value Added, Fixed and Working Capital, and Persons Engaged in Textile Mill Industry

A perusal of Table 1.1 reveals that during the period under review gross output (VOP) and net value added (NVA) of the industry have increased at the rate of 3.63 per cent and 1.13 per cent per annum respectively. This indicates that productive efficiency of the Textile Mill Industry is satisfactory. Net fixed assets (NFA)) in the industry has increased at the rate of 7.66 per cent per annum. This impressive growth in NFA evinces that technological change has occurred at a faster rate. However, during the same period, net-income (NI), working capital (WC), and persons engaged (PE) have declined at the rate of 1.60 %, 3.17 % and 2.02 % per annum respectively.

Table 1.1: Annual Compound Growth Rates for Indian Textile Mill Industry in Pre and Post-reform Period (in Per cent)

Period	NVA	NI	VOP	NFA	WC	PE
1973-74 to 1984-85	0.27	-1.01	2.66*	7.47*	-5.68*	-0.50
1985-86 to 1997-98	2.30**	-2.71	6.04*	10.52*	5.63	-1.06*
Over all	1.13*	-1.60**	3.63*	7.66*	-3.17**	-2.02*

Notes: * significant at 1 per cent level of significance, ** significant at 5 per cent level of Significance, *** significant at 10 per cent level of significance.

Though the industrial delicensing policy announced in June 1991, the era of liberalisation in the Textile Mill Industry has started quite early with the implementation of Textile Policy 1985. The policy allows free entry and exit of capacity. The liberalization has shown righteous impact on the mill industry, which is evident from the post-reform progress of the industry. Gross output has shown impressive growth (6.04 % per annum). Net value addition has shown good improvement (2.3 % per annum) as compared to 0.27 % per annum in pre-reform period. Lot of investment has come to the industry, which is evident from the 10.52 % growth rate in the net fixed assets. This signifies that policy reforms such as Export Promotion Capital Goods Scheme (EPCG) have made commendable impact on the industry. Industry also responded strongly by doubling its performance in gross output in post-reform period. There has been significant improvement in circulating fund position of the industry, which is evident from the 5.63 per cent growth rate in working capital, as against decline of

5.68 % per annum in pre-reform period. However, net-income of the industry further deteriorated at rate of 2.71 % per annum. It is interesting to note that while the growth in NVA is found positive, the growth in NI is observed negative. The negative growth in NI evinces that the profit, which is the lifeblood of any business organisation, has tremendously reduced during the period under study. Further, it can be concluded from the negative growth in NI that the Textile Mill Industry is heavily burden by interest and rent payments. In the post-reform period persons engaged in the industry declined at the rate of 1.06 % per annum, that means closure of mills and retrenchment of employees continued in post-reform period also.

3.2 Productivity Trends in Indian Textile Mill Industry

In the present study, net value added (NAV) to persons engaged (PE) and value of output (VOP) to persons engaged are computed and considered as proxy to labour productivity. Capital productivity has been measured as VOP/NFA (i.e. VOP per rupee investment in NFA). Rate of growth of above-mentioned single factor productivities has been worked out to capture the trends in productivity ratios. Growth rates are computed by using semi-log linear equation with respect to time.

3.2.1 Results and Discussions

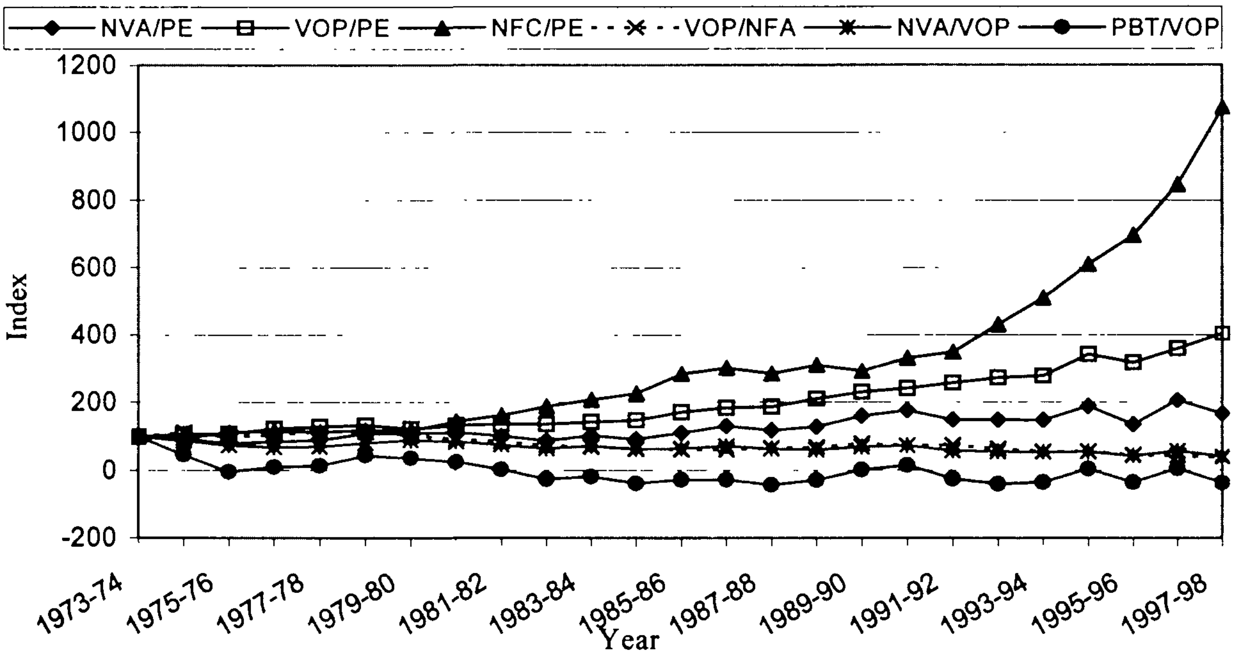
Labour productivity has shown increasing trend from 1973-74 to 1997-98 except for the year 1979-80 (Table 1.2 and Figure 1.1). The number of employees continues to decline since 1984-85, it is because of two reasons: retrenchment of employees and closure of mills. The average number of employees per factory has come down from 535 in 1973-74 to 227 in 1997-98.

Table 1.2: Factor Productivities in Textile Mill Industry (1973-74 to 1997-98)

	NVA/PE	VOP/PE	NFA/PE	VOP/NFA	NVA/VOP
ACGR (%)	3.23	5.78	9.87	-3.75	-2.4

Notes: NFA- Net Fixed Assets; PE- Persons Engaged (number); VOP- Gross Output; NVA- Net Value Added; PBT- Profit Before Tax. Source: Compiled from various issues of Annual Survey of Industries and Centre for monitoring Indian Economy Reports.

Figure 1.1: Trends in Employee and Capital Productivity, Capital Intensity and Profitability of Textile Mill Industry



Labour productivity has increased at a rate higher than that of capital productivity, which has contributed to the growth of gross output of the industry. The rate of growth in labour productivity is 5.78 per cent per annum for the period under review. On the other hand, capital productivity has declined at the rate of 3.75 per cent per annum. This is perhaps due to shortage of raw material and sluggish market demand.

Overall, improvement in productivity is mainly because of the contribution of labour to value addition, which is grown at the rate of 3.23 per cent per annum. It is found that the rate of growth in capital intensity has been 9.87 per cent per annum during the study period. It is also observed that value addition (NVA to VOP) in the industry declined at the rate of 2.4 per cent per annum. The growth of fixed assets in the industry is observed 7.66 per cent per annum as against 2.02 percent decline in labour force. Net fixed assets per factory has also been increased from 0.29 crores in 1973-74 to 6.71 crores in 1997-98.

3.3 Efficiency Trends in Indian Textile Mill Industry: A DEA Approach

3.3.1 Selection of Variables

Measurement of productive efficiency requires determination of input and output variables for a production process. There is no consensus amongst researchers about the input-output variables to be chosen for productivity measurement of an industry. In the present study, initially, we have considered Value of Output (VOP) or Gross Output, Net Value Added (NVA), Net Income (NI) and Profit as output variables. Net Fixed Capital (NFA), Working Capital (WC), and Persons Engaged (PE) as input variables. Output measures are regressed individually on these input variables to identify the best fit of input-output variables for DEA analysis. Adjusted $\bar{R}^2$ values estimated for VOP, NVA and profit are 0.91, 0.19 and 0.52 respectively, with the input variables. But, value of output does not give the idea about how much profit has been earned by the industry. Therefore, VOP based DEA analyses are unable to capture variations in industry performance because of losses and external environmental factors. It can reveal only about input(s) conversion efficiency of the industry. However, it is observed that NVA based DEA analyses are able to obtain variations in industry performance due to external factors under which it is working. NVA variable is inclusive of profit element; hence, analysis based on NVA takes into account impact of market conditions.

Year after year, textile mill industry has been continuously incurring losses. Industry data on profit variable are negative. DEA methodology needs strictly positive values for all input-output variables. Hence, the profit variable has to be dropped from the analysis. NVA as an output variable and NFA, WC, and PE as input variables have also used in the scholarly study of Majumdar [6]. Finally, we have selected net value added at constant prices as output variable and net fixed capital, working capital, and persons engaged as input variables to study the efficiency trends in the textile mill industry. The definitions of the selected variables as defined by Annual Survey of Industries, Government of India, are as follows:

Net Value Added (NVA): It is the increment to the value of goods and services that is contributed by the mill and is obtained by deducing the value of total inputs and depreciation from value of output (rupees in crores).

Net Fixed Assets (NFA): It represents the depreciated value of fixed assets owned by a factory as on the closing day of the accounting year (rupees in crores).

Working Capital (WC): WC is the sum of the physical working capital and the cash deposits in hand and at bank and the net balance of amount receivable over amounts payable at the end of the accounting year (rupees in crores).

Persons Engaged (PE): PE relates to all persons engaged by the factory and includes all administrative, technical, clerical staff and also labour engaged in production (persons in number).

3.4 The Model

Banker, Charnes, Cooper DEA (BCC-DEA) Model [3] has been used to estimate efficiency scores for each year.

3.4.1 Model Solution: The implementation of DEA requires access to a computer and linear programming software. The solution to the DEA model is carried out by using Efficiency Measurement System (EMS) version 1.2 developed by Professor Holger Scheel, Universitat of Dortmund, Germany, and cross checked by a DEA computer program DEAP Version 2.1 developed by Tim Coelli, University of New Engaland, Armidale, NSW, 2351, Australia has been used.

3.4.2 Efficiency Trends in Textile Mill Industry

Average technical efficiency of mill industry for entire study period has been observed 86 per cent. Average pure technical and scale efficiency have been found 90 per cent and 96 per cent respectively. This implies that inefficiency in the industry due to scale effects is 4 per cent. Loss of efficiency due to inefficient use of input resources and input mix is about 10 per cent. The difference between actual NVA and efficiency adjusted values of NVA exhibited in Figure 1.2 shows that there are large differences during 1980-81 to 1984-85 (pre-reform period) and at the end of study period (1995-96 and 1997-98) indicating inefficient performance. Figure 1.3 shows that the usage of capital was relatively efficient during the period 1973-74 to 1996-97. This result contradicts with the result of single factor productivity analysis. This is possibly due to limitation of single factor productivity analysis, which takes into account only two factors at a time in a ratio; where as DEA considers simultaneous use of multiple inputs.

Working capital has not been properly utilised in the industry during 1980-82, 1983-84, 1986-88, 1995-96 and 1997-98, which is evident from the high values of slack observed for this input variable during these years). Differences between observed and efficiency adjusted (i.e. targets) working capital are raised during immediate pre and post-reform period i.e. before and after 1985-86 indicating inefficient use of working capital (Figure 1.4). Substantial parts of labour surpluses are found in years 1977-78, 1982-87, 1995-96, and 1997-98 (Figure 1.5).

Table 1.3: DEA Results for Indian Textile Mill Industry during 1973-74 to 1997-98

	TE	PTE	SE
Average	0.86	0.90	0.96

Notes: TE- Technical /Relative Efficiency, PTE- Pure Technical Efficiency, SE-Scale Efficiency.

The overall efficiency trend for textile mill industry during1973-74 to 1997-98 is charted in Figure 1.6, where the value of efficiency score equal to one indicates that the output in that year was efficiently produced. It can be learned from the chart that the variations in efficiency scores for the period 1973-74 to 1997-98 are extreme. This implies that industry's performance was inconsistent. In late post-reform period (1994 onwards) the performance of the industry has worsened for the various reasons like, stagnant fabric demand, massive surge in cotton prices, South-East Asian economic crisis, industrial slow down etc.

Figure 1.2: Observed and Efficiency adjusted Net Value Added for Textile Mill Industry (1973-74 to 1997-98)

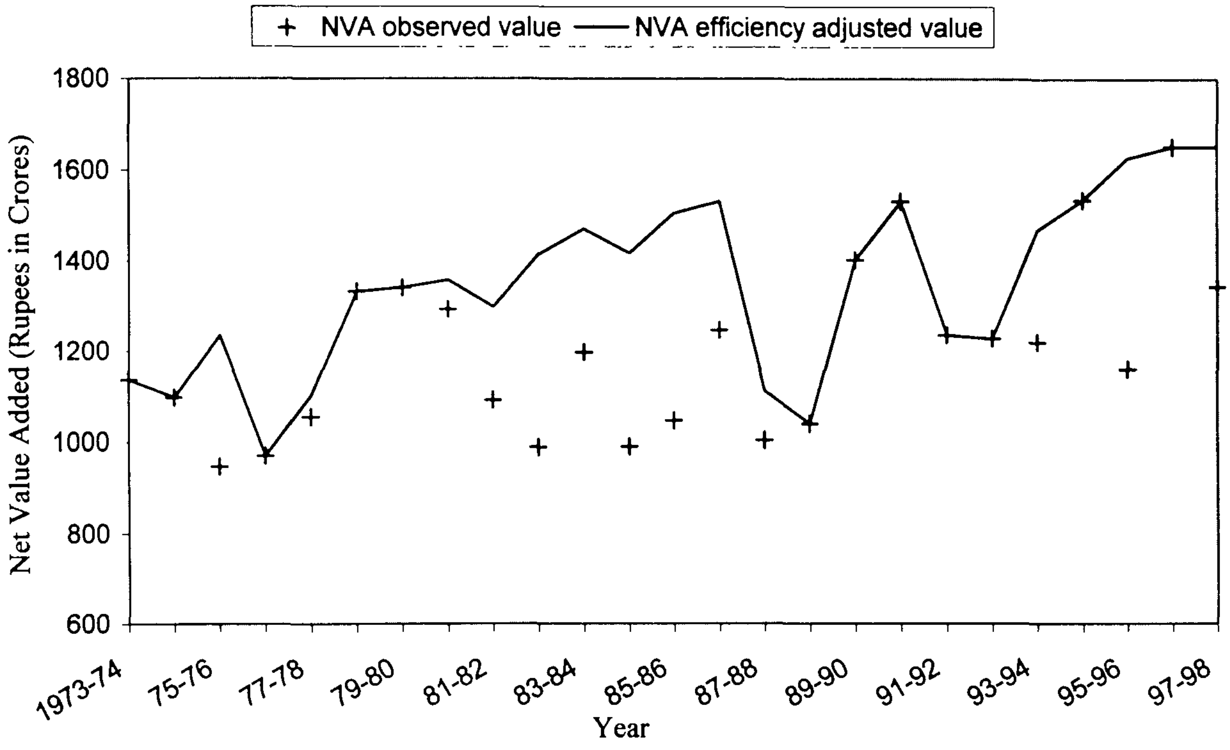


Figure 1.3: Observed and Efficiency adjusted Net Fixed Assets for Textile Mill Industry (1973-74 to 1997-98)

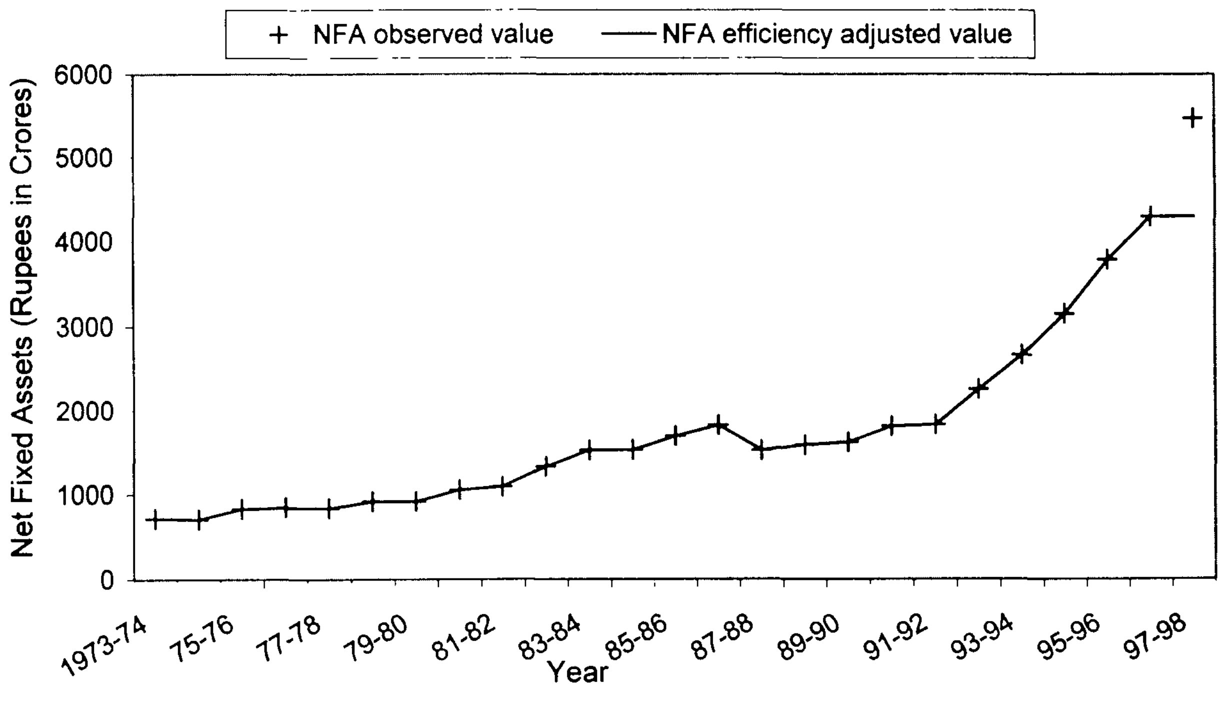


Figure 1.4: Observed and Efficiency adjusted Working Capital for Textile Mill Industry (1973-74 to 1997-98)

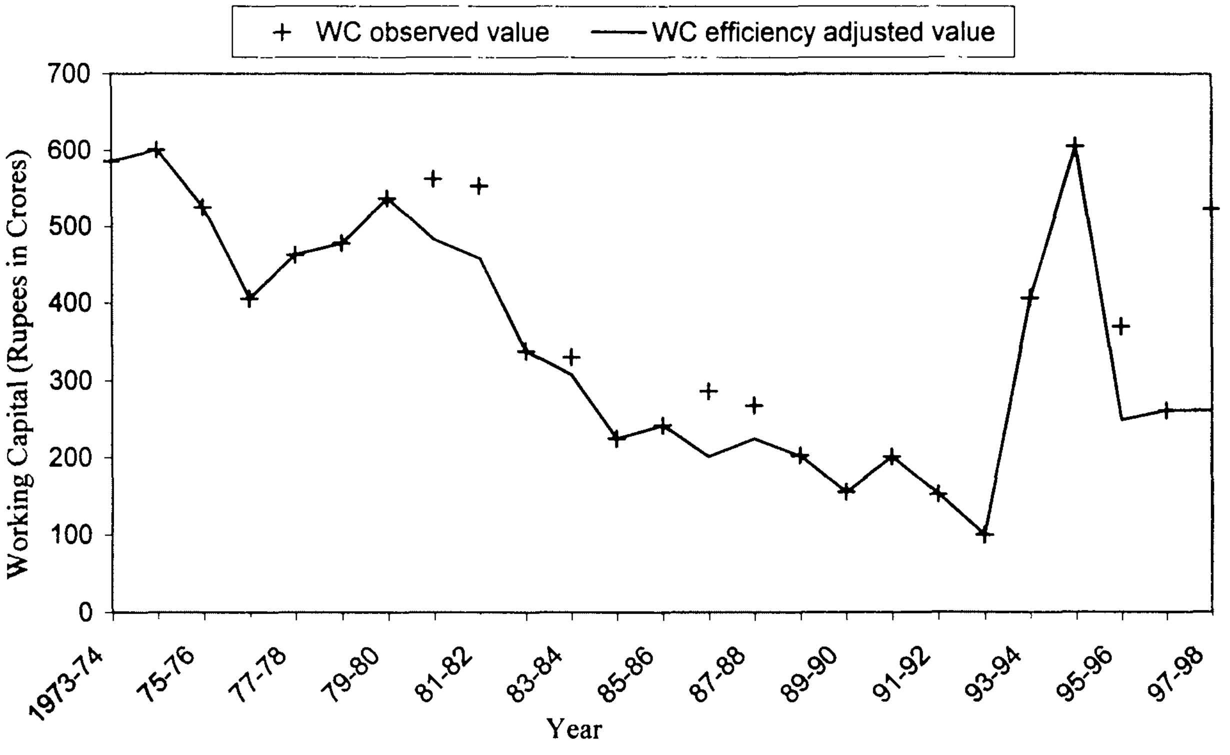


Figure 1.5: Observed and Efficiency adjusted Persons Engaged in Textile Mill Industry (1973-74 to 1997-98)

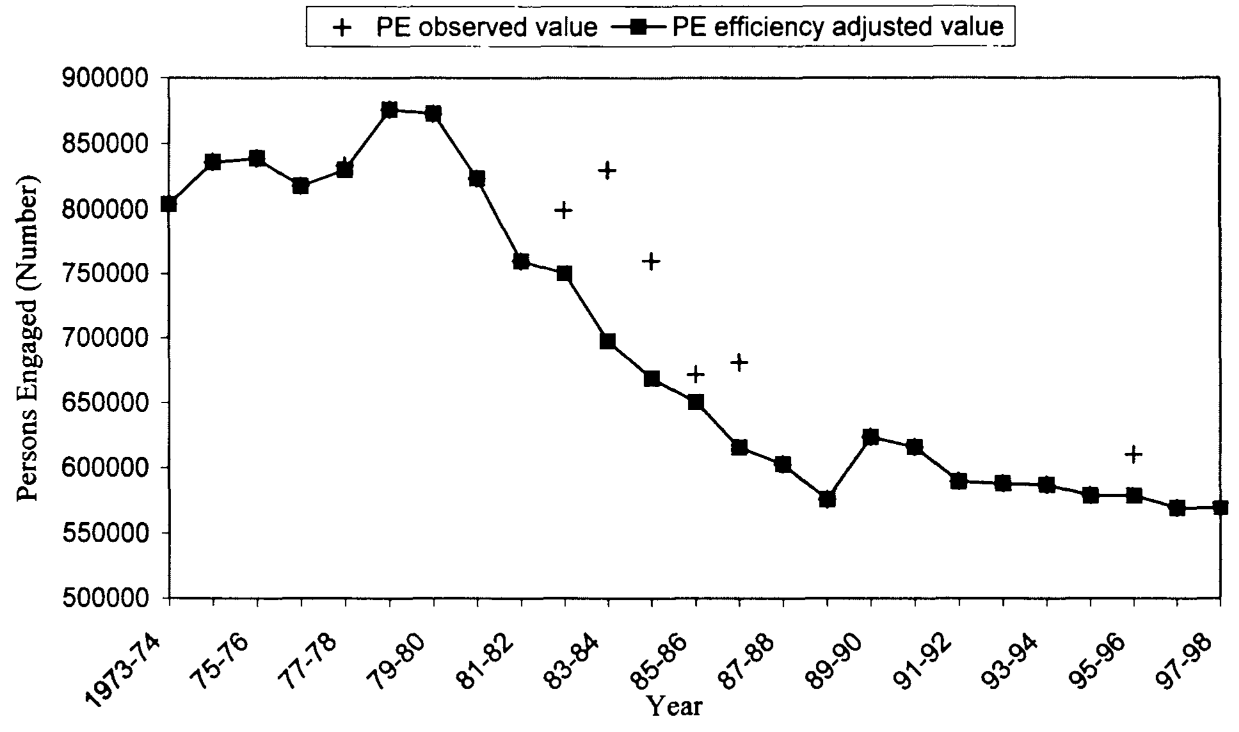
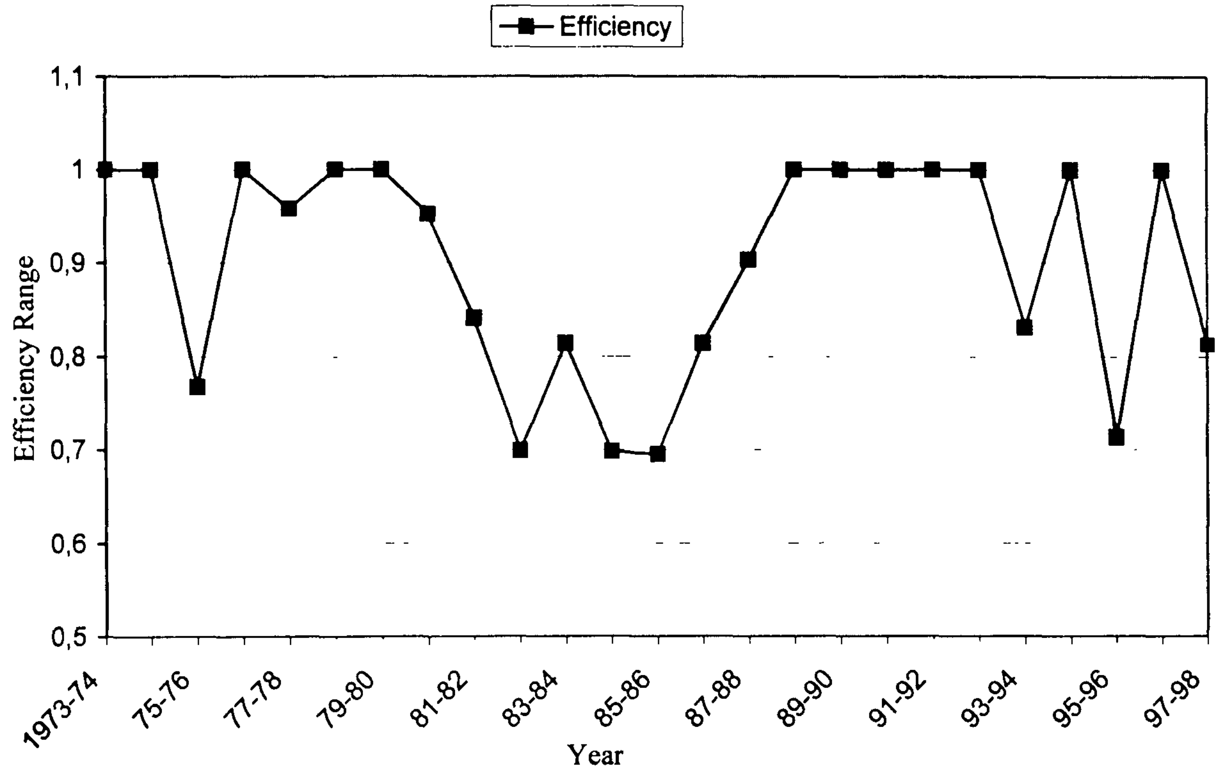


Figure 1.6 : Efficiency Trends inTextile Mill Industry (1973-74 to 1997-98)



Conclusions

The industry's gross output, net value added and net fixed assets have grown at an impressive rate. However, working capital, personnel, net income, and profit have invariably declined. Employment in the industry has declined on account of adjournment of mills, retrenchment of workers and increase in capital concentration. Based on single factor productivity analysis, it can be inferred that labour productivity has increased on account of capital intensity, retrenchment of workers and closure of mills, and not because of increase in efficiency and skill of labour. Technical inefficiency is aggrandized much more than that of scale inefficiency in the textile mill industry. Working capital and labour have not sensibly utilised in the industry. In pre-reform period (1973-1985), Textile Mill Industry has exhibited mixed performance. Reforms have made notable impact on the performance of the industry. However, in the late reform period (1996 onwards) the industry witnessed deterioration in performance.

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ABC Inputs plus DEA Measure the Relative Significance for University Departments

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Abstract

During the last decade Greek S.A.s, Ltds and Private Sector enterprises with annual turnover more than 300.000.000 GRD or 900.000 EURO (current limit) were obliged to implement a uniform chart of accounts, that is similar to the French chart and has adopted all the relevant European Union directives. On the other hand, in the last two years, Public Sector enterprises that are obliged to prepare and execute a budget must also implement a corresponding chart of accounts.

Public Sector enterprises include all the Universities, among which is the University of Piraeus. The number of freshmen admitted to the University every year is limited and the selection of freshmen is based on their preferences and their National Examinations scores.

In the research work presented in this paper, the University's cost data have been obtained from the conventional financial statements of the most recent year. According the ABC method (Activity Based Costing) the cost data have been re-defined by creating cost drivers and cost pools, while the new cost centres have been the nine University Departments (Maritime Studies, Economics, Business Administration, Informatics, Statistics, Industrial Management, Financial Management, Technology Education, International and European Studies). In this manner the inputs of each department have been determined accurately.

Regarding the outputs, several relative significance indicators have been introduced for each department, such as the teaching staff/student proportion, the proportion of graduates employed in jobs related to their degree, the demand/supply proportion according to the freshmen preferences and their admission to the University Departments etc.

Having gathered the aforementioned inputs and outputs, the capabilities of DEA have been utilized in order to derive the relative significance for each department.

This work tries to provide a decision making tool for issues like funding, defining the number of students in each department, analyzing the University departments, etc. The Administration (European Union, Central Government, University) has the ability to use this methodology, or, furthermore, to change the sort, the number or the weights of output measures, if the significance of the proposed indicators should be re-assessed.

Keywords: ABC, DEA, University Departmemts

1. Introduction

The initiative of costing a university's different departments causes an interesting issue for education research regarding the students, staff and academic textbooks numbers.

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For Greek Universities, such information has been neither available nor required, and a similar research, until recently, would have been difficult to persuade anyone that it is either achievable or useful.

Port and Burke (1989) say, to be useful, any costing method must be easy to understand and apply, and must help academic managers to understand the main factors that influence their costs, rather than just confuse them with masses of details.

Management Accounting offers various alternative solutions of costing. The system Activities Based Costing (ABC) introduces a different focus that puts the emphasis on activities and not necessarily on volume as the essential causes of cost changes. Management has, for some time, been in a situation where historical focus has been on variable cost – almost to the exclusion of fixed costs. ABC aims to change this view and promote the fact that many overheads, particularly sustaining operations, do fluctuate, but for reasons other than volume.

Tollington (1998) argues that ABC can generate accurate full product costs, e.g. it avoids the illusion that fixed costs have nothing to do with production. "ABC is similar to the traditional overhead absorption method, but provides a level of analysis which goes much deeper. We could say that it is still same overhead absorption cloth, but the attention given to the style (cost pool) and cut (cost driver) of the product has increased substantially".

Coupled with ABC, DEA becomes a scalpel that can be used to reduce waste in specific product lines, rather than a shovel used bluntly and clumsily on organizations as a whole (Kantor, Maital, 1999).

The remainder of the paper is organized as follows: Section two is concerned with the hypothetical implementation of Activities Based Costing (ABC) system at the nine departments of the University of Piraeus (**UP**) and determines accurately the input variables data for the DEA model. Section three remarks the encouraging indications for which the co-existence of the Activities Based Costing with the Data Envelopment Analysis is necessary. Section four presents the implementation of the DEA method for the assessment of the relative significance of the UP departments. The DEA model is constructed, using the ABC inputs in conjunction with introduced relative significance indicators as outputs. Section five concludes the paper, supporting the argument that ABC plus DEA is almost an obvious marriage.

2. Implementation of ABC at the University of Piraeus

2.1. Direct and Indirect Cost

Under the hypothetical implementation of such a costing system at the University of Piraeus, all floor reporting is adjusted to meet the requirements of the ABC system, as are the uniform chart of accounts, cost center structure, interdepartmental charges, accounts payable and payroll cost distribution practices, financial and management reports and every other cost-related facet of the accounting system.

For the implementation, cost data were obtained from historical financial statements and detailed staff records. Total expenditures are composed from production expenditures and administration expenditures for the year 2000.

Most of the production expenditures belong to the direct cost, while the rest of the production expenditures and the aggregate of administration expenditures belong to indirect cost. The direct cost includes the expenditures that are distributed directly to each University Department, like the department's general expenditures and the expenditures for the Department's Head, teaching staff and Secretariat. On the other hand, the indirect costs includes the expenditures that cover general University operations, and this paper attempts, through ABC, to distribute them to each department, in order to define each department's actual total cost.

2.2. Determination of the activities number

All indirect expenditures are considered to provide facilities and sustaining operations to the University of Piraeus (UP) and they are numbered from 1 to 25 (1-11 production, 12-25 administration). In most of these cases, each sustaining operation corresponds to only one activity, but there are 6 sustaining operations that correspond to 12 more activities. This above procedure enabled the construction of an ABC model with 25 sustaining operations that correspond to 37 (25+12) activities in total.

2.3. First Stage: Cost pools and cost drivers

The University's identified activities are classified or coded so that their information can be summarized. From the computerized double entry accounting system of the UP the aforementioned 37 activities that take place have been identified. These activities have defined the boundary of the overheads to be attributed according to the ABC system.

Activity data of the UP were obtained mainly through interviews with the staff responsible for the sustaining operations and with the finance department staff and by direct observation. Having obtained the activity data, taking into account the directions suggested by the interviews and combining them with the necessary flexibility of the ABC method, seven (7) cost pools are constructed by activities with correlated operations. Each cost pool is allocated to the cost centers by the use of a unique cost driver. In this manner, 2 large cost pools (1, 3) were created - out of 8 homogenous sustaining operations each and 26 activities in total - that include 71% of the overheads for the implementation of ABC and 3 small cost pools (4,5, 7) - out of 2 or 3 homogenous sustaining operations each and 9 activities in total. Furthermore, 2 cost pools with particular activity (2,6) were created, where an exceptional cost driver should be introduced.

Kaplan and Atkinson (1998) say that the goal of a properly constructed ABC system is not to have the most accurate cost system. Consider a target where a bull's-eye represents the actual cost of resources used each time a product is made, a service delivered, and a customer served. To hit this bull's-eye each time requires an enormously expensive system. But a relatively simple system – perhaps 30-50 activities and using good estimates and many transactions drivers, with few intensity drivers or direct charging – should enable the outer and middle rings of the target to be hit consistently; that is, activity and process costs will be accurate to within 5% or 10%. Traditional cost systems virtually never hit the target, or even the wall on which the target is mounted, as their highly distorted costs approximate firing a shotgun at a barn but shooting directly up in the air or to the sides. Good engineering judgement should be used; 90% or more of the benefits from a more accurate cost system can be obtained with relatively simple ABC systems.

2.4. Second Stage: Contribution of the UP's records data to the cost drivers

The total expenditures of the 7 cost pools (section 2.3) have to be allocated to cost centers by the use of the corresponding 7 cost drivers. In this paper, each UP department is a cost center, i.e. the total expenditures are allocated to the 9 UP departments or nine cost centers. Regarding the relative contribution of the University's records data to the construction of each cost driver the following assumptions were made:

Cost driver 1: Total number of active students, teaching staff and administration staff. The 15 activities (or, equivalently, 8 homogenous sustaining operations-1,14: V.Chancellor, 16: General Assembly, 17: Administration, 18: Financial, 19: Personnel, 20: Clinic, 25: Legal, etc.) related to cost driver 1 are allocated to the 9 University Departments according to the following relation: the total number of active students contributes 30%, the total number of teaching staff 40% and the total number of administration staff 30%.

<u>*Cost driver 2:*</u> The number of Professors, Associate Professors, Assistant Professors & Lecturers. The particular activity related to the exceptional cost driver 2 (4: the University Journal "Spoudai") is allocated to the Departments according to their total number of Teaching and Research Staff (TRS).

<u>*Cost driver 3:*</u> Total number of active students. The 11 activities (or, equivalently, 8 homogenous sustaining operations – 2: Technical, 5: Library, 6: Welfare, 8: Gymnastics, 10: Languages, 11: Campus, 12: Chancellor, 24: Historical Research) related to cost driver 3 are allocated to the 9 University Departments according to their total number of active students. They are considered the ones completing their degree within the regular time - 4 years - plus an additional 50%, i.e. 6 years (Active+Inactive = Total Students).

<u>*Cost driver 4:*</u> Total numbers of active students and teaching staff. The 3 activities (or, equivalently, 2 homogenous sustaining operations – 7: Director of Studies, 13: Public Relations) related to cost driver 4 are allocated to the 9 University Departments according to the following relation: the total number of active students contributes 40% and the total number of teaching staff (TRS+Tutors+Temporary Personnel) 60%.

<u>*Cost driver 5:*</u> Total number of students. The 3 activities (9: Cultural, 15: Counselling, 23: Photocopies) related to cost driver 5 are allocated to the 9 University Depts according to their total number of students.

<u>*Cost driver 6:*</u> Total number of academic textbooks distributed to students. The particular activity related to the exceptional cost driver 6 (3: provisions of academic textbooks) is accordingly allocated to the Depts.

<u>*Cost driver 7:*</u> Total numbers of teaching staff and administration staff. The 3 activities (or, equivalently, 2 homogenous sustaining operations – 21: Computer Room, 22: General Protocol & Records) related to cost driver 7 are allocated to the 9 University Departments according to the following relation: the total number of teaching staff contributes 50% and the total number of administration staff 50%.

The 7 cost pools are allocated to the 9 departments according to the assumptions discussed in paragraph 2.4 and the UP's records data.

2.5. Direct, Indirect and Total Cost

Having allocated the 7 cost pools to the nine UP departments, the total indirect departmental cost can be derived by summing up each department's attribution to the 7 cost pools. Next, the total indirect departmental cost is summed up with the direct cost, thus yielding the total cost of each UP department. The direct, indirect and total cost per student for each UP department can also be obtained by dividing the departmental costs by the number of active students. Finally, the nine departments are ranked according to the minimization of the total cost per student as follows: Financial Management & Banking, Economics, Business Administration, Maritime Studies, Statistics & Insurance Science, Technology Education, International & European Studies, Industrial Management, Informatics.

3. The Merger of ABC with DEA

Since 1966, Zlatkovich et al had said, about the definition of accounting supplied, that is the process of identifying, measuring and communicating economic information to permit informed judgments and decisions by users of the information.

Dean (1997) observes that the above definition leaves plenty of room for the application of mathematical techniques within accounting. However, the practice of accounting limits itself to numbers, as opposed to equations and coordinate systems. It only took the application of mathematics, coupled with the scientific experiment, to transform physics from an anecdotal practice into science.

In order to materialize this evolvement, an attempt is made to bring together a costing method, ABC, and a linear programming method, DEA. Charnes et al (1978) say that DEA can be applied when an analyst intends to measure relative efficiency of comparable Decision Making Units, which can be separate institutions, e.g. University Departments.

Tomkins and Green (1988) have defined the conditions under which DEA is useful. If the technique yields additional insights and helps evaluators to sharpen their focus of enquiry and debate, DEA is useful. If our evaluators are to be credible, they must be able to present reasoned methods for handling the multi-dimensional nature of the evaluation problem, which DEA highlights so well. Whether DEA is useful will depend to a large extent on the structure of the decision situation in which it is used – plausible number of variables, reliability of measurement, etc.

DEA allows each of the inputs/outputs to be measured in their respective units; i.e. the need for a common dominator such as money for all the variables considered does not arise. This is particularly important due to the fact that not all variables under consideration can be costed or converted into one unit of measurement - consider for example inputs such as school teachers and outputs like graduates (Kwimbere, 1987).

For measuring efficiency in a large mid-east bank, Kantor and Maital (1999) conclude that data generated by ABC systems are ideal for enabling DEA analysis. The merger of ABC with DEA enables activity-based management by providing performance – benchmarking indicators along with a set of diagnostics for identifying problems and inefficiencies.

4. DEA for University Departments

4.1. DMUs, Inputs and Outputs

Service organizations such as banks, hospitals and universities have several characteristics that distinguish them from manufacturing firms, including the following:

- Output is often harder to define
- Activity in response to service requests may be less predictable
- Joint capacity cost represents a high proportion of total costs and is difficult to link to output – related activities (Acton and Cotton, 1997).

Although the Jarrat (1985) Report of the Steering Committee for Efficiency Studies in Universities provoked some controversy, many of its comments were simply statements of what now appears obvious (Gillie, 1999). For example:

- It is in the planning and use of resources that universities have the greatest opportunity to improve their efficiency and effectiveness.
- Measures of input are better developed than measures of output.
- It is agreed that far more work needs to be done on measures of output.

In order to set up the DEA model presented in this paper, the UP departments that are going to be assessed (Decision Making Units) have to be selected. Furthermore, the model outputs should be defined.

i. *DMUs:* Firstly, only 5 of the 9 UP Departments are considered homogenous and are included in the DEA model. These belong to the same discipline (Discipline V –

Economics and Business Sciences, classification according to the Ministry of Education) and can provide a representative sample after more than ten years of operation. The other 4 UP Departments are not considered suitable for the DEA model.

ii. *Inputs:* The inputs are readily available from the ABC analysis (Section 2), that yielded the costs for all UP departments.

iii. *Outputs:*3 relative significance indicators have been introduced as model outputs for each Department. These indicators correspond to 3 sorts of criteria:

a. Internal criterion: An important factor contributing significantly to the establishment of effective or ineffective teaching conditions in a University is the teaching staff/student rate. This rate is adopted as output measure 1.

b. External criteria:

b1. The UP Careers Office has conducted a research on the rate of graduates (1993-1997) employed in jobs related to their degree. The research included 1.025 graduates over a total of 2.465, and the results, expressed in %, will be used for criterion b1.

b2. Employment perspectives according to the Ministry of Education is criterion b2. Departments with very good, good and limited perspectives are in this paper score 100%, 67% and 33% respectively.
The output measure 2 is the average of b1 and b2.

c. General criterion
The lowest entrance grades in the Higher Education Institutions for the years 2000 and 2001 are mostly indicative of the degree of difficulty in being admitted to these Institutions and demonstrate a particular hierarchy in them. The lowest entrance grades are output measure 3.

4.2 Implementation of DEA

Table 1 depicts the complete input & output data of the DEA model. It should be noted that input variables are costs per student, expressed in thousands of GRD, while all output variables have been converted into %.

Table 1: DEA Model Inputs and Outputs

Departments	**Inputs**		**Outputs**		
	Direct	Indirect	Grades	Employment	Teaching
Maritime Studies	523,7	184,9	80,9925	65,5	3,125
Economics	367,6	182,1	88,1575	69,0	2,174
Business Administration	415,3	200	89,325	91,0	2,778
Statistics & Insur. Science	524,4	189,6	85,7875	53,5	2,222
Financial Mngmt & Banking	311,5	172,1	94,345	72,0	2,000

For the implementation of DEA, the Warwick-DEA software was used, adopting the radial improvement model (input minimization), under constant returns to scale and uniform priorities. The implementation included 3 runs, involving the assessment of the DMUs relative significance rates and organized as follows:

Run 1: Total Weights Flexibility
Run 2: Constrained Inputs Weights
Run 3: Constrained Inputs and Outputs Weights

Table 2 depicts the relative significance ratings of the UP Depts assessed by DEA according to the 3 Runs.

Table 2: Relative Significance Ratings of the UP Departments Assessed

Department	Runs		
	1	2	3
Maritime Studies	100,00	96,59	74,17
Economics	93,36	91,90	88,84
Business Administration	100,00	100,00	95,44
Statistics & Insur. Science	88,15	70,73	61,36
Financial Mngmt & Banking	100,00	100,00	100,00

Run 1: The Business Administration, Financial Management & Banking and the Maritime Studies Departments score 100% relatively significant according to Run 1. The Statistics & Insurance Science Department scores 88,15% and the Economics Departments scores 93,36%. These relatively low ratings reflect the low teaching staff/student rate and entrance grades of these two Departments.

However, as Dyson and Thanassoulis (1988) say, allowing too great a flexibility in the determination of weights on inputs and outputs can lead to some DMUs being assessed only on a small subset of their inputs and outputs, while their remaining inputs and outputs are excluded from the assessment of the target DMU. This argument was verified in Run 1 of our model. As a result, the relative significance of a DMU may not really reflect its performance on the inputs and outputs taken as a whole. It is therefore necessary to attempt to assign weights to inputs and outputs, in order to ensure that the subsequent assessment cannot effectively ignore any inputs or outputs.

Run 2: it involved constraining the inputs weights. This was a rather straightforward task, since both inputs are expressed in money and their weights have a rather clear interpretation. Furthermore, it is obvious that the direct cost (Input Variable 1) is by its nature allocated to the departments in a more just way than the indirect cost (Input Variable 2). Therefore, inputs weights bounds are imposed, in order to obtain a rate of direct/indirect costs equal to 1,5 ±20%. Run 2 resulted in the relative significance rates depicted in Table 2.

It can be seen from Table 2 that restricting the inputs weights leads to 3 DMUs having lower relative significance rank. Namely, the Maritime Studies Department is no longer 100% significant, due to its high cost per student, while the Statistics and Insurance Science Dept. drops from 88,15% to 70,73% and the Economics Dept. drops from 93,36% to 91,90%. However, the Run 2 model is still totally flexible regarding the outputs weights. This means that DMUs may still completely disregard their less favourable outputs.

Run 3: It involved imposing bounds to both the inputs and outputs weights. Since the output variables are not market goods, their weights do not have a clear interpretation. This paper adopts the methodology proposed by Dyson and Thanassoulis (1988), which is determining the minimum amount of resource necessary to support a unit of each output after first using regression to estimate average values. Then, it is assumed that no department can support a unit of output at an input level of less than half the average cost. In this manner, a set of lower bounds for the weights on the outputs is obtained and the DEA model is run again, resulting in the relative significance ratings depicted in Table 2. These results are quite representative of the actual characteristics and activities of the UP Departments:

The Statistics Department ranks 5th regarding its relative significance rating, since, its 3rd place regarding teaching staff/student rate and to entrance grades is eliminated by its 5th place with respect to cost per student and employment rate.

The Maritime Studies Department ranks 4th regarding its relative significance rating, since it ranks 4th regarding both the per student cost and employment rate, while the best teaching staff/student rate is eliminated by the worst entrance grades.

The Economics Department ranks 3rd regarding its relative significance, as it ranks regarding the employment rate and entrance grades, while its 2nd place with respect to the per student cost is diminished by the 4th place with respect to teaching staff/student rate.

The Business Administration Department ranks 2nd regarding its relative significance, as it ranks regarding the teaching staff/student rate and the entrance grades. Although it ranks 1st with respect to the employment rate, the Department is no longer 100% significant. This decrease (4,56) is mainly due to the large number of "inactive" students (cost drivers 5,6), that leads to the 3rd larger per student cost among the five departments.

The Financial Management & Banking Department ranks 1st with 100% relative significance, which means that there is no evidence to argue that it could utilize its funds in a more efficient manner. The Department rates 100% significant according to all three runs, since, its 5th place with respect to the teaching staff/student rate and 2nd place with respect to the employment rate, is overridden by its 1st place with respect to cost per student and entrance grades.

This work tries to provide a decision making tool for issues like funding, defining the number of students in each department, analyzing the University departments, etc. The Administration (European Union, Central Government, University) has the ability to use this methodology, or, furthermore, to change the sort, the number or the weights of output measures, if the significance of the proposed indicators should be re-assessed.

5. Conclusions

ABC is a powerful management tool that has evolved in response to the ineffectiveness of traditional cost accounting and cost management practices. ABC not only helps a university to accurately measure its service, process and activity costs, but it also provides the financial and non-financial information necessary to identify opportunities for the cost reductions and operating improvements.

It seems clear that ABC is not a panacea for the overhead cost allocation problem in Universities, but it has a lot to offer in improving the relationship of such allocations to actual usage of service and, consequently, also improving the efficiency of allocations (Goddard, Ooi, 1998).

Researchers, who have worked with several Universities, have found that knowledge of the relative costs of different departments and of the reasons that influence these costs is a very powerful tool to performance measurement and strategic decisions. As Kantor and Maital (1999) aptly remark, ABC plus DEA is an almost obvious marriage. Indeed, in its early years, linear programming (of which DEA is a variant) was sometimes referred to as activity analysis (Dorfman, Samuelson & Solow, 1958). The detailed information on costs, activities and outputs that ABC generates often at high cost is directly applicable to the DEA algorithm that tries to see whether individual units are getting the most output out of their given inputs for each individual activity or profit (cost) center. Together ABC and DEA provide a two-dimensional portrayal of a business (university) across individual operating units and individual inputs and outputs.

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The Assessment of Higher Education Institutions Using Dynamic DEA: A Case Study in UK Universities

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Abstract
This paper compares dynamic DEA, static DEA and performance indicators as alternative tools for assessing the performance of higher education institutions (HEIs). Such units typically use multi resources in one or several years to secure outputs in the same or future years. The comparison focuses on how well the three methods agree on the performance of an institution relative to the selected HEIs.

1. Introduction

The most recent development of performance indicators (Pis) for UK higher education sector, at a national level, has been published by HEFCE in 2001 (see HEFCE (2001, 2000, 1999b)). The main reason of the development of PIs by HEFCE was the Government's concern with ensuring value for money, increasing accountability and the strengthening of institutional management. Therefore the development of PIs may help HEFCE in distributing the right funds to institutions in terms of their scores obtained from various PIs or to help the institutions with lower scores to improve them to national level relative to the other institutions.

However the main criticism of performance indicators is that they are taking into account only single input and single output at a time. A public sector organisation like a university usually provides a mix of outputs which cannot easily be aggregated into a single index of output. In particular some output may be the outcome of several years' investment both in teaching and research. Therefore with using PIs one must produce a set of indicators to over come this problem. Some studies attach weights to mulitple inputs and outputs and take weighted outputs and weighted inputs, but the weights must be given prior to the calculation of PIs. Readers interested in performance indicators in higher education are referred to Cave *et al.* (1991) or Johnes and Taylor (1990).

Data Envelopment Analysis when applied to the evaluation of universities has the advantage that there is no need to assign prior weights to inputs and outputs. DEA is attaching the 'best' weights possible for each institution's profile of input-output values. For example, Bessent *et al.* (1983) used the CCR model to analyse the performance of technical colleges. Ahn *et al.* (1988) used DEA to compare the efficiencies of private and public institutions in the USA. Beasley (1989) used DEA for comparing university departments. Readers interested in DEA in higher education could refer to Sarrico (1999). For comprehensive bibliography of DEA see Emrouznejad (2001).

However, in almost all DEA studies in higher education, data for one year is used. Some authors have indicated that the efficiency of a university could not be captured by analysis of one year's data only. For example Tomkins and Green (1988) in the assessment of UK universities pointed out that "ideally one needs data over more years for some of the variables used". Beasley (1989) used data for one year to analyse the performance of university departments but he has noted that "it is clear departments should be compared over a number of years (e.g. equipment expenditure in one year will affect research output in future years)".

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In this paper we demonstrate a dynamic DEA model that could be used for evaluating efficiency in higher education. In particular we assess the UK universities for the period 1995 to 1998. The next section identifies input and output variables and sets up the different models which can be used to assess HEIs.

2. Setting up the assessment model

Input output variables

The determination of input output variables is difficult in an educational organisation and in particular in university assessments. The main products of a university are its teaching and research outcomes. Therefore in order to assess HEIs on their responsibility of delivering knowledge it is necessary to identify input output variables pertaining to this function.

The inputs should represent all the resources used and the outputs the corresponding activity levels of the research and teaching as main objectives of the HEIs. However, following publication of HEFCE PIs, we want to use inputs and outputs as close to those of HEFCE as possible to make the comparison of the dynamic DEA results with this set of PIs easier. In this set, HEFCE (2001,2000, 1999a and 1999b) has used two inputs (Academic staff cost and Funding council allocation for research) and two outputs (Number of PhDs awarded and Income from research grants and contracts)

The HEFCE indicators therefore look on the number of PhDs awarded and income of research grants and contracts relative to the academic staff cost and to the funding council allocation for research to that institution. The main advantage of HEFCE PIs is that they took into account the different patterns of input to output in different cost centres and then combined them to give the single indicator. However in our DEA analysis we ignore the difference in different cost centres and treat all cost centres similarly.

The main criticism of the use of the above input output variables is that academic staff cost is used for training of both undergraduate as well as postgraduates, including PhDs. This is also pointed out in the first report of Performance Indicator in higher education (see HEFCE 1999a, page 21). An indicator of number of PhDs to academic staff cost may be incorrect and perhaps misleading when they are used solely for interpretation of university performance. A university that efficiently uses its resources on the academic staff cost for undergraduate purposes and does not produce a high number of PhDs may be given a very low score. Yet, a university which is not using its resource on the academic staff cost efficiently on teaching but produces a large number of PhDs will be given a higher score. However this indicator would be more acceptable if it used only *research* academic staff cost as input but unfortunately disaggregated data for academic staff cost by research and teaching is not available. The same problem applies to the indicator of research grants and contracts relative to academic staff cost. The numerator of this indicator covers the income from research activity while its denominator covers both research and teaching academic staff cost. To avoid this problem we have to recognise what other output should be involved when we include academic staff cost in a multiple input output model like DEA.

As a proxy of output of academic staff cost we also include in the model number of undergraduates and other postgraduates awarded degrees in addition to the number of PhDs awarded. With these three outputs we need to include other staff cost as well as academic staff cost. Therefore it would be more appropriate better to use total funding council grants for input purposes. This includes both academic and non-academic staff cost as well as any other cost in the institution.

The funding council grant can be generally categorised into recurrent and capital cost (Ahn *et al.* (1988)). Disaggregation of total funding council grant to current and capital enables us to define a dynamic model and to distinguish between current and capital input. Therefore on the input side the two main inputs in our model are capital and recurrent grants allocated by Funding Councils. The recurrent grants are the block grant for teaching and research and include academic and other staff cost. The capital grants include all non-recurrent grants from the funding council to support special initiatives and capital grants in respect of buildings and equipment. Therefore the inputs are:

- REC: Total recurrent grants.
- CAP: Total capital grants.

On the output side and following the above discussion we consider, for each academic year 4 output measures as follows.

- RGC: Income from research grants and contracts.
- PhDs: Number of PhDs awarded.
- PGs: Number of other postgraduate degrees awarded, not including PhDs.
- UGs: Number of undergraduate degrees awarded.

It must be noted that our model is mainly for comparison with the HEFCE PIs. Both assessments ignore other research outputs such as papers or the quality of research.

Note that we regard research income as an output measure. In HEFCE PIs also it is considered as output but this contrasts with some previous work, for example Beasley (1989) who used research income as input measure. Tomkins and Green (1988) pointed out that there is confusion over the role of research income. They noted that "some conceptual development is needed regarding income generation as a measure of output. Where income is generated to further academic research that income is an intermediate measure of output." Overall also some have used research income as an input measure and others used it as an output measure but research income is output in some stages and input at another stages. Therefore a static analysis will not be able to capture the role of the research income in educational organisations like universities. However we believe that our dynamic DEA model will capture the role of research income better than static DEA would since in a dynamic model we assess a university over a longer period.

Data

The assessment periods we are examining in this paper are the academic years 1994-1995, 1995-1996, 1996-1997 and 1997-1998. For simplicity, hereafter, we refer to each of these academic years to 1994, 1995, 1996 and 1997 respectively. The data we used in this study are derived from the publication of Higher Education Statistics Agency (HESA). The Higher education Statistics Agency is the official agency of the collection, analysis and dissemination of quantitative information between the relevant government departments, the higher education funding councils and universities and colleges.

REC, CAP and RGC are derived from HESA (1996), HESA (1997a), HESA (1998a) and HESA (1999a). UGs, PGs and PhDs are derived from HESA (1997b), HESA (1998b) and HESA (1999b). We include 102 Institutions in our analysis which data is available over the assessment periods.

Assessment by standard DEA

In order to formulate the DEA model for the academic year t we denote;

- REC_j^t : Total recurrent grants in year t for the j^{th} university.
- CAP_j^t : Total capital grants in year t for the j^{th} university.
- RGC_j^t: Income from research grants and contracts in year t for the j^{th} university.
- $PhDs_j^t$: Number of PhDs awarded in year t for the j^{th} university.

- PGs_j^t: Number of other postgraduates awarded in year t for the j^{th} university.
- UGs_j^t: Number of undergraduates awarded in year t for the j^{th} university.

It is assumed that constant returns to scale hold in the DEA analysis. Therefore the DEA model solved, in academic year t, to estimate the relative efficiency of university j_0 is Model 1. This is the weights based version of the CRS DEA model. The weights that Mode 1 determines are:

Input weights: v^t_{REC}, v^t_{CAP}

Output weights: $u^t_{UGs}, u^t_{PGs}, u^t_{PhDs}, u^t_{RGC}$

These weights are called "virtual multipliers". The weighted output in each year is the "virtual output" in the reference year, t; i.e.

$$WO^t = (u^t_{UGs} \times UGs)+(u^t_{PGs} \times PGs)+ (u^t_{PhDs} \times PhDs)+ (u^t_{RGC} \times RGC).$$

The weighted input in each year is the "virtual input" in the reference year, t:

$$WI^t = (v^t_{REC} \times REC)+(v^t_{CAP} \times CAP).$$

It is arguable that weights attached to PhDs should be no less than weights attached to PGs, and the weights attached to PGs should be no less than the weights attached to UGs. Therefore a simple weight restriction can be added to the model as follows:

$$u^t_{UGs} \leq u^t_{PGs} \leq u^t_{PhDs}$$

Beasley (1989) in the analysis of efficiency of UK higher education accounting departments used similar constraints but he restricted them more, ensuring that the weight associated with a PhD is at least 25% greater than the weight associated with a taught postgraduate and a weight associated with a taught postgraduate is at least 25% greater than the weight associated with an undergraduate student. Obviously setting up such weight restrictions would affect the results but for the purpose of our model we admit the concept of his weight restrictions and set up

$$1.25\, u^t_{PGs} \leq u^t_{PhDs}$$

$$1.25\, u^t_{UGs} \leq u^t_{PGs}$$

As Beasley (1989) also mentioned, it is clear that policy makers might have set up their own preferred weights and run the model again.

For university j_0 Model (1) finds the best weights for inputs and outputs so that its efficiency measure is maximised. In other words the model maximises the sum of the ratio of the virtual output to the virtual input in the reference year t. i.e;

$$\text{Maximise } \frac{WO^t}{WI^t}.$$

Therefore each university is assigned the highest possible efficiency score that the constraints allow from the given data by choosing the appropriate virtual multipliers (weights) for the outputs and inputs in the reference year t.

The constraints ensure that none of the HEIs register an efficiency measure greater than 1. If the optimum value of the objective function is 1 then university j_0 is relatively efficient in the sense that it cannot improve the level of any one output without at the same time shrinking the level of some other output or input.

Model 1. A DEA model for assessing HEIs in academic year t.

$$Max\ (u^t_{UGs} \times UGs^t)_{j0} + (u^t_{PGs} \times PGs^t)_{j0} + (u^t_{PhDs} \times PhDs^t)_{j0} + (u^t_{RGC} \times RGC^t)_{j0}$$

$s.t.$

$$[(u^t_{UGs} \times UGs^t)_j + (u^t_{PGs} \times PGs^t)_j + (u^t_{PhDs} \times PhDs^t)_j + (u^t_{RGC} \times RGC^t)_j\ ]$$
$$-[\ (v^t_{REC} \times REC^t)_j + (v^t_{CAP} \times CAP^t)_j\ ] \leq 0 \qquad ;\forall j$$
$$(v^t_{REC} \times REC^t)_{j0} + (v^t_{CAP} \times CAP^t)_{j0} = 1$$
$$1.25 u^t_{PGs} \leq u^t_{PhDs}$$
$$1.25 u^t_{UGs} \leq u^t_{PGs}$$
$$u^t_{CAPOUT} \leq u^t_{PhDs}$$
$$\text{All u and v} > 0.$$

We run the static Model (1) for each academic year 1995-96, 1996-97, 1997-98. As an overall static DEA efficiency we calculated the average of the efficiency scores obtained by each institution in these academic years. This average is more suitable for comparison with our dynamic DEA scores over the same years.

The distribution of institutions over the range of efficiency rating obtained is shown in Table 1. The results indicate that in comparative terms all but 5 institutions could reduce some of their source in these academic years.

As already noted, the sole data used in each academic year may mean that the efficiency estimates are incorrect or, alternatively, that an institution which appears relatively inefficient may be able to justify its lower activity levels for its resource levels by investing them for future purposes. This is in particular correct when high level of capital input, for example, could increase the level of future output but it can not be captured in static DEA, then the institution becomes less efficient in the reference assessment period.

Table 1. Distribution of average relative efficiency obtained from static contemporaneous DEA in 1995-1996, 1996-1997 and 1997-98.

Efficiency range	**Number of Institutions**
Efficiency < 39.99	6
40-49.99	18
50-59.99	28
60-69.99	24
70-79.99	12
80-89.99	5
90-99.99	4
100	5

The next section assess the performance of institutions over a longer period of time using the dynamic DEA model introduced in this paper.

Assessment by dynamic DEA

In this section we proposes a DEA based method for assessing the comparative efficiencies of HEIs operating production processes where input - output levels are inter - temporally dependent. One cause of inter - temporal dependence between input and output levels is stock input which influences output levels over many production periods. Such HEIs cannot be assessed by traditional or 'static' DEA (Thanassoulis, Emrouznejad (1996)).

Let us now consider assessment of HE institutions over 1995-96, 1996-97 and 1997-98. We use the dynamic DEA model for assessing the HEIs on the same data set and for the same academic years as above (see Thanassoulis, Emrouznejad (1996) for further details). For this, we need an initial and a final capital input. Obviously it is very difficult to estimate the initial capital but as a proxy measure the capital input in 1994 is considered as initial capital for assessment periods 1995 to 1997, thought this is only part of the larger underlying capital prior to 1995. We are not capturing changes to base capital prior to 1995. The capital output is the total capital during the periods under assessment and includes initial capital. We have not assigned any depreciation (or appreciation).

In order to formulate the model mathematically let;

- $CAPIN_j$ be the level of initial capital for the j^{th} university.
- $CAPOUT_j$ be the level of capital output as of the last year of the assessment period for the j^{th} university.

The other variables needed are REC_j^t, CAP_j^t, RGC_j^t, $PhDs_j^t$, PGs_j^t and UGs_j^t which are as defined earlier in this paper.

In setting dynamic DEA we set up a weights version of the model, as it is better for presenting the weights restrictions. Therefore for each university we find the best weights for inputs and outputs in each academic year:

- Input weights: v_{CAPIN}, v^t_{REC}, v^t_{CAP}
- Output weights: u^t_{Ugs}, u^t_{PGs}, u^t_{PhDs}, u^t_{RGC}, u_{CAPOUT}

We also find the sum of maximum ratio of the weighted output to the weighted input.
Like static DEA, the output and input weights are called "virtual multipliers". The weighted output in each year is the "virtual output" in the reference year, t:

$$WO^t = (u^t_{UGs} \times UGs)+(u^t_{PGs} \times PGs)+(u^t_{PhDs} \times PhDs)+(u^t_{RGC} \times RGC).$$

The virtual output over three years is the sum of the virtual outputs of the three years plus the virtual output for capital output in the last period, i.e.

$$WO= WO^{1995} + WO^{1996} + WO^{1997} + (u_{CAPOUT} \times CAPOUT)$$

The weighted input in each year is the "virtual input" in the reference year, t:

$$WI^t = (v^t_{REC} \times REC)+(v^t_{CAP} \times CAP).$$

The virtual input is the sum of the virtual inputs of the three years in the assessment horizon plus virtual input from initial capital input in the first year, i.e.

$$WI= (v_{CAPIN} \times CAPIN)+ WI^{1995} + WI^{1996} + WI^{1997}.$$

The model maximises the average of the ratio of the total virtual output to the total virtual input over periods under consideration subject to holding the virtual input of the institution under assessment equal to unity at each time and make sure that the total virtual output would not be greater than the total virtual input for all institutions in the assessment set.

Therefore each university is assigned the highest possible efficiency score that the constraints allow from the given data by choosing the appropriate virtual multipliers (weights) for the outputs and inputs over assessment periods.

Like static DEA to avoid attaching equal weights for UGs, PGs and PhDs we use the weight restrictions that we set up already. i.e.

$1.25\ u^t_{PGs} \leq u^t_{PhDs}\ ;\ \forall t$

$1.25\ u^t_{UGs} \leq\ u^t_{PGs}\ ;\ \forall t.$

Moreover, with respect to the capital output at the end of assessment periods we felt that the weight associated with it should be related to the weight associated with other outputs within the assessment periods. Essentially the purpose of considering capital output at the end of the assessment periods is that it can potentially be used to produce outputs in future. Arguably output after the assessment periods is less certain than that observed during the assessment periods and so the terminal output cannot be more valuable than the output during the assessment periods itself. Therefore for the purposes of this study we set up the following weights.

$u^t_{CAPOUT} \leq\ u^t_{UGs}$

$u^t_{CAPOUT}\ \leq\ u^t_{PGs}$

$u^t_{CAPOUT}\ \leq u^t_{PhDs}$

An alternative way would be to restrict the weight for terminal capital output in relation to the weight attached to the initial capital. Our initial capital only related to 1994 and so we did not pursue this approach.

With the above specification the model we solved for dynamic DEA is Model (2) which also includes extra constraints for weight restrictions.

Model 2. Dynamic DEA model for assessing HE institutions in 1995 to 1997.

$$Max\ \frac{1}{3}\sum_{t=1995}^{1997}\left[(u^t_{UGs}\times UGs^t)_{j0}+(u^t_{PGs}\times PGs^t)_{j0}+(u^t_{PhDs}\times PhDs^t)_{j0}+(u^t_{RGC}\times RGC^t)_{j0}\right]$$
$$+(u_{CAPOUT}\times CAPOUT)_{j0}-(v_{CAPIN}\times CAPIN)_{j0}$$

s.t.

$$(u_{CAPOUT}\times CAPOUT)_j +$$
$$\sum_{t=1995}^{1997}\left[\ (u^t_{UGs}\times UGs^t)_j+(u^t_{PGs}\times PGs^t)_j+(u^t_{PhDs}\times PhDs^t)_j+(u^t_{RGC}\times RGC^t)_j\ \right]-$$
$$(v_{CAPIN}\times CAPIN)_j - \sum_{t=1995}^{1997}\left[\ (v^t_{REC}\times REC^t)_j+(v^t_{CAP}\times CAP^t)_j\ \right]\leq 0 \quad \text{for } j=1,...102.$$

$$\left.\begin{array}{l}(v^t_{REC}\times REC^t)_{j0}+(v^t_{CAP}\times CAP^t)_{j0}=1\\ 1.25u^t_{PGs}\leq u^t_{PhDs}\\ 1.25u^t_{UGs}\leq u^t_{PGs}\\ u^t_{CAPOUT}\leq u^t_{PhDs}\\ u^t_{CAPOUT}\leq u^t_{PGs}\\ u^t_{CAPOUT}\leq u^t_{UGs}\end{array}\right\}\text{for } t=1995, 1996 \text{ and } 1997.$$

All u and v > 0.

Using this model the total of 102 institutions were assessed using data for the academic years 1994 to 1997. The distribution of HEIs over the range of efficiency ratings obtained are shown in Table 2.

Table 2. Distribution of relative efficiency obtained from dynamic DEA.

Efficiency range	Number of Institutions
Efficiency < 40	3
40-49.99	9
50-59.99	27
60-69.99	22
70-79.99	18
80-89.99	13
90-99.99	2
100	8

The model indicates that 8 institutions are dynamically efficient while the remaining 94 institutions are dynamically inefficient. It means that 94 inefficient institutions are able to reduce their resources used within years 1995 to 1997 and without reducing any of their output levels. Obviously we did not take into account the quality of output, notably the quality of the research output. This may affect the accuracy of the efficiency scores obtained. But this applies to static DEA and the HEFCE PIs too.

The next section assesses the performance of HEIs using performance indicators.

Assessment HEIs by Performance indicators

In order to compare the three approaches, Dynamic DEA, Static DEA and PIs we constructed PIs defined as the ratios of each output to each input variable used within the dynamic DEA for each academic year. Then the PIs constructed are:

- UGs/ CAP; Ratio of undergraduate degrees awarded to capital cost.
- PhDs / CAP; Ratio of PhDs awarded to capital cost.
- PGs/ CAP; Ratio of other postgraduate degrees awarded to capital cost.
- RGC/ CAP; Ratio of income from research grant and contracts to capital cost.
- UGs/ REC; Ratio of undergraduate degrees awarded to recurrent cost.
- PhDs / REC; Ratio of PhDs awarded to recurrent cost.
- PGs/ REC; Ratio of other postgraduate degrees awarded to recurrent cost.
- RGC/ REC; Ratio of income from research grants and contracts to recurrent cost.

Each one of these ratios is calculated for the three academic year 1995-1996, 1996-1997, 1997-1998. Some of these PIs are very similar to those defined and published by HEFCE (2001, 2000, 1999b). However we decided to reproduce them here. There are several reasons for this. First, the published PIs are available only for the academic year 1997-98. Our dynamic DEA model covers three academic years. Secondly, in the publication there are only 4 PIs while the number of inputs and outputs in our model gives rise to 8 PIs. Thirdly, our sector comprises 102 institutions hence our dynamic DEA and static DEA scores are represent the efficiency respect to the best frontier within the set of 102 institutions while HEFCE published PIs for 170 institutions. The data for three years is available for these institutions only. Finally, the published PIs are adjusted by cost centres neither our DEA models take into account the factor of different cost centres.

Table 3 shows the pair - wise correlation of eight PIs.

Table 3. Pair - wise correlation PIs

	UGs/ CAP	PGs/ CAP	PhDs/ CAP	RGC/ CAP	UGs/ REC	PGs/ REC	PhDs/ REC	RGC/ REC
UGs/ CAP	1							
PGs/ CAP	0.112326	1						
PhDs/ CAP	-0.37091	0.443588	1					
RGC/ CAP	-0.53604	0.307881	0.869438	1				
UGs/ REC	0.846854	-0.10698	-0.58161	-0.66861	1			
PGs/ REC	-0.16753	0.867131	0.386919	0.320694	-0.20319	1		
PhDs/ REC	-0.52272	0.299444	0.939361	0.862777	-0.61271	0.373416	1	
RGC/ REC	-0.70412	0.154068	0.781952	0.953973	-0.71601	0.283883	0.855585	1

The PIs do not generally agree on the performance of an institution. Therefore the correlation coefficients are generally low in most cases and are negative in some (in 19 pairs out of 28 pairs, the correlation coefficients are negative or less than 0.50). The negative correlation coefficients are not really surprising and they are fully consistent with different objective of the institutions in the comparison set. For example the negative correlation between UGs / REC and PhDs / REC (=-0.61271) is showing that universities with high level of research may fail in the undergraduate training and so universities with high level of teaching may not gain high level of the research output. Large correlation coefficients in table 3 are due to the highly correlated corresponding activities captured in those PIs. For example, the coefficient of 0.855585 between PhDs / REC with RGC/ REC indicates that both number of PhDs awarded and income from research grants and contracts are very correlated.

3. Comparison of dynamic DEA scores with static DEA and PIs

The dynamic DEA efficiency measure of institution j_0 maximises the sum of the ratio of the virtual output to virtual input over three academic years (See Model (2)). The virtual input and virtual output are determined based on the optimal weight value that Model (2) assigned to the institution under assessment. These weights values are determined so as the model maximises the efficiency score of the institution assessed simultaneously over three academic years and with consideration of what level of capital the institution had before the time horizon and what level of the capital the institution will have at the end of the horizon for the future. The static DEA scores in each year can be seen as being a particular instance of the corresponding dynamic DEA efficiency score. Let us for example assume that in the context of our dynamic DEA model we consider only the academic year of 1996-1997 and ignore the initial and capital constraints in the dynamic DEA. Therefore the dynamic DEA model will collapse to static DEA for the reference year 1996-97. In terms of similarity, hence, it can be seen that static DEA can be thought of as an instance of dynamic DEA. Dynamic DEA thus gives more realistic scores to units where they are operating over several years. One disadvantage of dynamic DEA occurs when there are large numbers of periods in the assessment horizon. In this case the weight flexibility of dynamic DEA may well lead to little discrimination between various units, while static DEA models may well represent the differences between DMUs better.

Similar to the above discussion each PI, in the reference period, can be seen as an instance of the static DEA model in that period with inclusion of the one input and one output as indicated in the PI and replacing all other input outputs to zero. Again the difference between static DEA and PIs will arise from the fact that DEA will examine the performance of a unit with reference to possibility of increasing all outputs or decreasing all input, simultaneously, while PIs consider the maximum gain in a single output from a single input, but both static DEA and PI are within the reference year.

Consistency of the three approaches

For comparison of theses models we ranked universities in each model and the correlation coefficients of the ranks shows that there are always positive but generally very poor agreement between individual PIs and dynamic DEA. The overall rank of dynamic DEA is highly correlated to static DEA rank. This suggests that generally dynamic DEA and static DEA are in the same direction with very high association. The more general practical significance of this finding is that we will get a similar view on performance from a period - specific static DEA and from dynamic DEA. Dynamic DEA takes into account more general performance by an institution over several years simultaneously and thus it conveys a broader view of the institution's efficiency.

Despite the overall agreement between the static and dynamic DEA the two approaches disagree substantially in some institutions. This can be seen by looking at the actual ranks of the two approaches. Comparison of the static and dynamic DEA results indicates that 62 institutions are ranked very closely (Absolute deviation of the two ranks <10), 27 institution are ranked with difference between 10 to 20, the remaining 13 institutions are ranked very differently in the two static and dynamic DEA approaches. The main reason that dynamic DEA gives different scores to these institutions is that, firstly, dynamic DEA assesses the institutions by examining them over three academic years simultaneously and secondly, the variation of capital input affects much more the dynamic than the static efficiency. We would argue that the three approaches complement each other rather to replace one another. Each gives a different insight to the efficiency of organisations like universities.

4. Conclusion

In this paper we introduced a dynamic DEA model which can be used for assessment of organisations with inter-temporal input output over several periods of time. We then compared dynamic DEA, static DEA and performance indicators as alternative tools for assessing the performance of higher education institutions in UK. Such institutions use resources to secure outputs over several years. We commented on the recent publication of HEFCE PIs (2001, 2000, 1999b) and extended it to cover several more PIs which could complement each other. Then we analysed the same data set using static contemporaneous technology. Static DEA is trying to find the best frontier in each year and ignores the possibility of using previous resources or the possibility of enhancing the resources left for future output. The issue is addressed by setting up a dynamic DEA model.

We then attached a rank to each institution on performance using each of above three assessments to make our results by the three alternative approaches reasonably comparable. The study showed that there is consistency as well as diversion between the three approaches. We concluded that the three approaches complement each other, rather than replace one by another, in the sense that each one offers a different perspective of the performance of each institution.

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Management Factors Influencing Efficiency of Childhood Immunisation Program in Australia

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Abstract
This study uses both Cost and Data Envelopment Analysis to estimate management efficiency of childhood immunisation program in Australia. Average and marginal cost per immunisation encounter are calculated for infant and school immunisation programs across 34 Local Governments in the State of Victoria. Cost analysis reveals considerable economies of scale, with throughput being the single largest predictor of the cost per encounter. The variation in cost is likely to relate to differences in management practices. DEA model is applied to analyse comparative efficiencies of participating LGs and potential efficiency gains are identified. Benchmarking identifies specific management practices as particularly cost effective. The important conclusion is that even those LGs operating outside their optimal productive scale appear to be more cost effective than local family doctors.

Keywords: Health Care Systems, Efficiency, DEA, Cost Modelling

1. Introduction

Local Governments (LGs) in Australia have a statutory obligation to offer immunisation services to children within their municipal district. LGs carry out regular immunisation sessions (clinics) at community venues for infants (0-5 year olds) and vaccinate school age children during school hours. The cost of vaccines is covered from the Federal budget, rendering them "free" for either the families of young children or immunisation providers. The cost of immunisation is met by LGs with some financial assistance from the Department of Human Services (DHS) of the State of Victoria in the form of a special-purpose grant. The size of the grant depends on the local area's demographic profile but is generally provided on a historical basis that is not directly linked to the unit cost or specific performance indicators.

According to the data provided by the Australian Bureau of Statistics, by mid-1990s childhood immunisation coverage in Australia fell below the level required to prevent the spread of infectious diseases. In 1995 33% of all Australian children aged three months to six years were fully immunised for their age (ABS, 1996). Listed among the "barriers to immunisation" were the increased complexity of the immunisation schedule[1] and changes in

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[1] As of 1999 the National Immunisation schedule for pre-schoolers included 4 immunisation encounters each involving 1 to 3 vaccines at a time during the first year of the child's life and two vaccine episodes at the ages of 18 months and 4 or 5. Secondary school immunisation schedule included 4 immunisation encounters involving 1 to 2 vaccines at a time. In addition Hepatitis B vaccine for infants is available on request. This is administered at birth, 1 month and 6-12 months.

attitude towards immunisation benefits among some parents and medical practitioners (Bailey, 1999).

As clinic attendances had fallen, some LGs, especially in rural areas, have reduced the number and/or duration of the clinics they provided thus reducing the service accessibility. Apparently a self-reinforcing feedback loop effect was thus established: the fewer immunisation sessions were offered, the fewer parents participated in LG's immunisation program.

The fall in attendance of immunisation clinics was paralleled by an increase in the number of general practitioners[2] (GPs), administering infant vaccines. Prior to 1995, only 15% of childhood vaccines in Victoria were administered by GPs in private practice (DHS, 1997).

This figure increased to about 45% by June 1998 when Immunisation Provider Incentive Scheme was introduced (HIC, 1999). This Federally funded Scheme partly compensated GPs and LGs for administrative expenses associated with providing information to the Australian Childhood Immunisation Register (ACIR) and offered GPs a financial incentive to fully vaccinate each child attending their practice. Another Regulation also introduced in 1998 ensured a strong incentive for parents of young children to adhere to the immunisation schedule (Bond, 1999).

By the time the data for our study was collected in 1997/1998, these combined policy initiatives halted a further decline in LG immunisation program participation. Since 2000 the provision of immunisation services remained equally divided between LGs and GPs[3]. Immunisation coverage in Victoria also improved; as of December 2001, 91% of all children in Victoria were fully immunised for their age (HIC, 2002).

The motivation for this study was provided by the request of the DHS to advise on the basis for resource allocation for immunisation programs in Victoria. The DHS also sought advice on the best preforming LGs (benchmarking). As this study was developing, its scope became sufficiently wide to accomodate the goals of both health care authorities: LGs as a principal funder and immunisation provider and the DHS as a policy setter and a part-funder. These goals included improving efficiency without compromising accessibility. Maintaining accessibility involved firstly, selecting various venues for the clinics, including those in remote areas; secondly, scheduling the clinics at various time of the day including after business hours, and, finally, providing adequate advertising targeting parents of young children.

In order to advise the industry on the best course of actions, this study set up the following objectives:

- to identify most suitable basis for immunisation program reimbursement policy and conduct cost analysis, and
- to locate "best practices" and investigate any potential for efficiency improvement

This paper is organised as follows: sections 2 and 3 present the suggested analysis framework from the Department of Human Services, and local government perspectives correspondingly; data collection and validation procedures are reported in section 4; cost analysis is conducted

[2] GPs are also known as family doctors, they provide the bulk of primary health care to Australian population.

[3] As of Feb 2002, 48.8% and 50% of all vaccinations were provided by LGs and GPs correspondingly. The remaining 1.2% were administered in the form of "opportunistic" immunisation at Maternity and Child Health Centres and at hospitals.

in section 5; section 6 is dedicated to the application of Data Envelopment Analysis to the problem described, while section 7 provides summary and conclusions.

2. Analysis Framework: Department of Human Services perspective

The DHS' main objective was to achieve maximum immunisation coverage for a given budget. From that perspective the DHS may not necessarily exercise any preferences with respect to an immunisation provider: if GPs proved to be more efficient in terms of immunisation coverage, then the funds would need to be relocated in their favour. Moreover, relegating immunisation services to private practitioners would shift the cost of immunisation from the State budget to the Federal one, as the bulk of GPs' remuneration has been coming from the Commonwealth-funded Medicare program. In practice, however, the DHS had a strong sentiment towards maintaining the viability of LGs' as immunisation providers.

As far as the DHS was concerned, economic efficiency improved if the size of immunisation subsidy was linked to the program outcome. In other words, the reimbursement rate would ideally be linked to the number of fully immunised children in the local area. Unfortunately, the data capturing protocols currently used by the industry did not easily allow tracing down childrens' immunisation status to the particular immunisation provider. By that reason the Immunisation Provider Incentive Scheme reimbursed LGs on the basis of immunisation encounter[4]. Establishing another reimbursement scheme, which would operate on an alternative basis, was not a feasible solution due to excessive stress it would have put on already complicated reporting and accounting system of the LGs. Therefore the cost per encounter was chosen as a unit cost. The implication of this approach was that reimbursement on the basis of cost per encounter would encourage LGs to minimise the cost per encounter and increase immunisation coverage up to the point where marginal cost exceeded the pay.

Although the DHS was equally committed to maintaining immunisation services accessibility, it could exercise a differential approach in assessing the long-run viability of LGs' immunisation programs. In particular, it may choose to close down LG provided vaccinations in some rural areas where scale inefficiencies may result in larger unit costs than the cost of visiting a GP. In such instances, if the supply of immunisation services from GPs can cover the entire local population of pre-schoolers, and no other barriers were in place, closing down the LGs' infant immunisation program would improve resource allocation from the State's perspective. Therefore when assessing comparative efficiency of LGs from the DHS perspective, we analysed both inefficiency due to operations outside the optimal productive size of immunisation program (scale inefficiency) and due to poor selection of resource inputs necessary for the production of a particular service (pure technical inefficiency) (Banker, 1984).

3. Analysis Framework: Local Governments' perspective.

Since LGs had no control over the supply of services from the local GPs or parental preferences towards an immunisation provider, we assumed the immunisation program output (number of immunisation encounters) to be exogenously determined and constant for the short run. Therefore the LGs' main objective was to provide immunisation services at a minimum cost to themselves. In order to ahieve this objective, the following set of management decisions should be addressed:

[4] Each encounter may involve more than one vaccine, but since the cost of vaccines is not borne by the provider, the cost per encounter does not vary significantly with the number of administered vaccines.

- to estimate the demand for immunisation services, i.e. annual number of immunisation encounters (a throughput) from the observed participation in immunisation clinics and the current school enrolment;
- to determine the size of immunisation program (i.e. annual number and duration of immunisation clinics);
- to decide on the staff mix for immunisation sessions;
- to ensure administrative support of the program by employing managerial and clerical staff.

LGs did not allocate two separate budgets for infant and school sub-programs. The single budget covered all the fixed costs, while all administrative and some vaccination staff were involved in both sub-programs. LGs had an option of contracting registered nurses on a casual basis, which allowed for greater flexibility in allocating staff according to the fluctuations in throughput. Although from the LGs' perspective estimating unit cost of infant and school immunisation programs separately provided some useful insights, for the purposes of efficiency analysis the data aggregated across the sub-programs should be used.

At the time of the study the trend to scale down the number of immunisation clinics was reversed in order not to decrease the service accessibility any further. This situation may have resulted in some of the LGs operating outside their optimal productive scale size. The primary purpose of efficiency analysis from the LGs' perspective was then to investigate any potential for efficiency improvement after the scale inefficiencies were accounted for.

The overall study framework encapsulating both DHS and LGs perspectives, as well as corresponding objectives and methods is presented in Table 1.

Table 1. The study framework.

Level of decision making	Objective	Task	Method
Local Governments: immunisation provider and a principal funder.	Minimise the total cost of immunisation program for a given throughput.	1. Calculate the average and marginal cost for each LG. 2. After adjusting for scale inefficiencies investigate the factors for efficiency improvement.	Cost-analysis. Variable return to scale DEA input oriented model.
Dept of Human Services (Victoria). Strategic policy maker and a part-funder.	Maximise immunisation coverage for a given immunisation program budget.	1. Calculate average and marginal cost of the immunisation program. 2. Estimate the long-term viability of inefficient LGs. 3. Select the best performing LGs according to efficiency and accessibility criteria.	Cost-analysis. Variable return to scale DEA output-oriented model. Benchmark selection.

4. Data collection and validation

Cost data and the number of immunisation encounters in the 1997/98 financial year were collected using a self-administered postal questionnaire. Out of 78 LGs in Victoria, 41 (53%) returned the questionnaires. The reasons for not participating included: closure of infant immunisation program (2 rural councils), and lack of resources (staff time) and expertise to undertake the task that required some basic understanding of accounting. Of that number, two LGs were able to provide complete data only on infant immunisation sub-program, therefore only partial use of these data was possible.

The questionnaire included a number of cross checks for internal consistency on salary costs, time use of staff, total budget and component cost data. External validity of the throughput for the infant immunisation program was checked against the data provided by the ACIR.

After the validation, the information from five LGs was found unreliable and consequently discarded, resulting in 37 (47%) LGs included in the cost-analysis of infant immunisation program and 34 (44%) in the cost-analysis of school immunisation program and efficiency analysis.

The study sample distribution over geographical areas with different size of the target population was similar to the distribution of the entire number of LGs over the target population of Victoria. For example, *t*-test (Lewis, 1990) showed that there was no statistically significant difference with respect to the average size of the population of 0-4 year olds residing in 14 metropolitan councils included in the sample and the remaining 18 urban councils (p=0.73) (Harris, 2000).

5. Cost modelling

The data on the resource input were collected in Australian dollars using 1998 prices. Typically immunisation staff included at least one doctor who is assisted by registered nurses. Clinic preparation and administrative duties were divided between nurses, environmental health officers and administrative officers. In rural LGs the population was spread across a larger geographical area than in metropolitan councils, which involved longer travel hours to and from immunisation sessions.

Staff costs were obtained in the form of staff time spent on each of the activities (travelling, preparing for the clinic, packing up, record keeping, etc.) and multiplied by the respective hourly rate for each staff category. Venue hire, corporate services (IT support, accounting, payroll etc), materials and small equipment were available as cost per annum. Annuitised cost of each individual capital item was calculated.

In order to explore the possibility of economies of scale in the provision of immunisation services and estimate a possible effect on differences in cost arising from the differences in geographical location (metro vs rural LGs) we used linear regression analysis. The combined impact of both variables on cost per encounter was investigated in a multiple regression on both variables: number of encounters and metro/rural.

Let C be the vector of average cost for each council; β_0 be a constant; E be the vector of number of encounters for each council; M be a metro/rural binary dummy variable (M=1 for metro and M=0 for rural); and u be a random error term. Then C can be estimated from equation (1) for a semi-log functional relationship or (2) for double-log functional relationship (Lewis, 1990):

$$C = \beta_0 + \beta_1 \log E + \beta_2 M + u \quad (1)$$

$$\log C = \beta_0 + \beta_1 \log E + \beta_2 M + u \quad (2)$$

Marginal cost analysis was conducted using the statistical model of the best fit to estimate the cost of immunising an extra child at the observed level of throughput. Cost analysis was performed separately for infant and school immunisation sub-programs.

Table 2 shows average cost per immunisation encounter with 95% confidence intervals by aggregated cost categories for infant and school immunisation programs.

Table 2. Average cost of infant and school immunisation programs by cost category

	Infant immunisation (N=37) ($)	School immunisation (N=34) ($)
Staff cost per encounter	**17.00** [95%CI 13.50 - 20.50]	**8.00** [95%CI 5.50-10.40]
Capital, consumables, corporate overheads and other costs per encounter	**6.20** [95%CI 5.00 - 7.30]	**4.50** [95% CI 3.40-5.70]
Total cost per encounter	**23.20** [95%CI 19.10-27.20]	**12.50** [95%CI 9.50-15.40]

Cost per immunising an infant was more than twice the cost of immunising a school student. This difference was statistically significant (*t*-test for paired samples: t=4.5. p<0.001) and was likely due to the combination of the following factors (Harris, 2000):

- Differences in clinic staff mix, with a doctor more frequently participating in vaccinating infants than school children.
- Infant immunisation involves considerably more administrative staff hours.
- Higher level of certainty in estimating the number of school children allows better planning for the number of staff needed for school immunisation sessions. On the contrary, the level of attendance of infant clinics is subject to random fluctuation, which may result in systematic over-staffing.

The regression model in semi log functional form (1) produced the best fit (in terms of explanatory power - R^2) for infant immunisation program, explaining 71% of the overall cost variation. Using this functional form the marginal cost of immunising one additional child was estimated for each LG. For example, at the mean encounter (n=2839) an extra encounter had a cost of approximately $10.00.

The regression model with a double log functional form (2) produced the best fit for school immunisation program confirming that throughput was the single largest predictor of the total cost per encounter, which explained 63% of the overall cost variation. At the mean encounter (n=2995) an extra encounter had a cost of $4.40.

The predictive power of the model (2) increased even further when the cost per encounter was estimated using the combined data from both sub-programs: the differences in throughput explained 78% of the overall cost variation. At the mean encounter (n=5834) an extra encounter had a cost of $5.40. This model estimated an average cost per encounter at $15.10, which is close to the observed cost of $16.30, calculated on the sample of 34 metropolitan and rural councils. Results of the parameter estimation of the linear regression models are shown in Table 3 (the level of 0.1% of statistical significance is indicated with asterisc).

Table 3. Coefficients of the regression model and goodness-of-fit statistic

Functional form	B_0	B_1	B_2	R^2	F
Infant immunisation program (N=37):	100.1*	-10.6*	5.5	71%	42.3*
School immunisation program (N=34):	5.40*	-0.42*	0.13	63%	25.9*
Both immunisation programs (N=34):	6.50*	-0.48*	0.22	78%	54.1*

There was considerable variation in the average cost across the councils. Councils with a smaller throughput had a much higher cost per encounter suggesting economies of scale. This is the main reason for the higher unit costs of rural councils that serve areas with smaller target population than metropolitan councils. The result indicates that although the differences in travel cost, staff mix etc. do explain some of the cost variation, throughput is the single largest predictor of the total cost per encounter for both infant and school immunisation programs.

6. Efficiency analysis

It was hypothesised that managerial decisions such as whether to employ a doctor to participate in clinics[5] and whether to use nurses in both vaccinating and administrative jobs would be the factors that differentiated LGs with respect to the unit costs and efficiency. Therefore the choice of input variables for the production model reflected a compromise between the maximum number of factors allowed by the sample size and the number of factors relevant to the variations in management practice and in local conditions. Table 4 lists inputs and outputs aggregated across the sub-programs.

Table 4. Inputs and outputs used in efficiency analysis.

	Variables	Mean	Median	SD	Min	Max
Inputs	1. Number of doctor hours	103	66	96	0	351
	2. Number of nurse clinic hours	390	333	326	0	1303
	3. Number of nurse hours spent on administrative tasks	94	0	172	0	625
	4. Number of administrative staff hours	862	665	660	30	2807
	5. Number of reimbursed travel hours for all staff categories	149	104	148	0	484
	6. Capital, consumables, other costs, and venue hire ($)	21726	13087	17255	3180	70462
Outputs	1.Number of infant immunisation encounters	2839	1733	2715	153	10525
	2.Number of school immunisation encounters	2995	1715	3031	154	13205

In the production model annuitised capital, consumables, corporate overheads, and venue hire were measured in monetary terms and combined in a single input to be considered as proxy for the aggregated physical quantities.

Both output variables were normally distributed with the mean of 2840 encounters (SD=2715) for infant immunisation program and 2995 encounters (SD=3030) for school immunisation program. *T*-test for paired samples indicated no statistical significance between the means (t=0.51, p=0.6). The outcome variables were highly correlated (R=0.83, p<0.01), indicating that for most of the LGs immunisation sub-programs were of a similar size.

Data Envelopment Analysis (DEA) has been used for the purpose of measuring relative efficiencies of LGs in their use of 6 inputs to produce two outputs: annual number of infant and school immunisation encounters. DEA involves the use of linear programming methods to construct a non-parametric frontier over the data and efficiencies are calculated relative to this surface. The method dates back to the early work of Farell (1957), and was subsequently developed further by Charnes et al (1978) and Banker et al (1984). The DEA software used in this study was developed by Coelli (1996) based on Fare et al (1994).

DEA derives a single summary measure of efficiency for each LG. For the inefficient LGs, DEA identifies the subset of efficient LGs, to which they are directly compared. On the basis of this subset of "peers" DEA also calculates targets for both inputs and outputs that correspond to the projection of the evaluated LG to the efficiency frontier. As indicated in Table 1, the efficiency analysis used input-oriented model as consistent with LGs' objective, that is, minimising total cost of immunisation program given a fixed throughput, and output-

[5] From 1995 the Drug, Poisons and Controlled Substances Regulation allowed registered nurses to administer vaccines without a doctor in attendance.

oriented model for the DHS purposes, that are to maximize immunisation coverage for a given budget.

Cost analysis demonstrated significant economies of scale, therefore the variable return to scale (VRS) model specification was appropriate for both DEA models. Under VRS, input and output oriented efficiency models can produce different efficiency scores and different set of input-output targets. This is because under the VRS condition and as long as the constraints are satisfied, the model can pick up any peer to build the composite LG against which the assessed LG is compared (Banker, 1984).

In our study however, the DEA results were robust with respect to the model orientation. The reference set remained unchanged with the difference in efficiency scores between the two models not exceeding 2%. Moreover, the same LGs were identified as inefficient with the same respective peers when results of the production model were compared with results of cost-efficiency analysis using cost equivalent of all the inputs listed in Table 4. Therefore input-oriented production model was sufficient to analyse the issues of pure technical inefficiency from either LGs or the DHS perspectives. Table 5 presents summary statistics of efficiency estimation (input-oriented production model).

Table 5. Summary statistics of efficiency estimation (input-oriented production model).

Efficiency	mean	SD	Number of inefficient LGs	Range of efficiency scores for the inefficient LGs
Pure technical efficiency	98%	5.0	4	76% to 94%
Scale efficiency	93%	16.6	11	36% to 98%

The results of the DEA analysis indicated that the average technical efficiency for the entire sample was close to 100% with only four LGs (all metropolitan) showing some scope for improvement that can potentially result in total productivity gain of about AU$48,000 or 1.8% of the total cost of LGs' immunisation programs.

Under the VRS some of the peers from the reference set may occasionally be very different in scale size from the assessed LG thus not being suitable for the benchmark. In our study both LGs with the largest throughputs of 17,200 and 22,500 were included in the set of peers for the inefficient LGs with the range of throughputs between 3,400 and 9,300 encounters per year. Restrictions on the DEA weights are sometimes applied to avoid this problem (Dyson and Thanassoulis, 1988). In this study, however, the benchmark analysis was conducted with the purpose of identifying efficient managerial solutions, so the membership of the reference set was examined from that perspective. All inefficient LGs had a higher than average aggregated cost of capital, overheads etc. One of them, in spite of being in the metropolitan area with high population density had an inflated cost of travel, while another had a disproportionately high cost of program administration. All inefficient LGs retained a doctor in attendance during immunisation sessions. To the contrary, efficient LGs from the peer sets either did not employ a doctor at all, or only as a consultant on a casual basis. The LGs with a relatively low proportion of infant immunisation encounters in the total number of encounters had a comparative advantage in achieving higher efficiency. One of such LGs was included in 3 out of 4 peer sets.

The average scale efficiency was also high with the majority of inefficient LGs (10 out of 11) having increasing return to scale that was consistent with the shape of the cost function and confirmed the fact that the LGs' pursuit for accessibility takes place at expense of maintaining the optimal productive size of immunisation programs. In the cost-efficiency model average scale efficiency was estimated at 92.5%. This is because one extra LG showed scale inefficiency of 14% due to the decreasing return to scale that was not observed in the production model. This particular LG had the highest unit costs in both immunisation sub-programs among the group of LGs with the similar throughput. Using the 15% cut-off point for scale inefficiency, six LGs were judged as significantly scale inefficient. The average cost per encounter for these LGs was $23.00 as compared to the sample average of $16.30. Marginal costs in this group ranged from just under $7.00 to $17.30, remaining yet below the minimum cost of $22.00 charged by GPs for a standard consultation (HIC, 1998).

Out of 21 DEA-efficient LGs some may be efficient simply because of the absence of a comparator with which a comparison could be made. In such cases efficient scores were obtained as a result of unusual/extreme weights being attached to the inputs or outputs. A cross-efficiency analysis (Doyle and Green, 1994) has been used to detect such LGs. During a cross-efficiency analysis stage new efficiency scores were calculated for each DEA-efficient LG using the weights of other DEA-efficient units, thus providing a "competitors view" on the performance of a given LG. The results indicated that eight LGs can be classified as "self-evaluators", i.e. they had no other comparator, but themselves. Among the remaining 13 LGs there were six LGs whose weights generated a 100% efficiency score for most of other LGs. These six included four LGs with the highest annual number of encounters and the lowest unit costs. Not surprisingly the two remaining LGs have already appeared in reference groups for the LGs with pure technical inefficiency.

The set of weights of one of them - a rural LG with immunisation program size that was very close to the sample mean, generated a 100% efficiency score for 10 other LGs. This LG was unique in its managerial approach, with immunisation staff specialising exclusively in either vaccination or administrative duties with both teams working very effectively. One doctor and one contract nurse administered all the vaccinations, while all administrative jobs were carried out by non-medical staff who never participated in immunisation clinics. Naturally, in this case, the number of nurse's hours spent on administrative duties was zero. As the doctor was not involved in clinic preparation, the number of doctor's clinic hours was only half of that of the nurse. Since both were employed on a contract basis, the number of paid travel hours was also zero. The cost per encounter in this LG was $5.00 below the sample mean.

7. Conclusions

The results of the cost analysis supported the DHS' intention to subsidise the sub-programs at a different rate, since the cost per encounter in school immunisation program was almost half the cost per encounter in infant immunisation program. Childhood immunisation program in Victoria was highly efficient overall. Improving pure technical inefficiency in four LG can potentially result in productivity gains of up to $48,000. Having a relatively low proportion of infant immunisation encounters in the total number of encounters improved a comparative efficiency score. Employing medical staff on a contract basis seemed to be the factor associated with higher efficiency. Longer travel hours, viewed as an uncontrollable factor for rural LGs, did not show any negative impact on efficiency scores, possibly because some LGs compensated contract staff only for clinic hours.

Analysis of the relation between the size of immunisation program and efficiency indicated that 18% of LGs had significant scale inefficiency due to increasing returns to scale. Expanding immunisation activities while maintaining the existing input levels, suggests a preferred strategy for efficiency improvement. It may be possible to achieve the DEA targets through promoting vaccination benefits while increasing awareness of the possible financial penalties resulting from non-compliance. Scheduling immunisation clinics to better suit the parents of young children may also have some potential for increasing participation. Immunisation program proved viable for the given level of throughput even among the LGs with the highest scale inefficiency scores when their marginal costs were compared against the GPs' lowest rates.

Although more accurate estimates of cost and efficiency factors would require full participation of all LGs within the State of Victoria, nevertheless, we believe that the results and recommendations presented in this study constitute a solid basis for policy- and decision making for both State and local governments in the area of child immunization programs.

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Study of the Efficiency in Five Subsectors of Colombian Economy Applying DEA

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Abstract
This searching work was done for five subsectors of the Colombian economy during a period of three consecutive years: 1995, 1994, 1993. Four of these subsectors are related to industrial sector, and the other to the services one.

The selection of the companies which would become part of these five groups was based on: the highest operational incomes during 1995.

The subsectors and the number of companies which became part of this study are: Textiles manufacture 77, Food products 72, Pharmaceutical products 65, Automotive vehicles selling 63 and Substances and chemical products manufacture 60 for the total 337.

1. Introduction
For each one of the following subsectors of Colombian economy: Textiles manufacture, Food products, Pharmaceutical products, Automotive vehicles selling, and substances and chemical products manufacture; two different models were used:

Model 1: *Output 1*: operational incomes. *Output 2*: operational profit. *Input 1* : current asset. *Input 2*: properties, physical plant, and equipment. *Input 3*: non current liability. *Input 4*: patrimony.

Model 2: *Output1*: operational incomes. *Output 2*: Net profit. *Input 1*: current asset.

Input 2: properties, physical plant, and equipment. *Input 3*: non current liability. *Input 4*: patrimony.

In addition, for each one of these models it was run for two different types of enveloping surface CRS (Constant return-to-scale) and VRS (Variable returns-to-scale).

Assuming that for some companies in some occasions, the operational profit and /or the net profit is negative, it was taken the decision of working with 0 since DEA does not admit non positive values.

2. Analysis Results
Textiles manufacture
Year: 1995.
Model 1
From the 77 companies studied in this sector for CRS, 10 efficient ones resulted. From these 10 companies just 4 of them are in the group of 10 companies considered with the best operational margin. (maximum 21.39%, minimum 11.13%) the other six efficient ones have an under 10% operational margin.

For VRS, 22 efficient companies resulted. From these 22 companies just 9 of them are in the group of the best operational margin (maximum 21.39%, minimum 9.35%); The other 13 companies have an under 9.34% operational margin and even some of them show a 0%.

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Model 2

It is had 6 efficient companies in CRS and just 2 of them are in the group of the 6 with the best net margin (maximum 8.30% minimum 5.76%) the other 4 efficient companies have an under 4.80% net margin.

En VRS there are 19 companies which conform the enveloping surface, from these just 6 of them are in the group of the best 19 companies according to the net margin (maximum 8.30%, minimum 3.93 %), The other 13 efficient companies have an under 3.13% net margin, and even there are some of them with a 0%.

Years 1994 and 1993.

In the following chart, the number of efficient companies for these years is shown:

Year 1994	Model 1		Model 2		Year 1993	Model 1		Model 2	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
	13	29	12	23		11	21	7	22

Comparative years 1995, 1994 and 1993.

For model 1 during these 3 years and for CRS, just 3 of the companies maintained in the efficiency border, representing only the 3.9% of the 77 companies studied in this sector. When VRS is evaluated, it is found that just 10 of the companies, which represent the 12.99%, maintain in the group of the efficient companies during this period.

For model 2 during these 3 years and for CRS, just 2 of the companies maintained in the efficient border, representing only the 2.60% of the 77 companies studied in this sector. When VRS is evaluated it is found that just 11 of the companies, which represent the 14.29%, maintain in the group of the efficient companies during this period.

Food products manufacture

Year 1995

Model 1

From the 72 companies studied in this sector for CRS, 10 efficient ones resulted. From these 10 companies just 3 of them are in the group of 10 companies considered with the best operational margin. (maximum 25.75%, minimum 10.97%) the other seven efficient ones have an under 9.60% operational margin.

For VRS, 21 efficient companies resulted. From these companies just 8 of them are in the group of the best operational margin (maximum 25.75%, minimum 8.01%); The other 13 companies have an under 6.14% operational margin, and even some of them show a 0%.

Model 2

It is had 8 efficient companies in CRS and just 4 of them are in the group of the 8 with the best net margin (maximum 22.56% minimum 9.79%) the other 4 efficient companies have an under 5.15% net margin.

In VRS there are 22 companies which conform the enveloping surface, from these just 8 of them are in the group of the best 22 companies according to the net margin (maximum 22.56%, minimum 4.70%) from the other 14 efficient companies there are some of them with a 0%.

Years 1994 and 1993.

In the following chart, the number of efficient companies for these years is shown:

Year 1994	Model 1		Model 2		Year 1993	Model 1		Model 2	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
	11	20	17	11		17	25	17	26

Comparative years 1995, 1994 and 1993.

For model 1 during these 3 years and for CRS, just 7 of the companies maintained in the efficiency border, representing only the 9.72% of the 72 companies studied in this sector. When VRS is evaluated, it is found that just 16 of the companies, which represent the 22.22%, maintain in the group of the efficient companies during this period.

For model 2 during these 3 years and for CRS, just 7 of the companies maintained in the efficient border, representing only the 9.72% of the 72 companies studied in this sector. When VRS is evaluated it is found that just 17 of the companies, which represent the 23.61%, maintain in the group of the efficient companies during this period.

Pharmaceutical products manufacture

Year 1995

Model 1

From the 65 companies studied in this sector for CRS, 16 efficient ones resulted. From these 16 companies just 5 of them are in the group of 16 companies considered with the best operational margin. (maximum 40.25%, minimum 18.10%) some of the other 11 efficient companies have a 0% operational margin.

For VRS 29 efficient companies resulted. From these, just 17 of them are in the group of the best operational margin (maximum 40.25%, minimum 14.85%).

Model 2

It is had 17 efficient companies in CRS and just 7 of them are in the group of the 17 with the best net margin (maximum 79.24% minimum 8.71%).

In VRS there are 27 companies which conform the enveloping surface, from these just 14 of them are in the group of the best 27 companies according to the net margin (maximum 79.24%, minimum 5.74%).

Years 1994 and 1993.

In the following chart, the number of efficient companies for these years is shown:

Year 1994	Model 1		Model 2		Year 1993	Model 1		Model 2	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
	13	26	11	28		10	21	9	20

Comparative years 1995, 1994 and 1993.

For model 1 during these 3 years and for CRS, just 6 of the companies maintained in the efficiency border, representing only the 9.23% of the 65 companies studied in this sector. When VRS is evaluated, it is found that 14 of the companies, which represent the 21.54%, maintain in the group of the efficient companies during this period.

For model 2 during these 3 years and for CRS, just 5 of the companies maintained in the efficient border, representing only the 7.69% of the 65 companies studied in this sector. When VRS is evaluated it is found that just 13 of the companies, which represent the 20%, maintain in the group of the efficient companies during this period.

Automotive Vehicles selling
Year 1995
Model 1
From the 63 companies studied in this sector for CRS, 25 efficient ones resulted. From these 25 companies just 9 of them are in the group of 25 companies considered with the best operational margin. (maximum 15.78%, minimum 3.51%) The other 16 efficient companies have an under 2.93% operational margin, even some of them show a 0%.

For VRS 33 efficient companies resulted. From these, just 18 of them are in the group of the best operational margin (maximum 15.78%, minimum 1.37%). The other 15 companies have an under 1.28% operational margin, and even some of them show 0%.

Model 2

It is had 25 efficient companies in CRS and just 10 of them are in the group of the 25 with the best net margin (maximum 20.85% minimum 1.87%).

In VRS there are 34 companies which conform the enveloping surface, from these just 18 are in the group of the best 34 companies according to the net margin (maximum 20.85%, minimum 1.32%).

Years 1994 and 1993.

In the following chart, the number of efficient companies for these years is shown:

Year 1994	Model 1		Model 2		Year 1993	Model 1		Model 2	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
	20	30	24	33		18	28	14	26

Comparative years 1995, 1994 and 1993.

For model 1 during these 3 years and for CRS, just 8 of the companies maintained in the efficiency border, representing only the 12.70% of the 63 companies studied in this sector. When VRS is evaluated, it is found that 17 of the companies, which represent the 26.98%, maintain in the group of the efficient companies during this period.

For model 2 during these 3 years and for CRS, just 6 of the companies maintained in the efficient border, representing only the 9.52% of the 63 companies studied in this sector. When VRS is evaluated it is found that just 18 of the companies, which represent the 28.57%, maintain in the group of the efficient companies during this period.

Substances and chemical products manufacture
Year 1995
Model 1
From the 60 companies studied in this sector for CRS, 12 efficient ones resulted. From these 12 companies just 6 of them are in the group of 12 companies considered with the best operational margin. (maximum 22.85%, minimum 17.84%) .

For VRS 24 efficient companies resulted. From these, just 12 of them are in the group of the best operational margin (maximum 22.85%, minimum 11.12%).

Model 2

It is had 12 efficient companies in CRS and just 5 of them are in the group of the 12 with the best net margin (maximum 16.35% minimum 13.22%).

In VRS there are 25 companies which conform the enveloping surface, from these just 15 are in the group of the best 25 companies according to the net margin (maximum 16.35%, minimum 4.66%).

Years 1994 and 1993.

In the following chart, the number of efficient companies for these years is shown:

Year 1994	Model 1		Model 2		Year 1993	Model 1		Model 2	
	CRS	VRS	CRS	VRS		CRS	VRS	CRS	VRS
	13	20	10	16		9	18	11	17

Comparative years 1995, 1994 and 1993.
For model 1 during these 3 years and for CRS, just 7 of the companies maintained in the efficiency border, representing only the 11.67% of the 60 companies studied in this sector. When VRS is evaluated, it is found that 10 of the companies, which represent the 16.67%, maintain in the group of the efficient companies during this period.

For model 2 during these 3 years and for CRS, just 5 of the companies maintained in the efficient border, representing only the 8.33% of the 60 companies studied in this sector. When VRS is evaluated it is found that just 9 of the companies, which represent the 15.0%, maintain in the group of the efficient companies during this period.

3. Conclusions

As a common conclusion for both, model 1 and model 2, it could be established that there are companies which are found in the efficient border, but however, as they do not report the best operational and net margins, they would not be considered as efficient organizations under the scheme of calculation of financial reasons.

Textiles products manufacture sector. Looking at the companies considered as efficient: For 1994 it is had the highest numbers, and in 1995 a fall is presented, denoting a receding when what would be expected is a better behavior, since the companies have a larger experience. However, the results of 1994 are low because they do not surpass 16.88% for CRS, and 29.87% for VRS, in other words they exist several companies which must improve its behavior to be in the efficient border.

Food products manufacture sector. Looking at the companies considered as efficient: For 1993 it is had the highest numbers, and in 1995 the lowest are presented, denoting a receding because what would be expected is a better behavior. However, the results of 1993 are low because they do not surpass 23.61% for CRS, and 36.11% for VRS, in other words, they exist several companies which must improve its behavior to be in the efficient border.

Pharmaceutical products manufacture sector. Looking at the companies considered as efficient: For 1995 it is had the highest numbers,(excepting model 2 VRS) and in 1993 the lowest ones are presented. However, the results of 1995 do not surpass 26.16% for CRS, and 44.62% for VRS, in other words they exist several companies which must improve its behavior to be in the efficient border.

Automotive vehicles selling sector. Looking at the companies considered as efficient: For 1995 it is had the highest numbers, and in 1993 the lowest ones are presented (excepting model 1 VRS). However, for 1995 they do not surpass 39.68% for CRS, and 53.97% for VRS, in other words they exist several companies which must improve its behavior to be in the efficient border.

Substances and chemical products manufacture sector. Looking at the companies considered as efficient: For 1995 it is had the highest numbers. However, they do not surpass 20.34% for CRS, and 42.37% for VRS, in other words they exist several companies which must improve its behavior to be in the efficient border.

Comparing the percentages of the companies considered as efficient in all the subsectors, it is established that the automotive vehicles selling shows better results, and it is the only sector of the five studied which does not carry on productive processes. Between the other subsectors (which carry on productive processes) the one with better results is the Pharmaceutical products manufacture.

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Explaining Economic Inefficiency of Thai Oil Palm Farms

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Abstract

The primary purpose of this study is to measure and explain the economic inefficiency of Thai oil palm farms. The two-stage data envelopment analysis (DEA) approach and farm-level cross-sectional survey data in 2000 are used to measure economic inefficiency. A Tobit regression is used to explain the likelihood of changes in inefficiencies by farm-specific socio-economic and management factors. The empirical results indicate that allocative inefficiency for the Thai oil palm farms makes a greater contribution to economic inefficiency. In addition, the inefficiencies are explained by age, education and member of co-operatives.

Keywords: Thai oil palm farms, data development analysis, economic inefficiency, Tobit regression, socio-economic and management factors

1. Introduction

Palm oil is an important crop in the Thai economy for two main reasons. First, palm oil is a raw material for producing cooking oil, so that, the continuity of palm oil production is crucial for stabilising the cooking oil price. In addition, it is important for cooking fats, margarine and as a raw material for industrial manufacturing, such as the pharmaceutical and cosmetic industries. As indicated in Suriyapee (2000), in 1997, around 63 per cent of total oil consumption in Thailand was produced from oil palm. Second, as a primary agricultural product, oil palm is a source of income and employment both in production and in manufacturing, at present and in the future.

There are at least three causes for worry concerning the future development of the oil palm industry in Thailand. First, the relatively high growth rate of palm oil production in Thailand has been achieved mainly through the expansion of cultivated areas, as indicated by the Ministry of Agriculture and Cooperatives (2000). Second, although, the high growth rate of oil palm production has been recognised, its yield in Thailand has generally been rather low. Compared with some selected Asian oil palm-growing countries, the yield of palm oil in Thailand was the lowest in 1997 (Ministry of Agriculture and Cooperatives 2000). Finally, the Thai government has significantly influenced Thai agriculture through a variety of policies over the past three decades. The most important policies in the agricultural economy were export taxes on agricultural products, and quotas and tariffs on machinery and fertiliser imports. They could cause imperfect competition in those inputs, and in output markets. Because of the above factors, economists and policy makers have raised the question about the economic efficiency of Thai oil palm production, especially at farm level.

The main purpose of this study is to measure and investigate factors affecting the economic inefficiency (decomposed into technical and allocative components) of oil palm production at farm level in Thailand. To estimate efficiency scores, the DEA method is applied to farm-level cross-sectional survey data of oil palm farms in three districts of the Southern Region in Thailand. Previous studies have investigated technical efficiency and its components at both the farm and aggregate levels in Thai agriculture (e.g., Tantavaruk 1985, Chayaputi 1993, Krasachat 2000a, 2000b). However, this study, to the best of my knowledge, has been the first

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application of DEA in order to measure and explain economic efficiency and its components at the farm level in Thai agriculture. This enables more detailed understanding of the nature of economic efficiency in Thai agriculture and, in particular, Thai oil palm farms.

This paper is organised into five sections. Following this introduction, the analytical framework is described. Next, data and their sources are described. The last two sections cover the empirical findings of this study, and conclusions and policy implications.

2. Analytical Framework

According to Coelli, Rao and Battese (1998), the constant returns to scale (CRS) DEA model is only appropriate when the farm is operating at an optimal scale. Some factors such as imperfect competition, constraints on finance, etc. may cause the firm to be not operating at an optimal level in practice. To allow for this possibility, Banker, Charnes and Cooper (1984) introduced the variable returns to scale (VRS) DEA model. Due to the consequence of the heavy intervention by the government in both output and input markets in Thai agriculture as mentioned earlier, farmers may well have been prevented from operating at the optimal level in farm production. Therefore, technical efficiency in this study is calculated using the input-oriented variable returns to scale (VRS) DEA model. Following Fare, Grosskopf and Lovell (1985), Coelli, Rao and Battese (1998) and Sharma, Leung and Zaleski (1999), the VRS model is discussed below.

Let us assume there is data available on K inputs and M outputs in each of the N decision units (i.e., farms). Input and output vectors are represented by the vectors x_i and y_i, respectively for the i-th farm. The data for all farms may be denoted by the $K \times N$ input matrix (X) and $M \times N$ output matrix (Y). The envelopment form of the input-oriented VRS DEA model is specified as:

$$\begin{aligned} &\min_{\theta,\lambda} \theta, \\ \text{st} \quad & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1 \\ & \lambda \geq 0, \end{aligned} \qquad (1)$$

where θ is the input technical efficiency (TE) score having a value $0 \leq \theta \leq 1$. If the θ value is equal to one, indicating the farm is on the frontier, the vector λ is an $N \times 1$ vector of weights which defines the linear combination of the peers of the i-th farm. Thus, the linear programming problem needs to be solved N times and a value of θ is provided for each farm in the sample.

In order to investigate the economic efficiency or cost efficiency, the cost minimisation DEA is specified as:

$$\begin{aligned} &\min_{\lambda, x_i^*} w_i' x_i^*, \\ \text{st} \quad & -y_i + Y\lambda \geq 0, \\ & x_i^* - X\lambda \geq 0, \\ & N1'\lambda = 1 \\ & \lambda \geq 0, \end{aligned} \qquad (2)$$

where w_i is a vector of input prices for the i-th farm and x_i^* is the cost-minimising vector of input quantities for the i-th farm. The total cost efficiency or economic efficiency can be calculated as:

$$EE = w_i'x_i^* / w_i'x_i. \quad (3)$$

Allocative efficiency can be specified and calculated as:

$$AE = EE/TE. \quad (4)$$

Note that this procedure will include any slacks into the allocative efficiency measure, reflecting an inappropriate input mix (Ferrier and Lovell 1990). Efficiency scores in this study are estimated using the computer program, **DEAP** Version 2.1 described in Coelli (1996).

In order to examine the effect of farm-specific socio-economic and management factors on farm efficiency, a regression model is estimated where the level of inefficiency from DEA is expressed as a function of these factors. However, as indicated in Dhungana, Nuthall and Nartea (2000), the inefficiency scores from DEA are limited to values between 0 and 1. That is, farmers who achieved Pareto efficiency always have an inefficiency score of 0. Thus, the dependent variable in the regression equation cannot be expected to have a normal distribution. This suggests that the ordinary least squares regression is not appropriate. Because of this, Tobit estimation, as mentioned in Long (1997), is used in this study.

3. Data

The data used in this study is based on a direct interview survey of 63 randomly selected oil palm farm households in three districts of Surathani province of Thailand. The selected districts were Phun Pin, Phra Saeng and Chai Buri. These are predominantly palm oil producing and have a similar climate and soil type. The data were for the 2000 crop year (January-December). The farms selected were owner operated and had faced a similar economic and marketing environment for inputs and outputs. In addition, all the farms used a similar technology for palm oil production except for differences in intensity and management.

One output and five inputs are used in the empirical application of this study. The five inputs groups are fertiliser, hired labour, capital, land and "other inputs". Because the variables of hired labour, capital and other inputs are measured in value terms, the calculation of the unit price for these inputs are far from satisfactory. Following Ferrier and Lovell (1990), the unit price of these inputs equals baht 1 for all farms. Land has been one of the most important factors of Thai oil palm production. Because of lack of data on the price of land, the average expenditure of land rent (Ministry of Agriculture and Cooperatives 2000) in the Southern Region equals bahts 4.54/rai for all farms.

Several farm-specific factors are analysed to assess their influence on productive efficiency. The farmer's age is defined in terms of years. Education is derived from farmer's years of schooling. Finally, the sample oil palm farms also differ in terms of belonging to co-operatives which is represented by a dummy variable (1 for belonging to co-operative, 0 for otherwise).

4. Empirical Results

Technical, allocative and economic efficiency scores of Thai oil palm farms were calculated using equations (2)-(4) at the sample. The empirical results indicate that the mean values of technical, allocative and cost efficiency of all farms are 0.827, 0.430 and 0.360, respectively. The values of technical efficiency range from 1.000 to 0.284. The values of allocative efficiency range from 1.000 to 0.102, while those of economic efficiency range from 1.000 to 0.056. These empirical results suggest four important findings. First, there are significant possibilities to increase efficiency levels in the Thai oil palm farms. Second, the average cost of all farms could be reduced by 64 per cent. Third, the results also indicate that allocative inefficiency makes a greater contribution to economic inefficiency among farms. Finally, the results indicate the substantial diversity of the scores of efficiency among farms. This suggests that the considerable variability of farms in farm-specific socio-economic and management factors, natural resources, etc., can have different impacts on efficiency in Thai oil palm production in different farms.

The measurement of allocative efficiencies indicates that some inputs are being used in incorrect proportions. To examine which inputs are being over- or under-used, following Singh and Coelli (1999), the ratios of the technically efficient input quantities to their corresponding cost efficient input quantities are calculated in this study.

The analytical results indicate that the Thai oil palm farms over-utilised fertiliser, hired labour and capital input, while it under-utilised land and other inputs. It is not surprising to see the farmers using fertiliser and hired labour more than land and other inputs because Thailand has experienced cheap labour and limited land for many years, as mentioned in Krasachat (2000a).

Tobit regression models are estimated to investigate the impacts of the farm-specific socio-economic and management factors on economic inefficiency and its components. Inefficiency measures are first obtained by subtracting the level of efficiency calculated in the first stage from 100. Then, each inefficiency measure is regressed on the farmer's age, education and membership of co-operatives.

The empirical results indicate that the farmer's age has a positive, except quadratic, effect on economic and allocative inefficiencies except technical efficiency. This suggests that younger farmers are less likely to be economically as well as allocatively more inefficient compared to their older counterparts, probably due to the fact that younger farmers are less experienced, and hence less knowledgeable in oil palm farming practices as compared to their older counterparts. Similar result is also found by Dhungana, Nuthall and Nartea (2000). However, younger farmers are more technically efficient than their older counterparts. Similar result is also reported by Llewelyn and Williams (1996).

The results indicate a consistent pattern of a negative relationship between farmer's years of schooling, and economic, allocative and technical inefficiencies, consistent with what is expected. That is, the more educated farmers are less likely to be inefficient as compared to their less educated counterparts, possibly due to their better skills, access to information and good farm planning. Similar results also indicated by Llewelyn and Williams (1996) and Dhungana, Nuthall and Nartea (2000), among others.

The results also show a consistent pattern of a negative relationship between farmer's membership of co-operatives, and economic, allocative and technical inefficiencies. This implies that the farmers who are a membership of co-operatives are achieve higher levels of efficiency. This may be due to their access to information and training programs.

5. Conclusions and Policy Implications

An input-oriented variable returns to scale (VRS) DEA model and a cost minimisation DEA model were used for estimating technical, allocative and economic efficiencies in Thai oil palm farms.

The results indicate that efficiency scores of some farms were considerably low. This implies that there is significant scope to increase efficiency levels in Thai oil palm farms. In addition, they also indicate that allocative inefficiency makes a greater contribution to economic inefficiency among farms.

The results also indicate that the Thai oil palm farms over-utilised fertiliser, hired labour and capital input, while they under-utilised fertiliser input. In addition, the inefficiencies are explained by age, education and member of co-operatives. This may suggest some policy implications such that the dissemination of the best farming practices to reduce the technical inefficiency should be strategically focused to younger farmers. In addition, implementing education and co-operative programs can increase the current productivity level in oil palm farms in Thailand.

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Data Mining Approach as Decision-Making Support in DEA

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Abstract

The choice of variables and decision-making units (DMU's), that may be considered in a DEA (Data Envelopment Analysis) performance evaluation, is the subject of analysis in this paper. Data Mining is considered a powerful tool for knowledge discovery for many researchers and it will be a big wave in this new century. Data Mining approach is used to decision-making support in a DEA application regarding Brazilian Airports Performance Evaluation. In this task, knowledge acquisition algorithms such as Column Importance, Clustering, and Association besides Data Visualization were used. Furthermore, the work suggests that it is possible to use Data Mining to choose the DEA model which best fits the data on focus. The text tries to show how the selection process is built and also to make clear which benefits it allowed in a business performance evaluation work.

Keywords: data envelopment analysis, air transport, artificial intelligence, decision-support system, data mining

1. Introduction

Almost all work in performance assessment using DEA (Data Envelopment Analysis) show no studies of methods and criteria to choose variables and decision making units (DMU's) that will be considered during the evaluation process. One of the reasons for this lack of work is that normally there are only a few variables available, then we have to consider all that variables in order to get satisfactory results, as suggest Lins, M.E. et Moreira, M.C. (1999) [1]. Regarding DMU's the only care done is normally to choose business units that belong to the same business, such as high schools, universities of medicine, factories that produces a specific electrical/ electronic product, airports, air carriers, etc.

With the rapid growth of performance assessment applications using DEA there will be a moment when preparation and planning of databases having registers of important variables of DMU's under evaluation will need a tool for decision-making support in order to avoid that this subject continues to be managed based on tries and errors.

This paper shows some possibilities that data mining algorithms offer to fill such potential need as much to choose the variables as also in the business units segmentation to find more homogeneous groups.

This effort is part of two Master in Science works that are in development in the Instituto Tecnológico de Aeronáutica – ITA, in São José dos Campos – São Paulo State - Brazil. One of them is about brazilian airports performance assessment, under development by Rossi Carvalho, A.A. (2002), and the other about data mining algorithm as decision-making support, under development by Carvalho, I.C. (2002).

2. Data Envelopment Analysis – DEA

Systems efficiency have been traditionally measured by productivity models. DEA models in a certain ways do the same using as measure for each DMU typically a ratio between outputs and inputs.

DEA methodology allows a multivariate approach of productivity in a simultaneous analysis of many inputs and many outputs of the common process of all DMU's under evaluation.

In this paper each DMU is an brazilian airport and the assesment is developed using the basic DEA models, with constant and variable return to scale, with radial and additive distances, and output, input and none orientation.

2.1. CCR Model –Constant Return to Scale

This models was proposed by Charnes, A., Cooper, W. W., e Rhodes, E., in 1978, with the objective to find the best relative efficiency of each DMU within a set of them. In our case the method is to maximaze the efficiency value of one airport considering the maximum efficiency of each airport in the reference set τ as a resctriction, and the results are best effiency value, output and input related optimun multiplier coefficients, and lack or surplus of the DMU's attributes.

2.2. BCC Model – Variable Return to Scale

This models was proposed by Banker, R. D., Charnes, A., e Cooper, W.W., in 1984, to add a variable return to scale behaviour to the CCR model. This new model has one further convexity restriction which is the sum of λ has to be equal to 1 (one).

The use of CCR and BCC together helps to determine the total technical and scale efficiencies of the airports under under study and in the data evaluation to find if they present variable return to scale or not, as showed in detail in Cooper, W., Seiford, L.M., Tone, K. (2000) [2].

2.3. Distances and Orientarion of the Models

Radial distance is the measure that indicates the possible improvement when all relevant factors are improved by the same factor equiproportionally. It applies as much in CCR model as in BCC model. See Farrel, M.J. (1957) [3].

Input oriented:	$\min \{ \theta \mid (\theta X^k, Y^k) \in \tau \}$
Output oriented:	$\max \{ \phi \mid (X^k, \phi Y^k) \in \tau \}$
Non-Oriented:	$\max \{ \theta \mid ((1 - \theta) X^k, (1 + \theta) Y^k) \in \tau \}$

Additive distance is the measure that quantifies the maximal sum of the absolute improvements – input reduction/ output increase - measured in slacks. It applies as much in CCR model as in BCC model. See Charnes et al.(1985) [4].

Input oriented:	$\max \{ \Sigma_i s_i \mid (X^k - s, Y^k) \in \tau , s \geq 0 \}$
Output oriented:	$\max \{ \Sigma_j t_j \mid (X^k , Y^k + t) \in \tau , t \geq 0 \}$
Non-Oriented:	$\max \{ \Sigma_i s_i + \Sigma_j t_j \mid (X^k - s, Y^k + t) \in \tau , (s,t) \geq 0 \}$

2.4. Others DEA Models

There are other DEA models in the available literature regarding this subject, however most of them are variations of the basic DEA models used in this paper.

3. Data Mining

According Berry, M.J.A et Linoff, G. (1997) [5]: "Data Mining is a process of exploitation and analyse, by automatic or semi-automatic means, of large quantity of data with the purpose to find significant patterns and rules". This capacity of knowledge extraction will be used in the choice of the variables and the DMU's properly that will be part of this efficiency assesment work.

Data Mining can be classified in two basic types: visual e analytical. Visual Data Mining can be represented by tree graphs, tridimensional, geografics and dispersion diagrams. Analytical data mining involves two algorithms classes – supervised – when we have the consequences of the possible actions in study, and non-supervised – when nothing is knowed about data behaviour and there is an intention to do an esploratory study. In the supervised analytical algorithms can be find the classification trees, the regression trees, column importance, and some neural networks. As non-supervised analytical algorithms can be included association, clustering, some neural networks and genetic algorithms.

3.1. Column Importance Algorithm

This algorithm selects columns as important related to a label column. Partitions are made by the algorithm and labeled. Each column is chosen due to its ability to supply more information about the labels than choices were done before. A measure called "purity" (a number from 0 to 100) informs how well the columns differentiate the different labels. Purity is a measure of the skewness of the label value distribution. The cumulative purity measure is a measure of the purity of partitioning the data. For a given set in the partition, the purity is 0 if each class has equal representation, and 100 if every record is of the same class. Similarly, the cumulative purity will be 0 if each set in the partition has an equal representation of classes, and 100 if each set in the partition contains record that all have the same class.

3.2. Algoritmo de agrupamento – Clustering

Clustering purpose is to determine what similar features are in a dataset. The algoritm is the k-means. The term *k-means* refers to the objective function determining possible good clustering based on similarity between records.

Dispersion is a measure of cohesiveness of a cluster; the higher the dispersion, the farther each record falls from the cluster center. Technically, dispersion is measured as the root mean squared distance from each record to the center of the cluster to which it is assigned. Dispersions from clusterings based on different datasets or different numbers or different numbers of clusters are not immediately comparable.

3.3. Association Rules Algorithm

Association rules let you mine data by constructing, verifying, and graphically representing models of patterns in large databases. These patterns are expressed by rules of association, which indicate how often column values occur together in a dataset. A simple association rule states that given that X is true, there is a certain probability that Y is also true. Four measures are used to analyze association rules: confidence, expected confidence, support and lift.

The *confidence* of the rule quantifies the number of records in which both sides of the rule appear, divided by the number of records in which the one rule appears. Forexample, if the confidence is 50%, *Y* occurs in 50% of the records in which *X* occurs. Thus, knowing that *X* occurs in a record, the probability that *Y* also occurs in that record is 50%.

The *expected confidence* measures the confidence of a rule as if there were no relationship between the left and right hand sides of the rule. It is computed based on the number of records in which the one side appears in the dataset. So the difference between expected confidence and confidence is a measure of the change in predictive power due to the presence of the other side item.

The *support* of the rule quantifies how prevalent the rule is throughout the dataset, or how often *X* and *Y* occur together in the dataset as a fraction of the total number of records. For example, if the support is 1%, *X* and *Y* occur together in 1% of the total number of records.

The *lift* is the ratio of confidence to expected confidence. The greater the number, the more unexpected the rule.

4. The Choice Process

This study began with data of DMU's, related to four years from 1996 to 1999, and with 17 proceess variables - atributes, as follow:

- Employee expenses and direct charges
- Other operational expenses
- Airplane parking area
- Number of check-in points
- Lounging area (Boarding)
- Number of employees
- Number of gates
- Number of passangers (boarded, landed and in transfer)
- Air movement (landing and take off)
- Air cargo and postal mail
- Operational revenue
- Financial revenue
- PAN and PAT revenue
- Operational results (P&L)
- Depreciation
- WLU (Work Load Unit) computed, and
- ICAO code of each airport.

Having this matrix of 96 rows and 17 columns we began to choose first the relevant variables, by choice, in order to apply later the DEA methodology.

4.1. The Choice of Variables

To use Column Importance algorithm there is the need to have a non-numerical variable to label the classes of the partitions of each subset and to compute the purity index of each partition subset. It was used ICAO code as labels column to the partitions. It may also be created a new labels column to the partitions based even so in subjective criteria, such as the client perception about the airport – optimum, good, regular and bad).

Results showed in Table 1 were obtained through the advanced mode module of this algorithm, where it can be considered and to choose other attributes with the same purity index that are more easely perceived by airport managers.

Before beginning to choose the variables it is possible to see the purity index of each atribute (column) related to airport labels (ICAO code). It can be seen that some attributes have the same maximum purity index – employee expenses, other operational expenses, number of passangers, air movement, cargo and operational revenue. The choice of one of them, which in this case was employee expenses, may exclude the others attributes with the same value in the next iterations.

Table 1: Choice of Variables

Variables	**Cumulative Purity**
Employee expenses - pes	71,37
Number of passengers - pax	90,94
Cargo and postal mail - carga	95,74
Airplane parking area - pátio	100,00

That were happend with the variables: other operational expenses, air movement and operational expenses.

4.2. Choice of DMU's

Once we just have the variables we can begin the choice of the DMU's using the clustering algorithm and those variables

Clustering algorithm was used many times to built in order to find 2, 3, 4 and 5 homogeneous groups within the dataset. Figures 1 and 2 show the vizualization of clustering results for 3 and 4 groups and they are representive of the observed groups. All results show only SBGR group in all years in study in na independent group (SBGR96, SBGR97, SBGR98 and SBGR99)

These results suggest the exclusion of SBGR group of the dataset of this study in order to have a more homogeous dataset of DMU's.

Figure 1: Clustering Results for 3 Groups

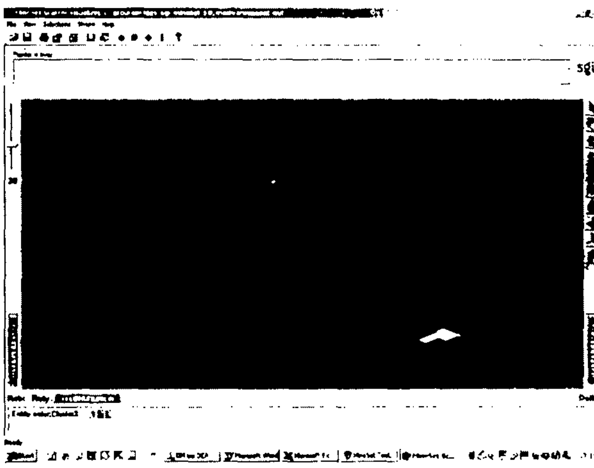
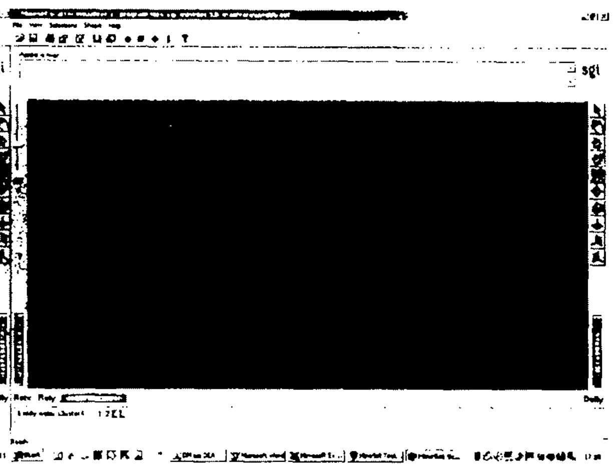


Figure 2: Clustering Results for 4 Groups



4.3. DEA Efficiencies Computation

Twelve DEA models were used in this task to get the relative efficienies of the airports under evaluation. The models were CCR (constant return to scale), with radial distance, and non-oriented, input oriented and output oriented - CRI, CRO e CRNO, the BCC (variable retur to scale), with radial distance and also with the same orientations - VRI, VRO e VRNO, and again the same models but with additive distance instead of radial - CAI, CAO, CANO, VAI, VAO e VANO.

All models were run by EMS software and the results are available with the authors.

4.4. Choice of DEA Model

In the task of to choose DEA models it was used as much airport label as WLU label to classify the partitions. Tables 4 and 5 show the results that were obtained by Column Importance algorithm wth and without SBGR group.

Table 4: Choice of DEA models by Data Mining

Choice	Models using airport label	Models using WLU label
1ª	CAI	CRO
2ª	CAO	CAO
3ª	VAI	CAI

Table 5: Choice of DEA models by Data Mining without SBGR group.

Choice	Models using airport label	Models using WLU label
1	CAI	CRI
2	CRI	CAO
3	CAO	VRI

The first choice were the CCR model with constant return to scale. The choice between radial and additive distance seems to be dependent of the labeling type and of the dataset considered. When airport attribute (ICAO code) was used prevails additive distance and when WLU was used the radial distance prevails.

Observing the three choices we can see that input orientation seems to supply more information to explain the reference atribute.

4.5. Association Rules Analysis

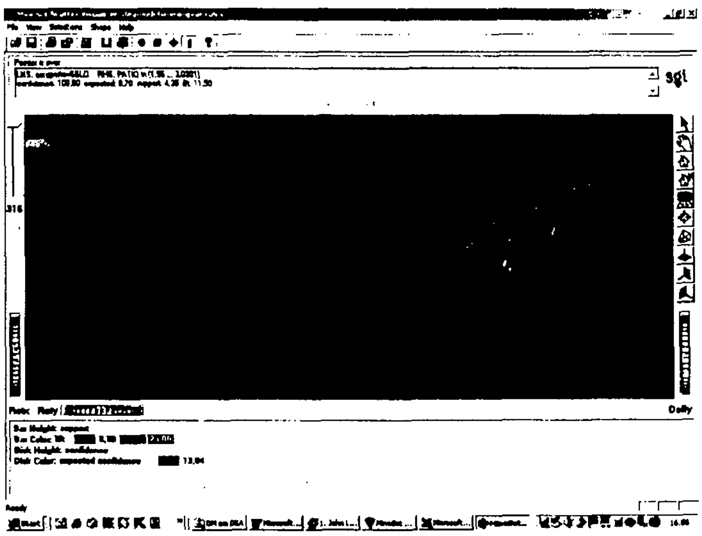


Figure 3: Association among choices

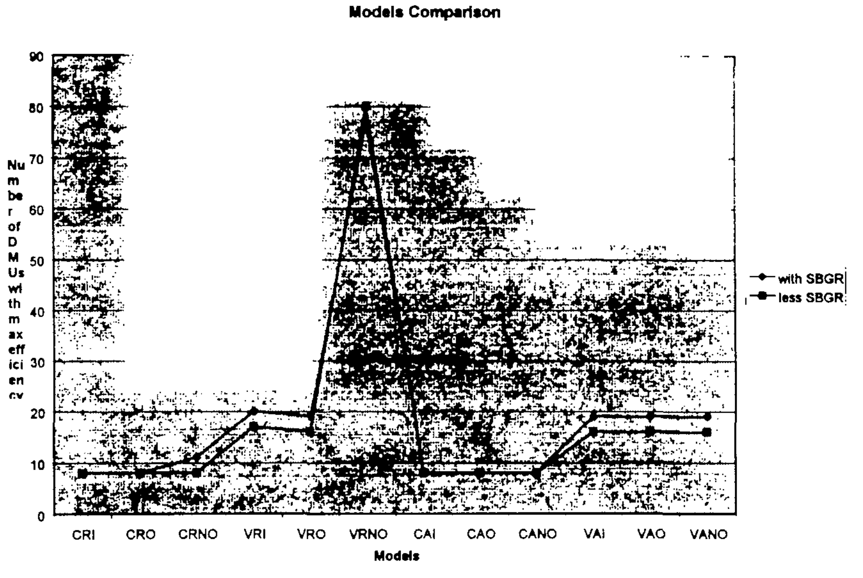
Other analyse of data that can be done is the influence of each attribute over each DEA model and within themselves, using the association algorithm. For exemple, Figure 3 presents the association of all the choices. One result apparentily unexpected is the relationship between the DMU SBLO and the variable patio – confidence = 100, expected = 8,7, support = 8,7 and lift = 11,5. Note that SBLO presents a low performance index – roughly 30% - and patio atribute could be a good candidate to be analysed deeply in order to improve its performance.

5. Summary and Conclusions

Procedures adopted in this decision-making process demand skill and knowledge in all phases of the study despite of the apparent simplicity.

Excluding SBGR group apparentily causes more impact over variable returns to scale and the unexpected result is that the action of excluding produces worst the overall results for the dataset as the quantity of DMU's with maximum efficiency (see Graph 1).

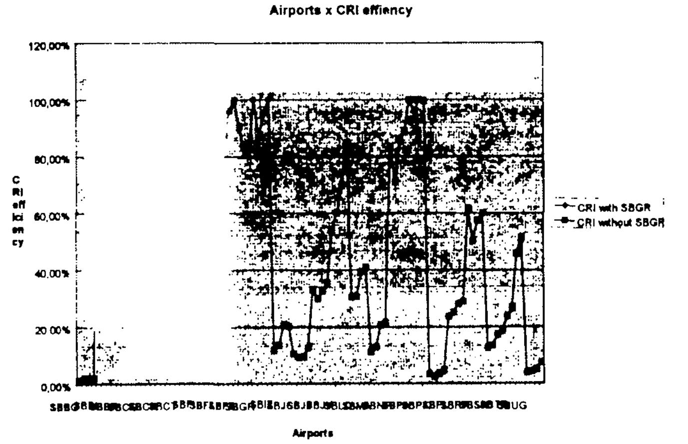
However it can be seen in Graph 2 that DMU's SBGR while in the dataset cause less efficiency score for some DMU's such as SBPA97, SBTE99, SBRF96 and so on. SBGR has maximum efficiency score only in two years - 1996 and 1999, what can be seen as na influence of the dataset over this cluster.



Graph 1: Comparison of clustering change action

Another interesting finding is the results of the model VRNO (Graph 1) which put more than 80% of all DMU's considered in the maximum relative score while the other models put less than 20% of all DMU's in the top.

Future contribution to this line of study can be other sequence of steps because each real problem has its own needs. For instance, a efficiency assessment in the very beginning stage may require first the choice of the DMU's to built a dataset.



Graph 2 – CRI Efficiency

Other contribution will be to test more insteresting references (label column) for Column Importance algorithm. For exemple, in a marketing oriented study the label column could be clients satisfaction for each DMU.
We got just a few things with association algorithm and those rules deserves much more time to find interesting insights. In this work the quantity of rules were so much that there was not enough time to analyse all the rules.

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Using a Group Decision Support System to Aid Input-Output Identification In DEA

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Abstract

In DEA operating units are compared on their outputs relative to their inputs. The identification of an appropriate input-output set is of decisive significance if assessment of the relative performance of the units is not to be biased. This paper reports on a novel approach used for identifying a suitable input-output set for assessing central administrative services at universities. A computer-supported GDSS was used to enable the analysts to extract information pertaining to the boundaries of the unit of assessment and the corresponding input-output variables. The approach provides for a more efficient and less inhibited discussion of input-output variables.

Keywords: DEA, GDSS

1. Introduction

The paper draws on work carried out in the context of a project co-funded by Aston University and the Higher Education Funding Council for England (HEFCE). The aim of the project is to identify 'Good Management Practices in Central Administrative Services' of UK Higher Education Institutions (HEIs). As a first step in this process we decided to deploy Data Envelopment Analysis (DEA) to identify cost-efficient practices in the delivery of central administrative services in UK HEIs. In order to use DEA a first and necessary step is to define the unit of assessment (or Decision Making Unit, DMU), by drawing the boundaries of the overall Central Administrative Services (CAS) and of the individual functions within it. In a DEA framework the unit of assessment is the entity whose performance is being assessed and compared with other entities of its kind. The unit of assessment uses a set of resources referred to as inputs, which it transforms into a set of outcomes referred to as outputs. The delineation of the unit of assessment and the identification of the corresponding input-output factors are of decisive significance in assessing performance. If we do not delineate the unit of assessment properly, or if we omit some important inputs or outputs, the assessment will be biased (see Thanassoulis 2001, section 5.2 for an elaboration). In this context, the input variables should capture all resources used by and the output variables all the outcomes related to the provision of central administrative services in HEIs.

In this study, the identification of the unit of assessment and the corresponding input-output variables is investigated using a novel approach. Specifically, a workshop was organised to explore the knowledge of a group of experts on CAS. The experts were drawn from senior academics and administrators in a number of different English Universities. Two facilitators used a computer-supported Group Decision Support System (GDSS) to enable the experts to more effectively explore the widest possible range of input-output variables. In this context, the use of a GDSS "aims to improve the process of group decision making by removing common communication barriers, providing techniques for structuring decision analysis, and

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systematically directing the pattern, timing or content of the discussion" (DeSanctis and Gallupe, 1987)

2. Drawing the Boundaries of Central Administration In UK Universities

The higher education sector in the United Kingdom is essentially a unitary system, where the 'university' model prevails. Nonetheless, the internal organisation, procedures and regulations of individual institutions within the sector vary enormously; the most important difference is of historical nature, which is the difference between those universities created before, and those, after the Further and Higher Education Act of 1992[1]. Differences between 'old' and 'new' universities relate not only to their origins, purposes, research capacities and educational portfolios but also to their internal governance structures and style of management. Moreover, the average size of universities has been constantly rising over recent decades, increasing the need for universities to be managed more professionally and leading to the creation of new roles which are now regarded as core functions (just consider, for example, IT); such factors are also contributing to changes in the organisational characteristics.

A survey of the administrative structure of UK universities was carried out between August and October 2000. The preliminary results of the survey provided the researchers with a first important answer: not two universities' administrative structures are the same. These differences in organisational structure reflect the legacy of the different paths and purposes that led to the creation of the UK HEIs. Pilot structured interviews with small groups of administrators separately from a number of universities were also carried out to arrive at the organisational charts of a number of institutions.

Difficulties in defining one (or more) common overall profile are generally due to both differences in the reporting structure and to differences in jobs title definitions.

The work undertaken at this stage highlighted a complex problem of unit of assessment delineation. The aim of the present study is to attempt to overcome such difficulties by employing a computer-supported Group Decision Support System (GDSS).

3. Group Decision Support Systems (GDSSs)

The use of group workshops (certainly computer-supported ones) to generate input-output variables is new in DEA. Traditionally the selection of input-output variables is based on the results of investigations by the DEA researcher. However, when attempting to consider the widest possible range of factors to include in a DEA model it might be beneficial to have a group of people with a wide range of expertise contributing to the identification of the issues (Jennings and Wattan, 1994). The approach of including a group of experts of CAS (experts in that each individual had a mass of knowledge and experience of a range of CAS activities) in the identification of input-output variables is one that might reduce the risk of a researcher missing a crucial variable. We used a group of experts, rather than a single expert, because groups have access to a wider range of expertise, and group members have the potential of being stimulated to consider additional aspects of the problem by other group members (Stasser et al, 1995). If experts advise what is included in (and excluded from) the DEA model then the model will be built under the guidance of local experts on the subject. This has the additional advantage in that those interested in the results might gain more confidence in their accuracy and meaningfulness because experts have influenced the model from early in the project.

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[1] The Further and Higher Education Act 1992 and The Further and Higher Education (Scotland) Act 1992 (sections 40, 42, 43 and 54).

In this study we followed broadly the JOURNEY Making methodology of group decision support (Eden and Ackermann, 1998), but in an adapted form. JOURNEY Making advocates that group members JOintly Understand, Reflect and NEgotiate on strategY. Strategy was not involved in this case, and so JOURNEY was used in a specially adapted form.

4. GDSS mediated identification of input-output variables for DEA

The workshop had the aim of enhancing the researchers understanding of Central Administrative Services through having the experts identify the functions, resources and deliverables of CAS.

a) Group composition

Ten experts, from six HE Institutions, attended this workshop. Half of the group members had expertise in a range of administrative roles within HE at a very senior level. The remaining members were academics who also held senior administrative roles. As group members held different roles in different organisations, the first task was to define the group context of Central Administrative Services.

b) Establishing Context and building upon it

Context was built through participants considering the services, which lay within the boundaries of CAS. The workshop was organised around five stages which lead the group through an effective decomposition of the complexity of CAS, and then explore and synthesise their expertise around this decomposition.

- Stage 1: Identifying the services that are within the remit of CAS.
- Stage 2: Exploring who are the stakeholders of CAS.
- Stage 3: Synthesising knowledge of the nature of the deliverables which are provided to stakeholders.
- Stage 4: Considering what resources are needed to meet these deliverables.
- Stage 5: Exploring how these resources can be measured effectively.

In Stage 1, group members defined the unit of assessment in order to have a common understanding of what lies under the remit of central administration. In Stages 2 and 3 group members defined the outputs of CAS, and in Stages 4 and 5 participants identified inputs or resources used by central administration.

c) The nature of the computer-supported group workshop

In the workshop two facilitators helped participants to share knowledge using computer-supported brainstorming. Participants were split into pairs and each pair was given a laptop computer. Each laptop computer was LAN-linked and running a computer software package that was designed for computer brainstorming. The ideas, which were shared during the computer brainstorm, were captured in a 'group map', using mind-mapping software (Eden and Ackermann, 1998). Each idea typed into the laptop was displayed on a large projector screen during the brainstorm. Hence once each member of the group had exhausted their own sharing of ideas, they were able to look at the projector screen and see what information other people had shared. Participants were encouraged to piggy-back off the ideas they read and share new ideas to enrich the group map. Different brainstorms were run to address each of the issues detailed in Stages 1-5 (above).

5. Deriving an Input- Output Set for the Assessment of CAS by DEA

As noted earlier, the assessment of CAS by DEA requires an input and an output set. The inputs are to encapsulate all resources and contextual factors affecting the delivery of Central Administrative Services while the outputs are to reflect all such services. The GDSS has led to a much more complex picture than identified following a few interviews with administrators from a sample of universities, conducted separately at each university. However, the GDSS also enabled the researchers to simplify matters because it highlighted a commonality of deliverable (outputs) from CAS that is shared by all institutions (at least those represented in the workshop) and the same holds true for the resources used. The organisational structures do differ between institutions in terms of particular sections of CAS. However, the organisational structures deployed by institutions are an endogenous operational matter and they only become the subject of our assessment in terms of identifying ex-post which organisational structures might be more conducive to efficient operations.

The workshop provided the researchers with a wider concept and a better understanding of central administration and of its functions. As a result of the workshop and the commonality of core CAS among institutions it demonstrated, however partitioned within specific administrative departments those services, we proceeded to define inputs and outputs as follows.

Inputs

The main inputs relate to administrative staff costs and to capital costs incurred in the delivery of central administration services. It is possible to define the input *Total Administrative Costs* as composed by *Total Administrative Staff Costs* and *Other Operating Expenses.*

Outputs

With reference to the results of the workshop, outputs mainly relate to support services offered to Students and Staff, Liaisons with other bodies and services offered to support what we have termed Technology Transfer from universities to businesses and the community. The term encompasses such activities as consultancy, joint ventures between the university and external organisations, setting up commercial companies to exploit the results of research and so on.

Table 1: Inputs and Outputs Variables

Inputs	Outputs
Total Administrative Costs (Total Administrative Staff Costs + Other Operating Expenses)	Total Income from Students
	Total staff costs (minus total administrative staff costs)
	Technology Transfer

It is interesting, and perhaps rather specific to the case in hand, that all layers of the nested CAS delineations serve the same stakeholders. That is the outputs in the DEA framework would be based on the same underlying factors (students, staff and technology transfer) whichever layer of CAS we adopted as our unit of assessment. There would be the following differences, however. Each layer would go with a different definition of the expenditure being modelled. Secondly, while the outputs may be based on the same underlying stakeholders for all CAS layers, they may nevertheless be reflected in a different manner. The layered nature of Central Administrative Services and its implications for the DEA assessment would not be identified efficiently, if at all, without the benefit of a simultaneous brainstorming of a significant number of those most familiar with this service, made possible by the GDSS we have used here.

To further the analysis, we have cross-checked our GDSS based input-output set with the more traditional regression-based identification of a potential input-output set to use in the

DEA assessment. If we regress the modelled CAS expenditure on the potential output levels in Table 1 with a view to ascertaining whether they are significant drivers of the input the resulting regression equation (2000 data) is:

Table 2: Summary Regression Results

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*R Square*	*Adj. R Square*
Intercept	3099.235	1262.43715	2.455	0.0157488	0.94464132	0.943044439
Students	0.4197404	0.053782473	7.8044	4 909E-12		
Staff	-0 4325798	0 081701036	-5.2947	6.683E-07		
TT	0 9867829	0.075424987	13.083	1 047E-23		

The model above explains 94.5% (94.3% R-Sq adj.) of the variation in Total Administrative Costs across UK universities. However, although the regression is significant, not all of the independent variables selected appear necessary. The high correlations between the outputs cause a problem of multicollinearity.

Table 3: Correlation Coefficients

	Tcosts	*Students*	*Staff*	*TT*
Tcosts	1			
Students	0 7142903	1		
Staff	0 9215031	0 8165204	1	
TT	0.9526239	0 6280251	0 9433918	1

Given such high correlations between our output variables and the negative sign for one of the regression coefficients in Table 2, it is possible that some of the output variables would have be dropped, possibly biasing the assessment. However, our output variables are in line with what those working in CAS would see as important drivers of staff and other costs and so we have retained them all in our basic model. This will permit those institutions whose output variables do not follow the correlations between output variables established to be assessed more fairly than if certain output variables had been dropped on account of their strong correlations with other retained output variables. Without the prevailing strong views offered by the GDSS panellists one may have be tempted to drop the drivers concerned.

6. Evaluating the GDSS-mediated identification of input-output variables in DEA

The GDSS mediated approach outlined in this paper can become an integral part of performance measurement whatever the performance method used. We have outlined the use of GDSS in the framework of a DEA-based assessment of performance. However, the need to define a unit of assessment and to identify a set of input- output variables is generic to all performance measurement methods. This is the case in many instances of econometric measurement of performance as well as in DEA based approaches.

The main advantages of the GDSS approach include:

- *Comprehensiveness*
- *Efficiency*
- *Consensus building*
- *Client/researcher relations*

To achieve a better understanding of the issues involved in the performance assessment close working relationship between the researcher and facilitator maybe necessary to identify the nature of inputs-outputs. This latter also helps minimising experts misunderstanding of questions that have an underlying technical rationale with which they are not familiar.

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Benchmarking Indicator-Systems and their Potential for Measuring Destination Efficiency

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Abstract

The aim of this paper is to improve an already existing Tourism benchmarking tool implemented by the Austrian Government in 1987 (Haemmerle and Lehar 1987). After a very brief introduction which overviews latest benchmark approaches within tourism (Kozak and Rimmington 1998; Ritchie and Crouch 2000) and emphasizing its significance of continually monitoring and emulating standards of performance the principal purpose of an already existing benchmarking tool is described. Both, the data gathering process as well as the operational sequences leading to a variety of indicators are briefly discussed. This part concludes by analyzing the strengths and weaknesses of this secondary data based benchmarking tool. The second section of the paper critically assesses the neglect of relevant elements within the production process of tourism services. Therefore, the existing indicator approach will be conceptually extended by linking it to both quality measures of customer satisfaction as well as resource allocation conditions (Weiermair and Fuchs 1999). Thus, in order to optimize service operations within tourism destinations all the major input resources needed to provide destination services will be considered simultaneously leading to a comprehensive destination efficiency measure (Karlof and Ostblom 1994; Vuorinen et al. 1998). For this purpose a Data Envelopment analysis (DEA) model to benchmark the efficiency of service delivery processes within tourism destinations is theoretically developed and critically discussed (Charnes et al.1978; Metters et al. 1999).

Keywords: Destination Benchmarking, tourism ressources, destination efficiency, data envelowment analysis

1. Introduction

Growth in world tourism has been so dramatic that many now claim tourism to be the "world's largest industry", generating more than 10% of global gross domestic product (GDP) and employment. Over the next decade, it is forecast that the tourism sector will realize a real growth of output of approximately 50%, reaching $7.1 trillion by 2006 (WTTC 1996). This implies that not only will tourism be a major contributor to global prosperity, but also that the very nature of tourism phenomenon will shape the lifestiles, societal structures, and inevitably the quality of life of many citizens of the world during the first segment of the third millenium (Crouch and Ritchie 1999, p. 138). Furthermore, globalization and shortened destination life cycles on account of shifting consumer (i.e. tourist) preferences have resulted in sharp competitiveness being the most important aspect in the discussion of tourism sustainability (Butler 1980; Flagestad and Hope 2001). Value for money becomes the key decision element for customers and hence, resource use has not only to be examined with respect to conservation, externality and inter-generational transfer aspects but has also to be dealt with from the vintage point of view of demand, or put differently - sustainable demand (Miller

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2001). In this context, destinations are not regarded as well-defined geographical areas (such as countries, islands or towns), but rahter as the amalgam of tourism products, offering an integrated experience to consumers (i.e. tourists) to be interpreted subjectively with respect to travel itinerary, cultural background, purpose of visit, educational level and/or past experience (Buhalis 2000, p. 97; Weiermair and Fuchs 2000).

Thus, destinations and their interpretation become the new strategic unities. Consequentely, more and more destinations are adopting a strategic perspective towards tourism development and marketing involving strategic visioning, a concern for the total impact of tourism development and not just the economic consequences, an eye to the long term as opposed to short-term effects, and an overall objective of sustainable tourism development. Those destinations that have adopted such a planned approach recognize that competitiveness is illusory without sustainability (Ritchie and Crouch 2000, p. 2). It is stated by the same authors elsewhere:

> "*To be competitive, a destination's development for tourism must be sustainable not just economically, and not just ecologically, but socially, culturally and politically as well. Thus, competitiveness is illusory without sustainability. Indeed, in our view the phrase, sustainable competitiveness, is tautological.*" (Ritchie and Crouch 2000, p. 5.)

The fundamental goal of sustainable destination management is to assess both the adquacy and effectiveness of the product, the facilities, the services, and the programs that together provide memorable destination experiences for the visitors. The necessity to understand the relationship and interplay between these "factors of competitiveness" led the same authors to establish the most accepted theoretical framework for destination competitiveness and sustainability (see figure 1).

Highly important questions, such as "what do you consider to be the main determinants of the 'cost' of a destination?" or "how important is productivity in determining the cost of destination tourist services, and in turn, destination competitiveness?" may be approached in a systematic manner. Consequentely, the core destination management activities are becoming the periodic monitoring of visitor satisfaction and the regular resource stewardship involving an effective maintenance and a careful nurturing of those resources that are particularly vulnerable to damage that may be caused by tourism. Such information will be essential to ensuring destination productivity and effectiveness in the long run (Crouch and Ritchie 1999, p. 149).

Furthermore, by considering the above mentioned theoretical framework, a systematic co-operation between competing and complementary destinations enable regions to learn from each other and adapt requirements to demand (McKercher, 1993). In fact, *benchmarking* the competitiveness and sustainability led by research and using new techniques and technologies will be the only way to manage tourism destinations in the future for the benefits of all their stakeholders (Buhalis, 2000, p. 114).

Benchmarking is defined as the search for best industry practices leading to top performance (Camp 1995, p 3); Some authors identified its benefits fourfold as showing organizations how to better meet customer needs, identifying their strengths and weaknesses, stimulating the

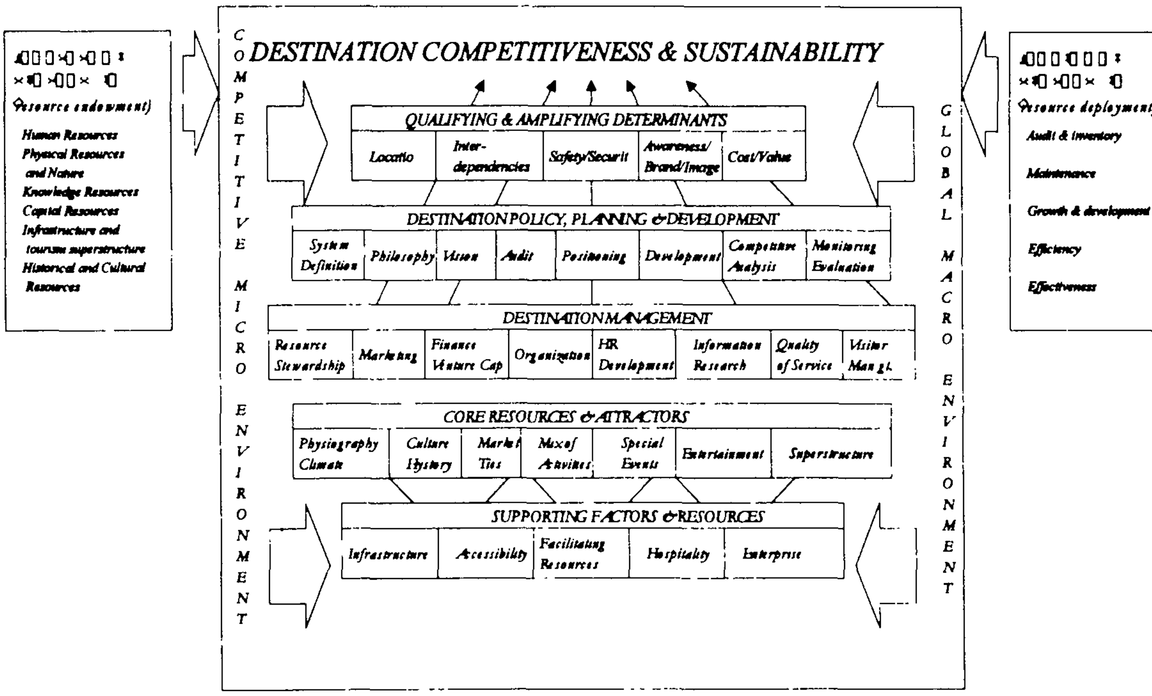

Figure 1: Destination competitiveness and sustainability (source: Ritchie and Crouch, p. 3)

continuous operational improvement and finally creating innovative ideas in a cost-effective way (Karlof and Ostblom 1994). Nevertheless, benchmarking studies have been applied most notably to the manufacturing industry by stressing the link to total quality management (Cook 1995). The few existing examples of benchmarking within the tourism industry are mainly those involving hotel operations (Boger et al. 1999) and/or applications in food and beverage management (Siguaw and Enz 1999). Tourist expectations and quality perceptions have also been analyzed within a benchmarking framework, with some authors investigating the functional areas affecting the creation of a positive customer value (Johns et al. 1996). Recently, highly valuable benchmarking studies were performed within the context of destinations (Go and Govers 2000). For instance, Kozak and Rimmington (1998) have argued that there is considerable potential for improving service quality by means of benchmarking not only within the small tourism business sector, but also within tourist destinations as consumers can benefit from clearer indications of the services to be offered, so that their service expectations are likely to correspond more closely with performance and which in turn will increase their satisfaction with the destination (Kozak and Rimmington 1998,

p. 184).

The aim of this paper is firstly to present an already existing benchmarking tool originally designed by the Austrian Provincial Government of Tyrol in 1987. The objective was to extend the National Statistics beyond time series for deciphering quantitative dimensions of tourism development over time. Secondly, a destination benchmarking framework based on Data Envelopment Analyis (Charnes et al. 1978) to improve the efficiency of (tourism) service production processes on a destinaton level will be conceptualized.

2. Objectives and Operational Sequences of the Barometer Model

Tourism plays an important role also for the Tyrolean industry (e.g. GDP's tourism portion stands at 10.8 per cent; Mayerhuber et al. 1998). In order to get a more detailed information base to strategically assist this leading branch of economic activity through appropriate tourism policies, the *Tyrolean Tourism Barometer* was introduced in 1987 by the Tyrolean Tourist Board and the Provincial Government of Tyrol (Amt der Tiroler Landesregierung 1987). The objective of the Barometer Model may be described as the monetary evaluation of structural shifts in tourism supply and demand with regard to different regional areas (i.e. destinations). The *Tyrolean Tourism Barometer* only uses two data intputs. One variable quantifies tourism demand (i.e. overnight stays) while another variable measures corresponding price developments. This approach can be justified on account of the fact that the total turnover volume of the Tyrolean accommodation sector is central to the tourism industry in that it includes over the half of all regional tourism expenditures (Haemmerle and Lehar 1987, p. 5). In order to obtain the necessary price data secondary data sources are employed. Room price lists for each accommodation category published by the regional Tourist Board serve as relatively precise proxies to provide relevant data refering to the prices for overnight stays and breakfast and/or half-board, respectively.

Data gathering for all of the existing 278 Tyrolean communities with the help of an universal census approach was considered as fairly impossible. Therefore, a representative sampling technique based on a-priori elaborated groups of tourism communities was chosen as the most adequate data gathering approach. In order to define structurally similar destination units, the study was built upon a matrix investigating 278 different Tyrolean tourism communities and 19 cluster-variables.[1] This approach allowed to cover the most important structural conditions of tourism development and its underlying dynamics of tourism demand. A *Mahalanobis* approach was used to eliminate possible biases associated with differences in the scales of the selected 19 variables which were employed in the multivariate analysis (Hair et al. 1995, p. 434). The objective was the defintion of an optimal number of clusters followed by the assignment of the statistical units (i.e. the 278 tourism commounities) according to a prespecified measure of similarity. A hierarchical clustering procedure (i.e. the *Centroid method*) was employed, displaying *eight* differing clusters as optimal (see Table 1).

No.	*Destination Type*	*Communities*	*%*	**Overnight stays %**
1	Capital City of Tyrol (e.g. Innsbruck)	1	0.4	3.7
2	Tourism centres	9	3.2	21.2
3	Destinations with intensive tourism	20	7.2	19.5
4	Destinations with intensive winter tourism	34	12.2	15.7
5	Destinations with intensive summer tourism	76	27.3	23.0
6	Destinations with city and transit tourism	20	7.2	6.9
7	Destinations with extensive summer / transit tourism	48	17.3	4.4
8	Destinations with extensive summer tourism	70	25.2	5.6
	Total	**278**	**100.0**	**100.0**

Table 1: Cluster profile of the eight destination types

[1] Time series data for the 19 selected cluster-variables include: overnight stays per community, overnight stays per inhabitant, overnight stays development, share of overnight stays / winter half-year, share of overnight stays in A1/A hotel facilities, bed occupancy rate/ winter half-year, Tourists' length of stay / winter half-year, number of cable cars, ski-lifts, chair-lifts, mountain railways, etc., capacity of cable cars, ski-lifts, chair-lifts, mountain railways, etc. per community, chare of skiing area per community, beverage tax per inhabitant.

When the survey was realised for the first time in 1987, a *multi-stratified* random-sample was drawn. As a result, 55 destinations emerged as an optimal sample size. Five years later, in 1992, the sample size was increased to 86 communities (i.e. 31 per cent) reaching about 8,000 accommodation units covering 70 percent of the total bed capacity and almost 75 per cent of the Tyrolean overnight stays (Berktold 1992, p. 76). Following the results of this preparatory work, both, the matrices for overnight stays as well as price matrices used in the analysis are further subdivided into six accommodation categories and eight destination types (i.e. clustered communities). Initially, *averarge* prices for "tourism core services" (i.e. overnight stays, breakfasts and/or half-board) were calculated by weighting them with the sales volume of the accommodation units in the sample. Subsequently, a Laspeyres type price index, average price levels per accommodation category and average price levels per destination type were obtained by weighting actual prices with sales figures from previous seasons (figure 2) The estimation model has been formulated by the following equation: [2]

$$\text{Turnover Index}_{(real)} = \text{Overnight Stays Index} \times \text{Price Index} \times \text{Quality Index}$$

The quality index serves as a residual-term to solve the displayed equation. Put differently, the constructed quality index shows how much turnover would have changed since the previous season, if no structural shifts had emerged, indicating qualitative shifts, both, between accommodation categories within a particular destination as well as between destinations with regard to the according accommodation type. Finally, calculations can be prepared for the entire benchmark area (figure 3).

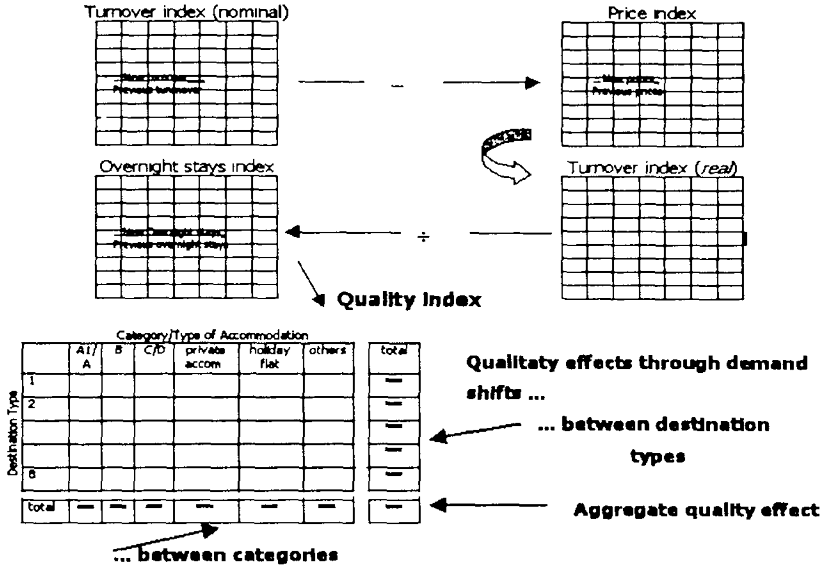

Figure 2: Derivation of the quality index (source: Fuchs & Weiermair 2002)

[2] In practice, simply dividing the turnover index $_{(real)}$ by the overnight stays index leads to a residual term with respect to the cumulative column and row values of the price matrices (Berktold 1992).

The data for the winter half-year 1989/90 display a decline of 2.9 per cent in overnight stays, while the accommodation sector still manages an increase in turnover of 1.8 per cent (figure 3). Thus, due to a faster price increase in 1989/90, the real turnover index is negative, standing at - 2.6 per cent. The positive difference between the latter index and the change in overnight stays (i.e. 0.3) may be interpreted as a (small) shift towards higher quality in tourism services. In other words, about 10 per cent of the losses on account of a drop in overnight stays was "picked up" by quality shifts in demand (figure 3). For the winter half-year 1999/2000 the traditional demand indicator of overnight stays, stood at 3.3 per cent, with a real turnover index amounting to 5.1 per cent. Thus, for this winters' total tourism performance, the benchmark area of Tyrol was showing both quantitative as well as qualitative improvements.

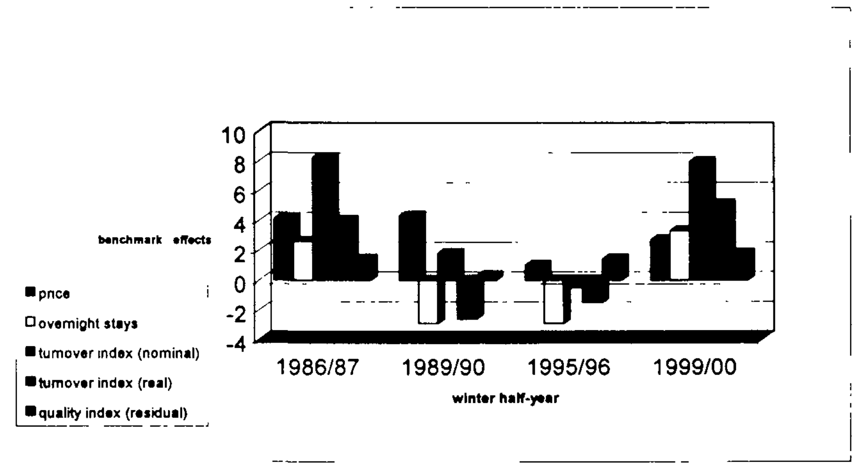

Figure 3: Aggregate benchmark data over time (data kindly provided by Amt der Tiroler Landeregierung, 2001)

3. The tool's potential for benchmarking destination efficiency

Although for the model application only a relatively small amount of input data is necessary, the main weakness of the *Tyrolean Tourism Barometer* is not its conceptional simplicity nor is it the fact that it focuses at the accommodation industry only, but rather its entire neglect of highly relevant elements within the production process of tourism (i.e. destination) services.

Tourism service processes which are produced and consumed along a given destination value chain may be seen from two viewpoints: In customer's eyes they provide benefits, the value of which is a function of the rather elusive characteristics of service quality. From a destination management perspective the service process generates income while consuming resources. Thus, productivity is the key determinant of value being closely related to all of the factors which influence value, namely quality, service and price (Fuchs 2002). It offers a first guide of measuring the well-being of destination organisations and may need to be carefully addressed and measured (Heap 1996; Teague and Eilon 1973):

- for strategic reasons, in order to compare the performance of a destination organisation with competitors (i.e. productivity measures remain the basis for benchmarking)
- for tactical reasons, to enable performance control of the destination organisation
- for planning reasons, to compare the benefits accruing from the use of different resource inputs or varying proportions of the same inputs

Productivity measurement may be used as a diagnostic tool, as a basis for measuring improvement and as a means of establishing progress towards defined destination targets. The fundamental questions are:

- What do customers (i.e. tourists) want?
- What are the real resource constraints?
- How are value adding processes performed?
- How are the same processes carried out by others (i.e. benchmarking)?
- How can things best be done?

Consequently, the management of tourism destinations has to improve their output rates and control their resource inputs. But in tourism, because of the nature of the output, the problem of measuring productivity is not without its problems. The intangible nature of tourism services means that traditional productivity concepts are less precise: Tourism services and their quality exist only in the perceptions of the customer, further obscuring the relationship between quality and value. What is being produced is a set of performances that are typically produced and consumed simultaneously trough one or more interactions between tourism producers and consumers (i.e. tourists). Figure 4 presents a destination efficiency framework adapted from Parasuraman (2002) that captures the company and customer perspectives of productivity and portrays the central role of service quality in linking the two: Inputs from both the destination and the tourists influence service quality in tourism, which in turn influences outputs from both the destination and the customer perspective (i.e. dotted arrows). Relationship 1, in line with the resource-based view, captures the notion that as destinations channel more resources into service provision, tourists' input should decline (Collis and Montgomery 1995; Parasuraman 2002: 7). The moderating effect (i.e. market-based view) represented by link 2 suggests that the extent to which changes in destination inputs trigger changes in customer inputs will depend on how the destination allocates available inputs (Løwendahl and Revang 1997). Finally, relationship 3 demonstrates the positive impact of tourists' output on the output of tourist destinations (Heskett et al.1994; Go and Govers 2000; see figure 4).

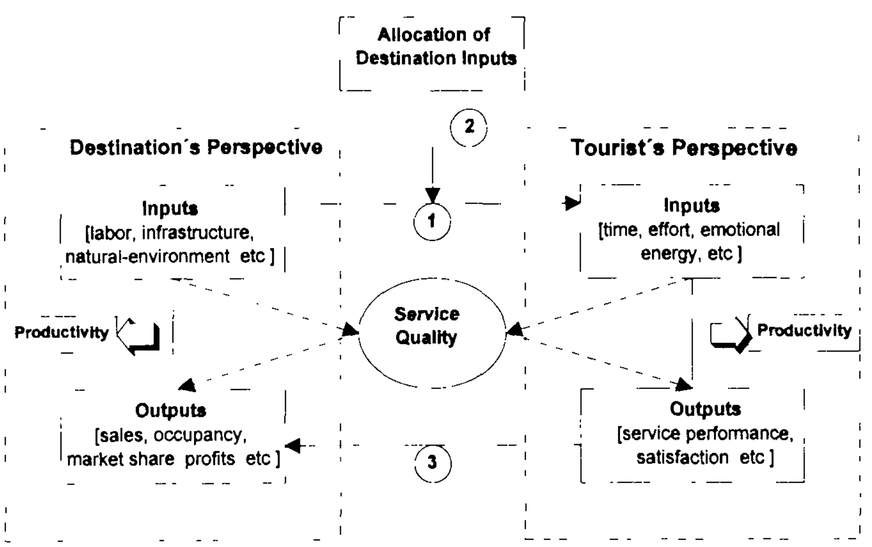

Figure 4: Destination efficiency framework (adapted from: Parasuraman 2002: 8)

Optimising tourism service quality in tourism destinations has two effects: On the one hand it should improve and/or secure the quality perceived by tourists. Thus, it is necessary to have some means of measuring the tourists' level of service satisfaction (Kozak and Rimmington

1998; Buhalis 2000). On the other hand it should make the conversion of destination inputs to outputs more efficient.

In empirically measuring progress towards more efficient production processes in tourism destinations, the perceptions of stakeholders are to be examined to identify the extent to which tourism fulfills the three core elements of meeting the interests of local residents (e.g. quality of life issues regarding both social as well as economic factors), satisfying the requirements of tourists (i.e. value creation perspecitves) and preserving the value of the natural environment (i.e. ecological aspects). A tourism barometer model of sustainable competitiveness should therefore provide a systematic way of organizing, combining and measuring indicators so thath policymakers can draw conclusions about the state of health (e.g. system quality) of both the human as well as the (natural) ecosystem of a destination (WTO 1993).

A vast enhancement over the above presented barometer model′s performance may be realized by considering the major input resources needed to provide destination experiences, such as managerial and technical skills, investors′ resources and the tourists′ expectations on the demand side (Weiermair and Fuchs 1999). Moreover, as tourism services offered in destinations are compounded by many elements, it may be argued that tourism services are produced by many subsystems that *jointly* deliver these services along a given destination service chain (Buhalis 2000). In economic language, subsystems within destinations combine a number of input resources in order to transform them to desired output levels. Consequentely, both, input resources as well as the economic output of these production/consumption processes should be considered simultaneously, leading to comprehensive destination efficiency measures. A highly valuable technique to benchmark operational efficiencies is the data envelopment analysis (Charnes et al. 1978, Post and Spronk 1999).[3] This method can be described as a tool with the ability to compare efficiencies of multiple service units (e.g. destinations) that provide similar services by explicitly considering their use of multiple inputs (i.e. resources) to produce multiple outputs (i.e. tourism services). In technical terms data envelopment analysis (DEA) is stated as a linear programming model attempting to maximize a service unit's efficiency, expressed as a ratio of outputs to inputs, by comparing a particular unit's efficiency with the performance of the benchmark (Fitzsimmons and Fitzsimmons 1997, p. 451).[4] Assuming only two input resources (e.g. x_1 and x_2) in the tourism production process and only one standardized output, it can be shown graphically that DEA, firstly, compares a group of destinations to identify relatively inefficient ones (i.e. those positioned to the right of the data envelope) and secondly, measures the magnitude of these infefficiencies. Finally it discovers ways to reduce those inefficiencies by comparing inefficient destinations with efficient ones (e.g. point A for destination 5; see figure 5).

[3] So far there exist some interesting tourism benchmark studies which have attempted to employ this technique (Mayrhuber et al. 1998, Wöber 2000).

[4] DEA corporates multiple inputs and multiple outputs into both the numerator and the denumerator of the efficiency ratio wihout the need for conversion to a common dollar basis. Thus, it circumvents the need to develop standard costs for each service.

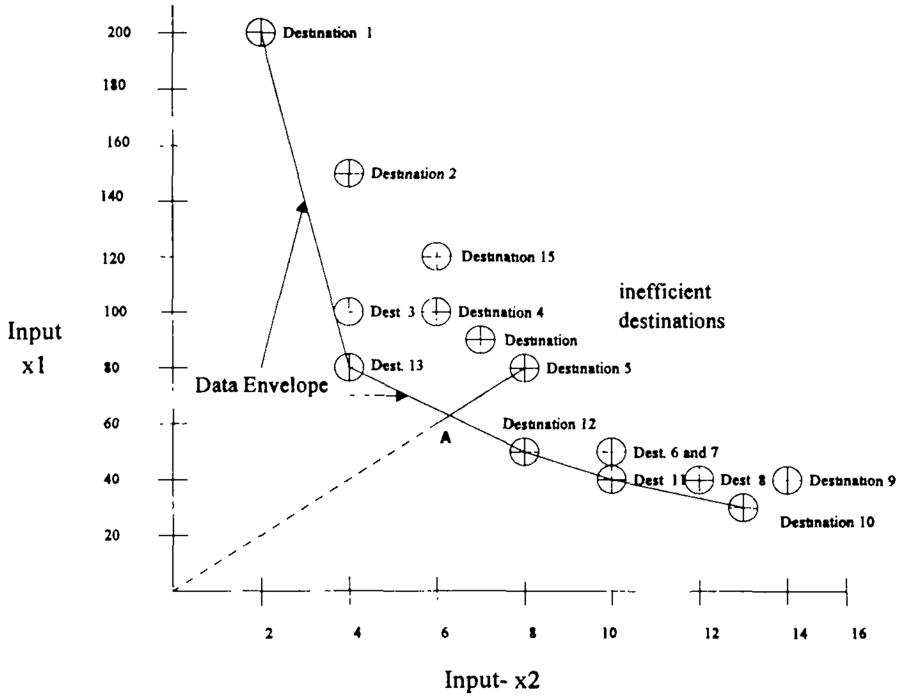

Figure 5: DEA and destination efficiency

For the practical use of DEA in a destinational context, of course, much effort must be put into the selection of appropriate input and output indicators. As desintation productivity may technically be defined as the ability to use inputs for providing services with quality matching the expectations of tourists, an indicator system suitable to DEA should ideally consider variables which include both quantitative as well as qualitative dimensions of input and ouput resources. Particularly, service output has to be seen as the *value* for the consumer (i.e. tourist) and for this reason destination output has to be defined by its underlying quality levels (Gale 1994, Vuorinen, et al.1998, p. 392). Thus, a compound destination *efficiency ratio* may be comprehensively constructed as follows (figure 6):

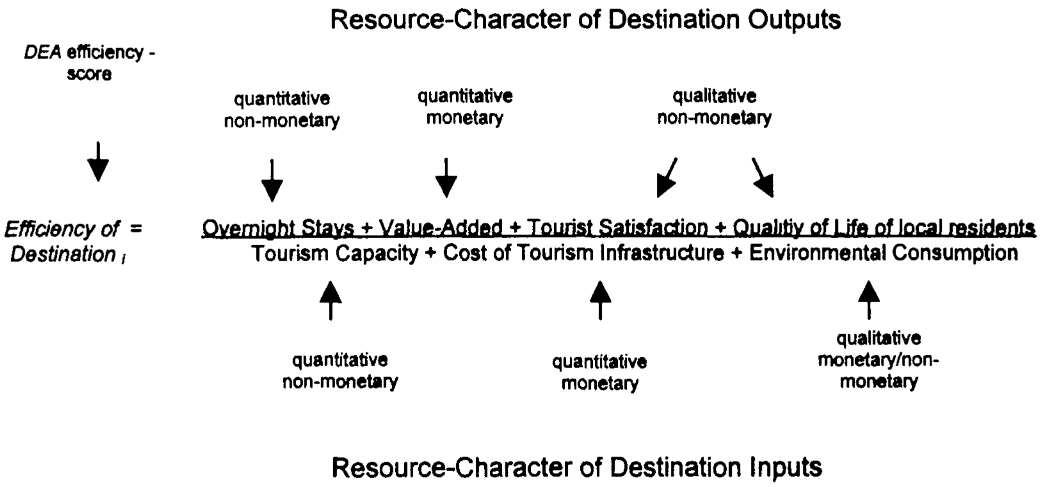

Figure 6: DEA-Indicator-System to benchmark destination efficiency

As the result of DEA brings out the resource profile's efficiency ranking of a destination and also indicates optimal paths for improvement (e.g. point A in figure 5) it must be emphasized, that this step of analysis cannot be considered as the final one, but rather as the starting point for intensive further benchmarking exercises (Zairi 1996). Here, efficient destinations serve as reference units (i.e. *peer-groups*) to analyse best practices which should be adapted for sustainable tourism production (e.g. *troughput conditions*).

4. Conclusions

Value creation through tourism within the context of a destination is firmly linked with social, cultural and natural environments. Hence, the management of sustainability of these resources with the purpose of maintaining and increasing their value as support functions is closely related to - and a condition for - the strategic success of destinations (Flagestad and Hope 2001, p. 458). As different types of tourist services call for different approaches in the formulation of a destination productivity meausure, the proposed DEA model considers both quantity as well as quality dimensions of destination resources. The measure receives different weightings depending on the nature of the service in the eyes of the customers and the stakeholders (i.e. tourists and residents). Obviously, this made clear, that benchmarking in the context of a destination using a unidemensional and relatively less developed tool, such as the *Tyrolean Tourism Barometer* will not suffice to empirically explore pahts of sustainable tourism development. Hence, the paper has outlined an enhanced approach to evaluate destination efficiency, whereby it is felt that the techniques discussed will facilitate a clearer understanding of the mechanisms by which destinations can meet the goals of competitiveness and sustainability, namely to improve the quality of life of the host community, to provide a high quality of experience for the visitor and to maintain the quality of the environment on which both the host community and the visitor depend (WTO 1995).

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