A DEA STUDY OF TELECOMMUNICATIONS SERVICES IN OECD COUNTRIES

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Abstract. In this study, an analysis of public telecommunications services in OECD countries is carried out. This evaluation is based on the relative efficiency calculated by the Data Envelopment Analysis (DEA) technique. In particular, the variable returns to scale DEA model under the radial outputs maximization is used. Several approaches, including reference frequency, cross-efficiency, super-efficiency and level efficiency, are used to evaluate the performance of OECD countries regarding the telecommunications services they provide.

Keywords: Data Envelopment Analysis (DEA), telecommunications services, ranking, OECD countries.

1 Introduction

The attainment of high levels of performance is a key issue for the success of every organization. Therefore, an adequate management framework is necessary to evaluate the current performance, identifying benchmarks to use in seeking improvements, and to understand why some units in a particular organization are operating inefficiently.

Data Envelopment Analysis (DEA) is a linear programming-based technique that is used to evaluate the efficiency of a set of Decision Making Units (DMUs, which are homogeneous units with some decision autonomy). Each DMU is characterized by “consuming” several inputs and by “producing” several outputs. DEA models use these factors (inputs and outputs) to compute the efficiency degree of a particular DMU when this DMU is compared with all the others DMUs. The DMUs that are considered (relatively) efficient belong to the efficient frontier and, therefore, they can be used as performance benchmarks to study the DMUs that are operating inefficiently.

In this study, DEA is used for the evaluation of public telecommunications services in OECD countries. The main objective of this study is oriented towards the evaluation of the modernization degree of telecommunications services offered to customers. Several approaches, including reference frequency, cross-efficiency, super-efficiency and level efficiency, are used to evaluate the performance of OECD countries, regarding the telecommunications sector. These results could be used to support decisions regarding the future policies of the countries (namely by regulating entities) in guiding their strategy aimed at providing more advanced and competitive telecommunications services.

The data used in this study is obtained from the most recent report published by the International Telecommunications Union (ITU, 1998), which includes an extensive set of indicators concerning the telecommunications services. In a different context, Sueyoshi (1994) also used some of these indicators to develop a new technique that combines LAV (Least Absolute Value) regression with DEA.

In the next section the evolution of public telecommunications networks is broadly described. In section 3, an evaluation model is proposed by characterizing the inputs and outputs to be used in the DEA models. In section 4, a brief introduction to DEA is made. In section 5, the results obtained by using different methodologies are discussed. Finally, in section 6 some conclusions are drawn and further work is outlined.

2 Evolution of public telecommunications networks

Public telecommunications networks have experienced profound transformations. The telecommunications sector's growth in number of users and its fast geographic expansion was accompanied by the creation of a diversified number of specialized networks. The evolution of the public telecommunications networks can be broadly presented in five phases, which mainly consider the telephone network because it is still the dominant network in dimension and in the number of users until today:

(i) Analog network – Telecommunications networks, in the first phase of their development, were characterized by the use of analog technology in the transmission and switching systems. In this initial phase, the telephone was the main service, while the other service used was text transmission through the telex network.

(ii) Digital transmission and analog switching network – The transmission process was digitized in the second phase, but the switching process remained analog. The digital transmission has important advantages, such as the elimination of transmission noise or the recovering of analog signal without attenuation. Also in the second phase, the first autonomous data networks appeared, firstly using circuit switching and then packet switching (e.g., X.25 protocol).

(iii) Integrated Digital Network (IDN) – In the third phase, both processes, transmission and switching, became digital. The digitization of telecommunications systems is a crucial issue both in technical and economic terms because systems become less complex in the interfaces and cheaper in technology. However, the subscriber lines mostly remained analog.

(iv) Integrated Services Digital Network (ISDN) – The main characteristic of the fourth phase of the evolution of the telephone and data networks is the digitization of the subscriber lines. The offer of higher transmission rates with respect to the analog network paved the way for the utilization of a wide range of different type of services. (e.g., videotext, telefax, teletext).

(v) Broadband ISDN – In this phase, the fundamental characteristic is the integration of all types of services: with the need of very high rates (e.g., real time video, high definition TV) or small rates (e.g., the ISDN services of the fourth phase). To be implemented, this phase requires the development of new technologies (in the transmission and switching processes) in order to support the high rates required by new and more sophisticated services. A new form of information transmission, where optical technologies have an important role, is known as Asynchronous Transfer Mode (ATM). ATM combines the flexibility of packet switching with the simplicity of synchronous temporal techniques of circuit switching.

The *Comité Consultative International de Teléphone et Telégraphe* (CCITT) is the ITU body responsible for normalization in the telecommunications sector. CCITT has been providing several technical recommendations during the process of telecommunications networks evolution. The first recommendations for the protocol X.25, ISDN and ATM where issued in 1976, 1984 and 1988, respectively.

Having this evolution of technology in perspective, the modernization degree of telecommunications services in a country is determined by its situation in the fourth and fifth phases.

3 Model definition

The main objective of this study is to compare OECD countries regarding the telecommunications services offered to the users, namely as far as its modernization is concerned. To accomplish this goal, it is necessary to develop an analytical framework to study how these countries manage their resources (inputs) in order to offer their customers specific telecommunications services (outputs).

Tavares and Antunes (1999) developed a model, illustrated in figure 1, which is based on a large list of indicators related to the telecommunications sector (ITU, 1998), taking into account the evolution of public telecommunications networks (see section 2).

Figure 1: Groups of inputs and outputs that influence the modernization degree of telecommunications services.

The modernization of the telecommunications services offered by a country has been modeled as a function that relates three groups of outputs (technology, utilization and demand) to three groups of inputs (socio-economic factors, resources and staff). Note that, in the framework of DEA, it is not required to state explicitly the functional forms which are assumed to relate inputs to outputs.

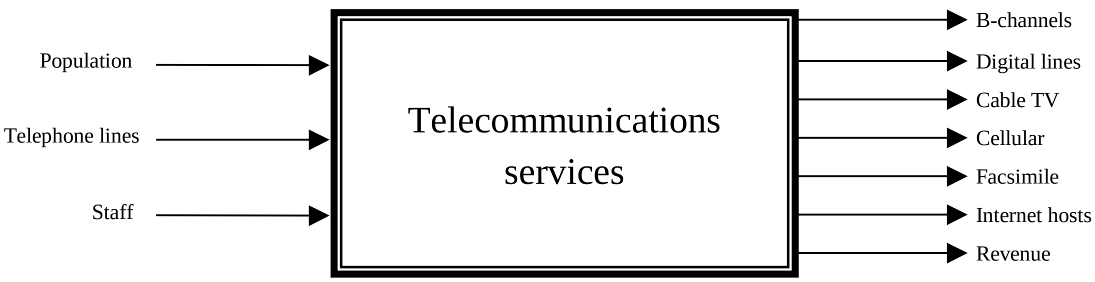

Figure 2: Inputs and outputs that influence the modernization degree of telecommunications services.

The factors that better distinguish (Tavares and Antunes, 1999) the groups of inputs and outputs in figure 1 can be seen in figure 2. By using this model, the performance analysis of the countries is characterized by a number of factors, where the explicit relationship between them is not known. Also, the telecommunications companies operate depending on regulating entities, but they also work under market economy rules. By selecting the OECD countries as the target of the study, the condition that DMUs operate according to the same market conditions is fulfilled since the countries belonging to this international organization have, in general, open market economies. DEA is an adequate technique to study organizational units that possess such characteristics.

4 DEA introduction

Data Envelopment Analysis (DEA) is a non-parametric performance measurement technique that is used to analyze the efficiency of a homogeneous set of individual entities referred to as DMUs. In this study the units are all OECD countries. Each unit is characterized by the "consumption" of several inputs (m) and by the "production" of several outputs (s).

In DEA, a DMU is considered efficient (Pareto optimal) if there is no other DMU, or a linear combination of factors (inputs and outputs) of several DMUs, that can improve one factor, without worsening the value of at least one other factor.

DEA models characterize an extreme frontier in a $m+s$ dimension space. This frontier is defined by the observed values of the efficient DMUs (or by the values obtained by the linear combination of a subset of efficient DMUs). If a DMU does not belong to this envelopment surface and it is in its interior, then that DMU is operating inefficiently.

Several distinct models (e.g., Seiford and Thrall, 1990) can be applied to classify a DMU as efficient or inefficient. In addition to this categorization, DEA models usually return an efficient projection point of operation to each inefficient DMU.

Consider the example illustrated in figure 3 with 10 DMUs, 2 inputs and 1 output.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Input$_1$	4.5	6	9	13.5	7.5	8.5	10.5	12	13	16.5
Input$_2$	135.7	145	133	93.9	150	100	24.5	120	175.5	65
Output$_1$	12.8	24.5	34	38.5	21	8.75	15.6	29.3	31.5	17.5

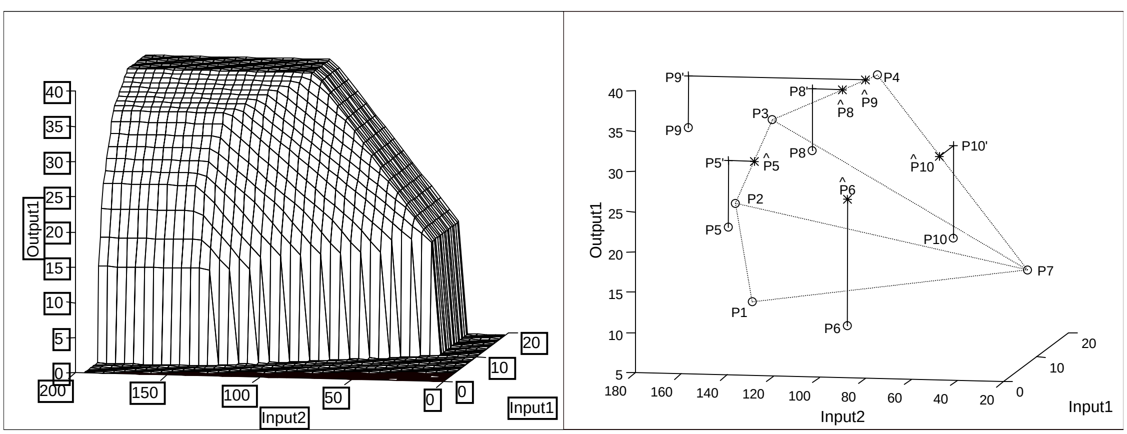

Figure 3: Efficient frontier and BCC (Banker, Charnes e Cooper, 1984) projections oriented to output maximization.

This example assumes an environment of Variable Returns to Scale (VRS). Three efficient triangular faces ($\{P_1, P_2, P_7\}$, $\{P_2, P_3, P_7\}$ and $\{P_3, P_4, P_7\}$), whose vertices are the operating points of the efficient DMUs, define the efficient frontier. Each of all the other DMUs is inefficient and it is projected on one point of the extreme frontier, oriented to the maximization of Output$_1$. P_6 is directly projected on the efficient triangle $\{P_2, P_3, P_7\}$. The other inefficient DMUs are not directly projected on the efficient frontier because the resulting projection by maximizing Output$_1$ does not reach a point on the efficient frontier (that is, the projection generates a weakly efficient solution[1]), and consequently it is necessary to consider the slacks to achieve an efficient projection.

To study the degree of modernization of telecommunications services in OECD countries (sec. 5), the VRS model of Banker, Charnes and Cooper (1984) is used. This model is known as BCC model (envelopment problem, BCC-E) and the outputs' radial maximization (ϕ_k) orientation is used. The model applied to each DMU (country) k is formulated as follows:

$$\max_{\phi_k, \lambda_k, s_k^-, s_k^+} \quad T_k = \phi_k + \varepsilon \sum_{i=1}^{m} s_{ik}^- + \varepsilon \sum_{r=1}^{s} s_{rk}^+ \qquad \text{(BCC-E)}$$

subject to:

$$\begin{aligned}
\sum_{j=1}^{n} \lambda_{jk} x_{ij} + s_{ik}^- &= x_{ik}, & i &= 1,\dots,m \\
\sum_{j=1}^{n} \lambda_{jk} y_{rj} - s_{rk}^+ &= \phi_k y_{rk}, & r &= 1,\dots,s \\
\sum_{j=1}^{n} \lambda_{jk} &= 1 & & \\
\lambda_{jk} &\geq 0, & j &= 1,\dots,n \\
s_{ik}^- &\geq 0, & i &= 1,\dots,m \\
s_{rk}^+ &\geq 0, & r &= 1,\dots,s \\
\phi_k &\text{ free} & &
\end{aligned}$$

The BCC model returns the maximum radial improvement of all outputs (in ϕ_k). If this improvement is 1 ($\phi_k = 1$) and all slacks ($\mathbf{s}_k^-, \mathbf{s}_k^+$) are zero then DMU k is operating efficiently.

[1] A solution is weakly efficient if and only if no efficient solution that is strictly better in every factor exists.

Otherwise, DMU k is operating inefficiently, and the model returns a radial efficient projection (possibly with nonzero slacks) given by the convex combination of the DMUs ($\{j:\lambda_{jk}>0\}$) on a facet of the efficient frontier:

$$\left(\hat{X}_k,\hat{Y}_k\right)=\left(\sum_{j=1}^{n}\lambda_{jk}X_j,\sum_{j=1}^{n}\lambda_{jk}Y_j\right)=\left(X_k-s_k^-,\phi_k Y_k+s_k^+\right)\quad\wedge\quad\sum_{j=1}^{n}\lambda_{jk}=1$$

ε is a non-Archimedean quantity (i.e., satisfying $0<\varepsilon<1/N$ for all positive integer N). The purpose of this quantity is to avoid the return of weak efficient solutions by the model.

The dual problem of the model BCC-E (known as the multipliers problem, BCC-M) is obtained in the following manner: each one of the nonnegative variables (or multipliers) corresponds to a constraint of the primal; the free variable ω_{0k} corresponds to the convexity constraint ($\sum_{j=1}^{n}\lambda_{jk}=1$); the equality constraint corresponds to the free variable ϕ_k; the constraints of the type "$\le$" correspond to the λ_{jk} variables; the constraints of the type "$\ge$" correspond to each one of the slack variables ($\mathbf{s}_k^-,\mathbf{s}_k^+$).

$$\begin{aligned}
&\min_{\omega_k,\mu_k,\omega_{0k}} L_k=\sum_{i=1}^{m}\omega_{ik}x_{ik}+\omega_{0k} \qquad\qquad \text{(BCC-M)}\\
&\text{subject to:}\\
&\sum_{r=1}^{s}\mu_{rk}y_{rk}=1\\
&\sum_{r=1}^{s}\mu_{rk}y_{rj}-\sum_{i=1}^{m}\omega_{ik}x_{ij}-\omega_{0k}\le 0,\quad j=1,\dots,n\\
&\omega_{\mathrm{ik}}\ge\varepsilon,\quad i=1,\dots,m\\
&\mu_{\mathrm{rk}}\ge\varepsilon,\quad r=1,\dots,s\\
&\omega_{0k}\ \text{free}
\end{aligned}$$

Frequently, in DEA literature, two types of envelopment surfaces are distinguished in each model. The efficient frontier can assume Constant Returns to Scale (CRS) as in the CCR model (Charnes, Cooper and Rhodes, 1978), or the efficient frontier can assume variable returns to scale as in the BCC model. The difference between these two types of envelopment surfaces is the presence of the convexity constraint.

5 OECD countries situation – Presentation and results discussion

The main objective of this study is to carry out a comparative analysis of OECD countries regarding the modernization degree of telecommunications services. The values of the factors to use in the analysis (figure 2) are displayed in figure 4.

Four distinct methodologies are used to make this comparison: reference frequency, cross-efficiency, super-efficiency and level efficiency. Each of these techniques has a particular interpretation and these differences will be outlined in this section. Each methodology produces a "ranking" of the countries.

		millions	thousands	thousands	thousands	thousands	thousands	thousands	thousands		US$ millions
OECD countries		**Population**	**Main telephone lines**	**Telecommunication staff**	**B-channel for the ISDN subscribers**	**Main digital telephone lines**	**Cable TV subscribers**	**Cellular subscribers**	**Facsimile machines**	**Internet hosts**	**Telecommunications revenue**
AUL	**Australia**	18.31	9500.0	80.3	23.60	7030.0	0	3815.0	475.0	514760	13423.9
AUS	**Austria**	8.06	3779.0	17.2	122.56	2720.8	897	598.7	284.7	88811	2675.7
BEL	**Belgium**	10.16	4725.5	26.2	73.29	3454.3	3658	478.2	190.0	65064	4479.7
CAN	**Canada**	29.96	18050.8	82.1	41.50	17148.2	7867	3420.3	800.0	603325	13229.2
CR	**Czech Republic**	10.32	2817.2	27.1	0.00	929.6	475	200.3	79.5	40846	1158.8
DEN	**Denmark**	5.26	3251.2	16.3	89.57	2308.3	1383	1316.6	250.0	106732	3491.8
FIN	**Finland**	5.12	2813.0	15.8	88.57	2813.0	842	1495.9	179.0	314141	2691.0
FRA	**France**	58.38	32900.0	166.4	1800.00	30597.0	1477	2462.7	1900.0	236874	27336.5
GER	**Germany**	81.91	44100.0	214.8	5150.00	37044.0	16700	5790.0	1800.0	691864	44578.2
GRE	**Greece**	10.48	5328.8	23.8	4.57	2280.7	0	550.0	40.0	16738	3132.5
HUN	**Hungary**	10.21	2661.6	16.2	11.13	1447.9	1381	473.1	45.0	29840	1287.2
ICE	**Iceland**	0.27	155.4	1.0	0.00	155.4	1	49.0	4.1	11542	155.7
IRE	**Ireland**	3.52	1390.0	11.6	0.00	1153.7	535	288.6	80.0	26895	1771.8
ITA	**Italy**	57.40	25259.0	100.0	364.21	21495.4	0	6422.0	1800.0	147873	23015.0
JAP	**Japan**	125.76	61525.9	213.1	823.53	59680.1	11005	26906.5	14300.0	734406	93622.2
KOR	**Korea (Rep.)**	45.55	19601.0	66.6	16.81	12760.2	3864	3181.0	400.0	66262	8727.8
LUX	**Luxembourg**	0.41	244.2	0.8	14.07	244.2	135	45.0	15.0	3518	317.9
MEX	**Mexico**	93.07	8826.1	49.0	0.00	7766.9	1214	1021.9	220.0	29840	6936.0
NET	**Netherlands**	15.52	8431.0	29.7	95.00	8431.0	5842	804.0	500.0	270511	8467.9
NZ	**New Zealand**	3.57	1782.0	9.1	2.42	1764.1	1	493.0	65.0	84532	2142.4
NOR	**Norway**	4.39	2440.2	18.5	148.71	2210.8	665	1261.4	130.0	150130	3590.6
POL	**Poland**	38.64	6532.4	73.7	0.48	2848.1	2719	216.9	55.0	52852	2538.4
POR	**Portugal**	9.93	3724.3	21.8	81.93	2957.0	171	663.7	50.0	23482	4457.1
SPA	**Spain**	39.27	15412.8	67.2	96.04	10388.2	425	1307.9	700.0	113227	11629.7
SWE	**Sweden**	8.84	6032.0	19.9	100.00	5790.7	1875	2492.0	450.0	237832	5139.6
SWI	**Switzerland**	7.10	4547.0	20.6	399.18	4319.6	2450	662.7	207.0	132925	8468.4
TUR	**Turkey**	63.90	14286.5	73.8	0.00	11200.6	483	806.3	102.1	17507	2566.1
UK	**United Kingdom**	58.14	30677.8	141.0	969.13	28407.6	2068	7109.4	1800.0	719333	28561.9
USA	**USA**	266.56	170568.2	897.7	2497.69	137307.4	63840	44043.0	17000.0	10112888	182683.5

Figure 4: OCDE countries and telecommunications indicators.

A particular study of each country can be done (see Tavares and Antunes (1999) for the analysis of Portugal). However, the aim of this study is to draw general conclusions about the telecommunications services of all OECD countries.

Because the objective of this study is closely related to the outputs and the scale of the countries is taken into account, the VRS model oriented to the radial maximization of outputs has been selected.

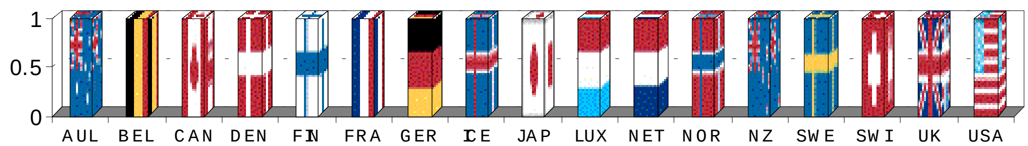

Figure 5: Efficient countries according to the BCC model.

The set of OECD countries that are on the efficient frontier is displayed in figure 5. Since this model returns an efficient projection that coincides with itself, the radial output growth of these countries is zero ($\phi_k = 1$).

According to the radial output maximization, the set of inefficient countries is displayed in figure 6. For instance, if Portugal wants to operate efficiently then it has to improve all outputs at least in 23 percent.

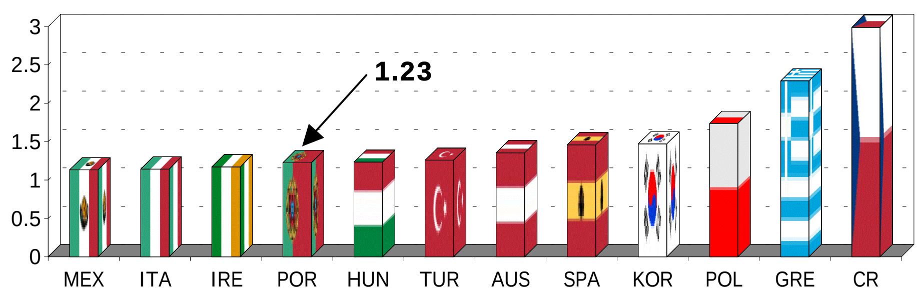

Figure 6: Inefficient countries according to the BCC model.

5.1 Reference frequency

To detect cases where a country does not have a balanced set of factors, although being efficient, an indicator is calculated by registering the frequency of each country appearing in the group of peers of the other countries. The higher is the number of times that a country belongs to the linear combination that generates the other countries (DMUs) projected points, the higher it is the probability that this country is a good representation of an efficient unit.

If the countries are ranked according to this indicator, the inefficient countries are all tied in last position because an inefficient unit never belongs to a group of peers. The reference frequency highly depends on the projection orientation or the type of envelopment surface. This means that a country could be a good example of an efficient unit in one orientation (e.g., radial output maximization), but could be a bad example in a different orientation (e.g., radial input minimization).

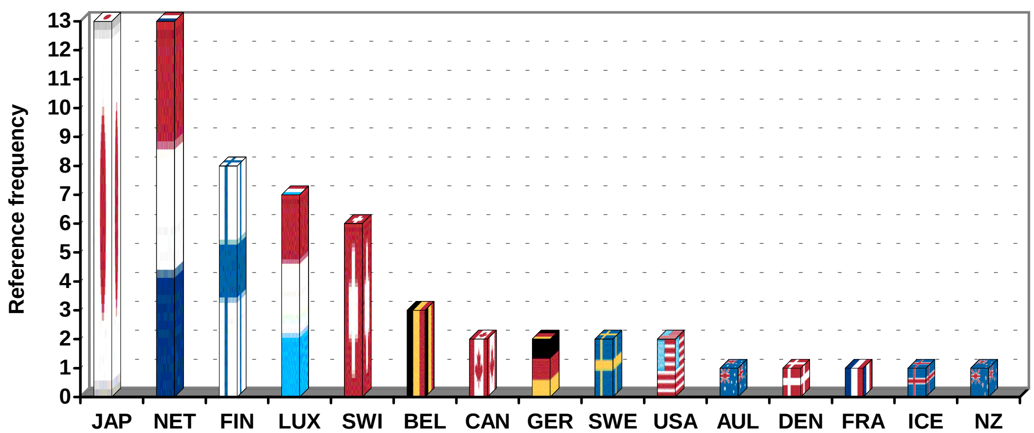

Figure 7: Reference frequency of efficient OECD countries.

The reference frequency of the efficient OECD countries is displayed in figure 7. Both Japan and the Netherlands lead this indicator with 13 appearances as a peer of the other DMUs. Finland, Luxembourg, Switzerland and Belgium follow with 8, 7, 6 and 3 appearances, respectively. After these countries, the countries with 2 appearances come out: Canada, Germany, Sweden and USA. Finally, Australia, Denmark, France, Iceland and New Zealand are only peer of themselves.

5.2 Super-efficiency

If the constraints associated with the DMU being analyzed are removed in model BCC-E, then a new indicator called super-efficiency (Andersen and Petersen, 1993) is obtained. The super-efficiency does not alter the projection of an inefficient DMU because these DMUs are still compared with the same efficient countries. However, if the DMU is efficient then it is only evaluated against the other DMUs, its own information being omitted.

For the BCC model used in this study, the super-efficiency measures how much an efficient country can decrease its outputs still remaining efficient. With this indicator, the efficiency robustness of the countries is evaluated.

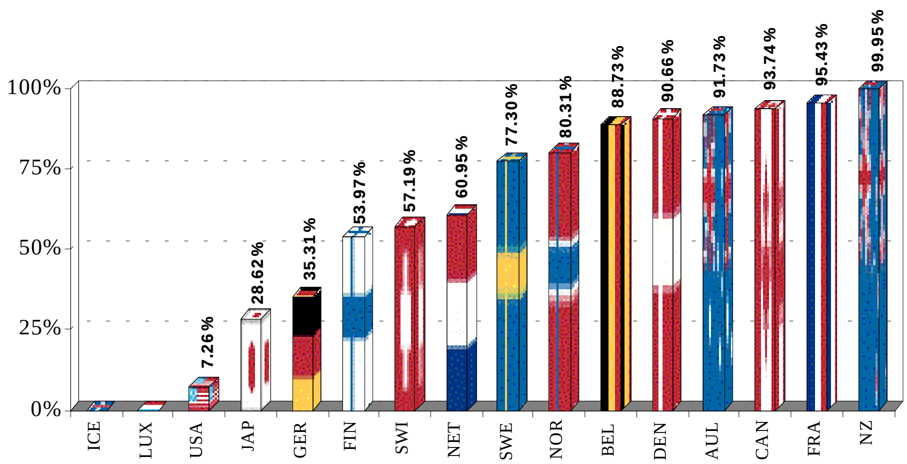

Figure 8: Super-efficiency of efficient OECD countries.

The efficient countries (assuming VRS) ranked by the super-efficiency can be seen in figure 8. In this graph, the new measure of "efficiency" is less than 100%. The lower this value, the higher the probability that the DMU is less sensitive to the outputs change while remaining an efficient one.

Iceland and Luxembourg lead this indicator. They can decrease their outputs in any quantity and be efficient countries at the same time. This happens because super-efficiency favors DMUs with isolate data (Bouyssou, 1999). The USA, Japan and Germany follow with 7.3%, 28.6% and 35.3%, respectively. On the other side, Canada, France and New Zealand have a super-efficiency of 93.7%, 95.4 and 99.9%, respectively. New Zealand is very sensitive to the change of its outputs because if all outputs decrease only 0.1% then this country becomes inefficient.

5.3 Cross-efficiency

The idea of cross-efficiency (Sexton et al., 1986; Doyle and Green, 1994) is to find the weights of a DMU (see the (BCC-M) formulation) and using them in the computation of other DMUs' efficiency. This means that each country contributes to the efficiency of the others by using its own best weights. The BCC version of cross-efficiency of DMU j according to the perspective of DMU k is given by:

$$E_{kj} = \frac{\sum_{i=1}^{m} \omega_{ik} x_{ij} + \omega_{0k}}{\sum_{r=1}^{s} \mu_{rk} y_{rj}}$$

If E_{kk} is maximized subject to $E_{kj} \leq 1$ with positive weights, $\mu_{rk}, r = 1,...,s$ and $\omega_{ik}, i = 1,...,m$, then the formulation of the BCC-M model can be obtained. After all cross-efficiencies have been calculated, the average of DMU j efficiencies can be found:

$$\overline{E}_j = \frac{\sum_{\substack{k=1 \\ k \neq j}}^{n} E_{kj}}{n-1}$$

The higher the value of $\overline{E}_j$, the higher the tendency of DMU j to reflect the observed reality of all other countries. An issue that may reduce the utility of these values is the fact that the weights that maximize the efficiency of a DMU (country) could be not unique. To avoid this situation Doyle and Green (1994) proposed the utilization of an aggressive and a benevolent formulation. However, in this study, for the sake of simplicity, the weights of BCC-M model will be used.

Table 1: Cross-efficiencies of OECD countries.

Cross-efficiencies ranking					
OECD countries		E_{kk}		$\overline{E}_k$	
NET	**Netherlands**	1.0000	1	1.0810	1
FIN	**Finland**	1.0000	1	1.1257	2
SWE	**Sweden**	1.0000	1	1.1416	3
SWI	**Switzerland**	1.0000	1	1.1550	4
CAN	**Canada**	1.0000	1	1.1815	5
JAP	**Japan**	1.0000	1	1.2069	6
USA	**USA**	1.0000	1	1.2414	7
NOR	**Norway**	1.0000	1	1.3083	8
GER	**Germany**	1.0000	1	1.3154	9
DEN	**Denmark**	1.0000	1	1.4357	10
BEL	**Belgium**	1.0000	1	1.4736	11
AUS	**Austria**	1.3566	24	1.7380	12
IRE	**Ireland**	1.1734	20	1.7489	13
UK	**United Kingdom**	1.0019	17	1.7494	14
KOR	**Korea (Rep.)**	1.4741	26	1.9202	15
MEX	**Mexico**	1.1359	18	2.0088	16
HUN	**Hungary**	1.2338	22	2.0426	17
FRA	**France**	1.0000	1	2.6390	18
POR	**Portugal**	1.2269	21	2.7613	19
POL	**Poland**	1.7378	27	2.9140	20
LUX	**Luxembourg**	1.0000	1	2.9175	21
SPA	**Spain**	1.4621	25	3.5230	22
CR	**Czech Republic**	2.9915	29	3.9027	23
TUR	**Turkey**	1.2606	23	4.3121	24
AUL	**Australia**	1.0000	1	17.3253	25
NZ	**New Zealand**	1.0000	1	21.5982	26
ICE	**Iceland**	1.0000	1	29.3403	27
ITA	**Italy**	1.1459	19	105.5809	28
GRE	**Greece**	2.2921	28	236.8938	29

Some results obtained from the cross-efficiencies of OCED countries can be seen in table 1. E_{kk} represents the efficiency of country k. $\overline{E}_k$ represents the average efficiency of country k, when it is seen by the best "perspective" of all other countries.

Table 1 is ranked by increasing order of $\overline{E}_k$. Netherlands is the best scored country. Finland, Sweden and Switzerland follow with average cross-efficiencies of 1.12, 1.14 and 1.15, respectively. At the end of this ranking Iceland, Italy and Greece appear with average cross-efficiencies of 29, 106 and 237.

The fact that an inefficient country can be ranked before an efficient country shall be emphasized. This means that this inefficient country is "better" from the others' point of view (weights) than the efficient country ranked below it. An example of that is Austria, with an average cross-efficiency of 1.74 and a BCC inefficiency of 1.36, that is ranked before France, with an average cross-efficiency of 2.64 and being BCC efficient.

5.4 Level efficiency

In Divine (1986), and independently in Tavares (1998), a simple way of grouping the DMUs into classes or levels of efficiency has been proposed. These levels are obtained by phases, one for each level. Firstly, a DEA model (VRS in this study) is used to get the first level efficient DMUs. Then, the same DEA model is used again but the DMUs to be analyzed are the inefficient DMUs of the first phase. The efficient DMUs obtained in the second phase are the efficient DMUs of the second level. This iterative process is repeated until a phase with no inefficient DMUs is found.

Table 2: Level efficiencies of OECD countries.

Level efficiencies of OECD countries																
1st level	AUL	BEL	CAN	DEN	FIN	FRA	GER	ICE	JAP	LUX	NET	NOR	NZ	SWE	SWI	USA
2nd level	AUS	HUN	IRE	ITA	KOR	MEX	POL	POR	UK							
3rd level	CR	GRE	SPA	TUR												

Three levels of efficiency have been found in this study, which are displayed in table 2. The (BCC) efficient countries (see figure 5) are the countries in the first level. The (BCC) inefficient countries (see figure 6) are split into two levels.

As suggested in Tavares (1998), studying each level separately could be a more realistic approach to analyze the modernization degree of telecommunications services, enabling to develop stepwise modernization strategies.

6 Conclusion

In this study, an analysis of telecommunications services in OECD countries has been carried out. A functional model has been proposed to evaluate the modernization degree of public telecommunications services in OECD countries. This evaluation was based on the relative efficiency calculated by the DEA performance evaluation technique. In particular, the VRS DEA model, under radial output maximization, has been used.

Several approaches, including reference frequency, cross-efficiency, super-efficiency and level efficiency, have been used to evaluate the performance of OECD countries. Each approach has a different interpretation and, therefore, different rankings were obtained. Currently, the authors are working to find a consensus ranking from these individual rankings.

The level efficiency approach shall be emphasized because it is a technique to partition the set of DMUs into classes, where a country is “similar” to the others in the same efficiency class. According to this study, there are three levels of efficiency in which the 29 OECD member countries are partitioned.

Other possible future developments of this study are: using other type of returns to scale (e.g., constant returns to scale (Charnes et al., 1978)); using different projection orientations (e.g., simultaneous inputs minimization and outputs maximization (Thanassoulis, 1996)); using weight restrictions (e.g., DEA cone ratio models (Charnes et al., 1989)); making a multi-period analysis (e.g., Malmquist index (Färe et al., 1992)).

7 References

Andersen, P. and N. C. Petersen, (1993), "A procedure for ranking efficient units in data envelopment analysis", *Management Science*, 39 (10), 1261-1264.

Banker, R. D., A. Charnes and W. W. Cooper, (1984), "Some models for estimating technical and scale inefficiencies in data envelopment analysis", *Management Science*, 30 (9), 1078-1092.

Bouyssou, D., (1999), "Using DEA as a tool for MCDM: Some remarks", *Journal of the Operational Research Society*, 50 (9), 974-978.

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

Charnes, A., William W. C., Q. L. Wei and Z. M. Huang, (1989), "Cone ratio data envelopment analysis and multi-objective programming", *International Journal of Systems Science*, 20(7), 1099-1118.

Divine, J. D., (1986), *Efficiency analysis and management of not for profit and governmentally regulated organizations*, Ph.D. dissertation, College and Graduate School of Business, University of Texas, Austin, USA.

Doyle, J. R. and R. H. Green, (1994), "Efficiency and cross-efficiency in DEA: Derivations, meanings and uses", *Journal of the Operational Research Society*, 45 (5), 567-578.

Färe, R., S. Grosskopf, B. Lindgren and P. Roos, (1992), "Productivity changes in Swedish pharmacies 1980-1989: A non-parametric Malmquist approach", *The Journal of Productivity Analysis*, 3, 85-101.

International Telecommunications Union, (1998), *World telecommunications development report 1997*.

Seiford, L. M. and R. M. Thrall, (1990), "Recent developments in DEA: The mathematical programming approach to frontier analysis", *Journal of Econometrics*, 46, 7-38.

Sexton, T. R., R. H. Silkman and A. J. Hogan, (1986), "Data envelopment analysis: critique and extensions". In: Silkman, Richard H. (ed.), *Measuring efficiency: An assessment of data envelopment analysis*, Jossey-Bass, 73-105.

Sueyoshi, T., (1994), “Stochastic frontier production analysis: Measuring performance of public telecommunications in 24 OECD countries”, *European Journal of Operational Research*, 74, 466-478.

Tavares, G. and C. H. Antunes, (1999), *Evaluation of the modernization of telecommunications services in OECD countries using DEA: The situation of Portugal* (in Portuguese), Investigação Operacional, 19, 177-192.

Tavares, G., (1998), *Data envelopment analysis: The basic models and their main extensions. A model to analyse the modernization of telecommunications services in OECD countries* (in Portuguese), M.Sc. dissertation, Faculty of Sciences and Technology, University of Coimbra, Portugal.

Thanassoulis, E., (1996), *Warwick DEA user manual*, Warwick Business School, Warwick University.