

AN EFFICIENCY ANALYSIS FOR THE EUROPEAN TELECOMMUNICATION SECTOR

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Abstract

The telecommunication sector has gained a significant role within the global economy in the past two decades. Its production and revenue efficiencies have played a crucial role in countries' economic growth and have served as financial leverage. The goal of this study is to investigate technical and pure technical efficiencies in the telecommunication sector of European countries during the period 2010-2011. Charnes, Cooper & Rhodes (1978) proposed Data Envelopment Analysis (DEA), a valuable mathematical programming technique that has been applied to measure the efficiencies of decision-making units. The basic form of DEA is a CCR model that depends upon the constant returns to scale assumption. Furthermore, Banker, Cooper & Charnes (1984) developed an alternative DEA model that includes a variable returns to scale approach. In empirical studies, DEA analyses have been carried out with revenue and production-based efficiency models. This paper presents the efficiency results of the telecommunication sector for European countries, and Austria and Spain were found to be completely efficient in terms of technical, pure technical and scale efficiencies. In addition, DEA analyses for the telecommunication sector of European countries have revealed that 2010 efficiency scores have decreased slightly in 2011.

Keywords: Data Envelopment Analysis, Production Efficiency, Revenue Efficiency, Telecommunication Sector, Europe

1. INTRODUCTION

The telecommunication sector has become one of the most important sectors in regard to boosting economic development. Information exchange at global level has improved substantially due to the developments in satellite, optical fibre, mobile technology and the internet. It is largely for economic, social and political reasons that the telecommunication sector has become significant.

Moreover, in an emerging global economy the ability of the telecommunication sector to provide an internationally competitive network for transferring information has a significant implication for trade and economic growth. Efficient transmission of telecommunication services provides direct benefit by means of low transaction costs and enhanced marketing information and indirect benefit by means of expeditious information distribution. The formation and transmission of information are the most important resources to growth in more developed countries. Furthermore, because telecommunication is a high technology sector, there is the potential for desirable and unspoken incentives of human resource development and inquiry. These benefits generated an important efficiency in production, which has a great diffusion potential in all sectors of the economy (Madden & Savage 2000).

The telecommunication sector was a monopoly in countries for quite a long time. Its liberalization first arose in the United States of America (USA) in the early 1980s, which was closely followed by Japan and United Kingdom (UK). Thus, the telecommunication sector has become competitive. Additionally, movements to liberalize the European telecommunication sector began in 1998 on the basis of the 1987 Green Paper's opening of the progressive market at the European level (Cave & Williams 1996).

In a large part of the 20th century, telecommunication sector was relatively steady. Also, it was directed by state-owned monopolies in fixed communications and a small group of operators in mobile services. Even the introduction of competition during the 1980s and 1990s caused to competitors selling corresponding services with the same basic business model of selling a connection at a fixed rental price and then charging for usage on top of that. The advent of the internet and widespread multi-access broadband networks have substantially changed with the ways people communicate, giving chance to communication via voice, video, and text-based services at anytime and anywhere. It has become even more technologically advanced and varied as the internet developed (Kearney 2013).

The global telecommunication carrier services market was anticipated to grow by 4.2% in 2012. However, large regional differences exist in terms of performance in 2012. While the EU's telecommunication sector is becoming smaller in terms of traffic, revenues and users, in other regions of the world there is significant growth where uptake rate of mobile broadband is much faster (European Commission 2014). Europe's share of the telecommunication market declined from 30% to 22% in 2002-2012 period. Across Europe, the revenue of telecommunication services was EUR 273.8 billion in 2012. On the other hand, the growth of mobile revenues was negative for the first time in 2011 (ETNO 2013).

DEA, a frequently used method in efficiency analyses, is a non-parametric and a linear programming technique that has been used to compare the technical efficiency (TE) of relatively homogeneous sets of decision-making units (DMUs). In this context, it does not require any theoretical model as measurement benchmarks (Murthi, Choi & Desai 1997).

Farrell (1957) measured the technical and allocative efficiency of firms in the single input-output setting. Farrell's efficiency measurement (1957) was reformulated under the assumption of Constant Returns to Scale (CRS) as a multiple input-output case by Charnes, Cooper & Rhodes (1978) called the CCR model. The CCR model later was developed by Banker, Cooper & Charnes (1984) with the addition of the convexity constraint under the assumption of Variable Returns to Scale (VRS); it was called the BCC model.

Sueyoshi (1994) has established two DEA models in order to measure the performance of the US telecommunication sector. In addition, Madden and Savage (1999) have examined the efficiency of 74 countries with total factor productivity (TFP) and Malmquist between 1991 and 1995. Uri (2000) has used DEA for 19 local exchange carriers. The technique not only provides a measure of the change in productivity, but it also allows for decomposition into two mutually exclusive and exhaustive components that change in TE over time and shift in technology over time. Koski and Majumdar (2000) have built three models regarding the 1980-1995 period and using DEA have revealed performance differences of the 22 countries of the Organization for Economic Co-operation and Development (OECD).

Moreover, Lien and Peng (2001) have demonstrated the production efficiency of OECD countries in the telecommunication sector during the 1980-1995 periods. Azadeh, Izadbakhsh & Bukhari (2007) have estimated the TE of 27 countries using DEA methods and principal component analysis (PCA). Yang and Chang (2007) have calculated the TE of 28 Asian countries with the methods of Stochastic Frontier Analysis (SFA) and Panel Data. Resende (2008) has investigated the robustness of different efficiency measures that can support the implementation of diverse forms of incentive regulation in the context of United States (US) telecommunication. Giokas and Pentzaropoulos (2008) have formed two models to measure production and revenue efficiency of 30 OECD countries using the methods of DEA and Analytic Hierarchy Process (AHP). In this regard, the goal of this study is to analyze and compare the production and revenue efficiency of the 32 European countries for the period 2010-2011. We have investigated the production and revenue-based efficiency levels of the mentioned countries in terms of TE, pure technical efficiency (PTE) and scale efficiencies (SE).

The paper is organized as follows. The operational and technical figures regarding the European telecommunication sector are presented in the second part. The DEA technique is mentioned in the third part. Empirical results are presented in the fourth. Lastly the fifth part of the paper presents the assessments.

2. AN OVERVIEW OF THE EU TELECOMMUNICATION SECTOR

In the early 1980s, many developed countries began to privatize and liberalize the telecommunication sector. A number of studies were conducted to evaluate the performance of the telecommunication sector before and after the reform (Lam & Shiu 2010). The liberalization movement in telecommunication markets occurred first in United States (US) in the early 1980s, with Japan and the UK the first countries to follow (OECD 2011).

Conversely, liberalization movements in the European telecommunication sector began following gradual market expansion established at the European level in the 1987 “Green Paper”¹. As a result, the telecommunications markets were privatized in most European countries by 1998 (Gruber & Koutroumpis 2010).

After the Lisbon Strategy², European countries put the Europe 2020 program into practice to correct this situation. In this program, it was emphasized that Europe was also weak before the 2001 crisis and fell behind the world average in terms of growth rates (European Commission 2012).

Work structure and future financial capacity of the European telecommunication sector can be summarized in four major areas (Liebenau, Calderwood & Karrberg 2012):

- transmission of income resources to the internet, especially in mobile applications,
- investments to increase EU and national service expansions have affected shareholders’ dividends in the sector,
- demographic changes in users, as well as digital product and service models,
- transformation of interaction and forms of service on digital platforms.

In this context, various international organizations, such as the UN, OECD, International Telecommunication Union (ITU) and the EU, tried to direct the process through some studies aiming to pioneer developments in the telecommunication sector and provide regular and beneficial expansion of it.

The EU has increasingly continued efforts to regulate the establishment of a single electronic communications market. European policymakers therefore focus on providing operators with “Three Freedoms” that can be identified as follows (Kearney 2013):

- “freedom to develop retail pricing propositions that are customer-centric and unconstrained by regulations on building or restrictions on rebalancing,
- freedom to innovate on the same terms as a non-telecoms operator,
- freedom to pursue in operation, whether in- country or cross-border.”

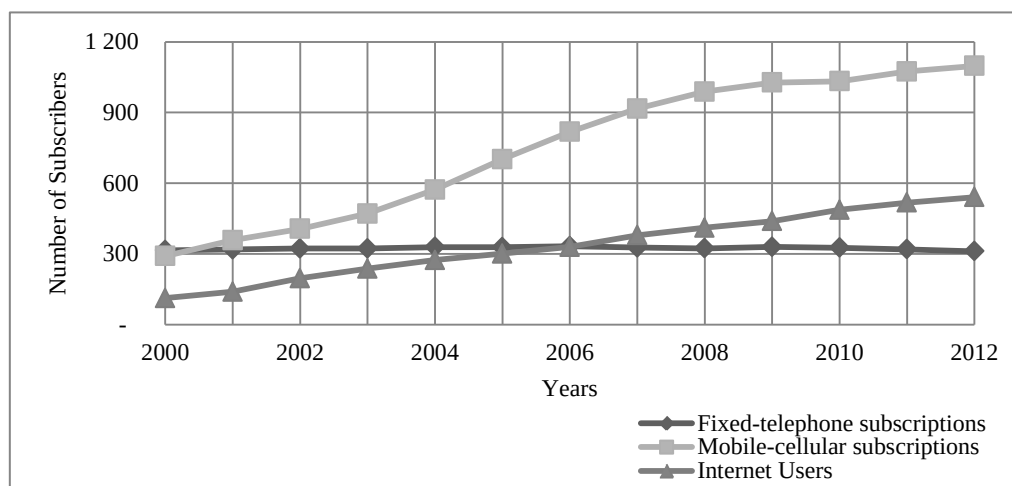
Since the 1990s, mobile technology has become increasingly popular in the telecommunication sector. Wider use of mobile technology has improved the sector’s efficiency and productivity (Lam & Shiu 2010).

Fig. 1 presents the change in European fixed-telephone subscriptions, mobile-cellular subscriptions and internet users from 2000 to 2012. It shows that mobile cellular subscriptions have steadily increased from 2000 to 2012; conversely, it seems that fixed line subscriptions changed significantly from 2000 to 2012. Internet users have continuously risen over the years.

¹ Green Papers are documents published by the European Commission to stimulate discussion on given topics at the European level (European Commission 2014a).

² The European Council reached an agreement on the Lisbon Strategy. The aim of LS launched in March 2000 by the EU heads of state and government was to make Europe “the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion”(European Commission 2014b).

Fig.1. Summary Statistics at European Telecommunication Sector in the 2000-2012



Source: Worldbank (2014), ITU (2014).

The dynamism and diversity within the European telecommunication sector propose convincing potential for growth and innovation. In this regard, to succeed this true possible, the European telecommunication sector must eventually enjoy not just the freedom to compete. Therefore, the right policy framework for growth contains stronger price competitiveness, improved capacity to innovate, and the freedom to operate more efficiently. The right policy framework for growth needs all three of these to succeed (Kearney, 2013).

Table 1. Telecommunication Sector Figures of the European Countries in the period 2008-2011

Country	Market Share of the Operators (2011)	Frequency of Internet Access % (2008-2011)	Telecommunication revenue in the GDP % (2008-2011)	Cellular Mobile Voice Traffic % (2008-2011)
Austria	4	10.00	-0.39	13.21
Belgium	4	12.00	-0.22	8.61
Czech Republic	4	12.00	-0.64	22.36
Denmark	4	7.00	-0.15	22.09
Finland	3	8.00	0.28	10.70
France	3	11.00	-0.17	3.46
Germany	4	9.00	-0.27	24.22
Greece	3	14.00	-0.56	34.43
Hungary	3	10.00	-0.58	13.34
Ireland	5	14.00	-0.06	-1.51
Italy	4	14.00	-0.30	25.06
Luxembourg	3	9.00	-0.09	27.23
Netherlands	3	7.00	-0.10	4.76
Norway	3	5.00	-0.06	20.92

Poland	4	14.00	-0.54	5.22
Portugal	3	13.00	-0.66	41.49
Slovakia	3	10.00	-0.53	27.54
Spain	4	13.00	-0.49	1.93
Sweden	3	8.00	-0.05	28.30
United Kingdom	4	11.00	-0.33	11.46

Source: EUROSTAT (2014), OECD (2011).

Table 1 shows the number of operators and the changing frequency of internet access, telecommunication revenue as a percentage of Gross Domestic Product (*GDP*) and cellular mobile voice traffic for the EU-19 in 2008-2011. In Europe, generally three operators have been active in the telecommunication market. Greece, Ireland, Italy and Poland have witnessed a higher frequency of internet access compared to other countries, and Turkey shows strong performance in cellular mobile voice traffic. Finland is seen to have accumulated higher telecommunication revenue compared to its change in *GDP*, which is better than other countries.

Conversely, comparing European markets with their counterparts in the US and Japan, the markets of the latter have performed better. While growth in Japan is also negative, the decrease of 1.2% is smaller than in Europe. In the US, growth slowed in 2012 compared to 2011 but remained solidly positive at 2.5% year-on-year. This evolution also translates into a decline of Europe's weight in the global telecoms services market. Europe's share of this market peaked at 30% in 2002 and declined to 22% in 2012 (ETNO 2013).

3. LITERATURE

DEA has been used to compare the TE of relatively homogeneous sets of DMUs that is a non-parametric and a linear programming technique. The theoretical thought of TE has occurred in the economic literature by Koopmans (1951) who defined TE as a feasible input/output vector where it is technologically impossible to increase any output without simultaneousness (Ruggiero 2000).

DEA takes advantage of techniques such as mathematical programming that can approach a wide range of variables and constraints. This situation enables to evaluate the requirements when one is limited to choosing only a few inputs and outputs. Used of the techniques will encounter difficulties (Cooper, Seiford & Tone 2006).

Farrell (1957) measured TE and allocative efficiency using single-multiple input and output for business companies. Charnes, Cooper & Rhodes (1978) developed Farrell's idea under the assumption CRS and measured the comparative efficiency of 70 schools using multiple input and output variables. Afterwards, Banker, Cooper & Charnes (1984) proposed adding the convexity constraint in the CCR model, which has since been known as the BCC model.

DEA models can be classified into two categories that are output-oriented and input-oriented models. The output-oriented models represent the capacity of a DMU to acquire the maximum volume of production (output) with the available inputs. On the other hand, the input-oriented models refer to the ability to continue the same capacity of production using a minimum number of inputs (Cooper, Seiford & Tone 2000, 2006).

According to, two basic DEA models are the CCR model and the BCC model, a DMU is evaluate the situation as efficient if TE corresponds to "1" ($TE = 1$). On the contrary, if the TE score is less than "1", it points to what extent a DMU should decrease inputs to be able to produce its level output as efficiently as technically efficient DMUs (Fandel 2003).

One of the main objectives of a DEA technique is to calculate the inefficient DMUs onto the production frontiers such as the CCR-projection and the BCC-projection. These projections have two directions which are input-oriented and output-oriented. The input-oriented aims to decrease the number of inputs as much as possible while keeping at least the present output levels. Moreover, the output-oriented maximizes output levels under the highest present input consumptions (Cooper, Seiford & Tone 2006).

DEA's ability to classify both as sources and amounts of efficiency in each input and each output for each asset (hospital, store, etc.) and as the benchmark members of the efficient set used to carry out these considerations and classify these sources (and amounts) of inefficiency were noticed as advantages of DEA (Cooper, Seiford & Tone 2006).

3.1. Efficiency Analysis Models

3.1.1. Constant Returns of Scale Approach

DEA is the concept invented in operations research literature by Charnes, Cooper & Rhodes (1978) to calculate the TE of a given investigated DMU assuming CRS. Thus, their linear programming formulation enabled multiple inputs and multiple outputs. Also, it allows for implementations to a wide variety of activities. The concept of DMU to represent any asset is to be assessed in terms of its abilities to change inputs into outputs (Ruggiero, 2011).

The observations that form the production possibility make it possible to evaluate the CCR model from a wider point of view (Cooper, Seiford & Tone 2006).

The CCR model targets to minimize inputs as contenting at least the given output levels and it is called the input-oriented model. On the other hand, the model called the output-oriented model tries to maximize outputs without using more than the observed amount of any input values. This model is formulated as (Cooper, Seiford & Tone 2006):

$$(DLPO_o) \max_{\eta, \mu} \eta \quad (1)$$

s.t.

$$x_o - X\mu \geq 0 \quad (2)$$

$$\eta y_o - Y\mu \leq 0 \quad (3)$$

$$\mu \geq 0 \quad (4)$$

Above formulation solves the output-oriented CCR model (*CCR-O*) represented by (1)-(4). In this model, the optimal efficiency score η identified the output enlargement rate and satisfies $\eta \geq 0$. However, this value by its inverse as $\theta = \frac{1}{\eta} (\leq 1)$. This is expressed by the CCR-O efficiency score that is represented to as TE in terms of DMUs (Cooper, Seiford & Tone 2006).

3.1.2. Variable Return Scale of Approach

An alternative model was proposed by Banker, Cooper & Charnes (1984). They enhanced the CCR model to evaluate PTEs and SEs of units. As indicated above, the models with CRS assume that an increase in inputs will result in a proportional increase in outputs. However, for some reasons DMUs may not handle in an optimal scale, so this proportional at input levels can give rise to dissimilar proportional alteration at output levels (Cooper, Seiford & Tone 2006).

In this context, The DEA model for VRS was developed to account for this effect. Thus, this model enables an increase in input values to result in a non-proportional increase in output levels. So, The VRS surface covers the population by associating the furthest DMUs and it comprises the one approached by the CRS surface. Hence, the BCC model covers more data, and efficiency scores are bigger than or equal to the scores acquired by CCR. The output-oriented BCC (*BCC-O*) model is formulated as follows (Cooper, Seiford & Tone 2006):

$$(BCC - O) \max_{\eta_B, \lambda} \eta_B \quad (5)$$

s.t.

$$X\lambda \leq x_o \quad (6)$$

$$\eta_B y_o - Y\lambda \leq 0 \quad (7)$$

$$e\lambda = 1 \quad (8)$$

$$\lambda \geq 0 \quad (9)$$

The convexity condition is the only difference between the BCC and CCR models. The convexity constraint ($e\lambda = 1$) is taken into consideration to make certain that inefficient firms are only “benchmarked” against firms of a comparable size. Thus, it occurs for the calculation of PTE. In other words, the project point (for that firm) on the DEA frontier is a convex combination of examined firms (Coelli et al. 2005).

3.1.3. Scale Efficiency

Banker, Cooper & Charnes (1984) establish the term of most productive scale size unchanging with technically efficient production on the CRS surface of the production frontier. Production originates on an increasing or decreasing return to scale surface. That is, production is not most productive and scale inefficient. Also, the measure of SE proximity for most productive scale size is supplied the calculation of SE (Ruggiero 2011).

The scale efficiency is measured the TE calculated under both CRS and VRS assumptions. There should be a difference between the scores of TE under CRS and VRS for a certain DMU. The difference points out scale inefficiency of the DMU (Cooper, Seiford & Tone 2006). Cooper, Seiford & Tone (2000, 2006) express the SE for the DMUs as in the following equation:

$$SE = \frac{\text{Technical Efficiency}}{\text{Pure Technical Efficiency}} \quad (10)$$

If the SE is equal to “1”, the DMU is scale efficient. On the other hand, if the SE is smaller than “1” ($SE < 1$), DMU is not scale efficient. That is, the combination of inputs and outputs are scale inefficient.

3.2. Efficiency Studies in Telecommunication Sector

The dynamics of the telecommunication sector have been shown to be a suitable ground for fixed measurement, research, analysis and comparison of suitable performance properties. At the same time, when we looked at the methodology, micro and macro studies have taken part in telecommunication sector studies. Micro studies generally evaluate the performance of operators in a country whereas macro studies compare countries’ telecommunication sector efficiency. Especially investments in telecommunication infrastructure have the potential to improve national efficiency and economic growth (Madden & Savage, 1998).

Attention about measuring the productivity and efficiency of the telecommunication sector increased in the early 1980s. Recently, production frontier models known as DEA and the Malmquist approach begin using to measure productivity and efficiency performance of the telecommunication sector (Lam & Shiu, 2008).

Sueyoshi (1994) applied DEA together with Least Absolute Value to compare the performance of Public Telecommunications Operators (PTOs) in 24 OECD member countries in 1987. The results indicated that not only large PTO countries but also small PTO countries had achieved higher efficiency.

Majumdar (1998) measured the efficiency of 40 major US telecommunication companies in the period 1973-1987 by using the output-oriented BCC model. Madden and Savage (1999) analyzed 78

countries in the period 1991-1995 using the TFP and Malmquist Index. In addition, Uri (2001) measured US telecommunication sector efficiency by using input-oriented CCR and BCC models on 19 American local telephone central operators in the period 1988-1998.

Koski and Majumdar (2000) calculated the efficiency of 22 OECD countries by using DEA output-oriented models and three different efficiency models. In these models, inputs are operator investments and employee number; output is total number of main telephone lines in first model, second model includes two outputs as total number of main telephone lines and percent of digital main lines and lastly, the third model involves three outputs as the number of main telephone lines, the number of cellular subscribers and percent of digital main lines.

Azadeh, Izadbakhsh & Bukhari (2007) measured the TE of 27 countries for 2003 by using DEA and PCA approaches with the following input variables: monthly business telephone subscribers, monthly residence telephone subscribers, employees, telephone failures per 100 main lines and output variables as cable modem internet users, cellular mobile users, DSL internet users, public telephones and total telecom service incomes.

When examining the studies of countries' efficiency comparisons in literature, Symeou (2011) measured the TE of 139 countries between 1990 and 2004 by using SFA. As input variables, he used the number of employees in the telecommunication sector and telecommunication investments, and as output variables the number of fixed line telephone, internet and mobile phone subscribers. Moreover, Petrović et al. (2011) measured the efficiency of 20 developing country telecommunications sectors. They used total telecommunication services revenue as the output measure, while as inputs they considered the total number of subscribers, total full-time staff employed and annual telecommunication investment.

Lam and Shiu (2010) measured 112 countries' efficiency with TFP and collated them with the Kruskal Wallis period in 1995-2004. As input variables they used main telephone line processor, telecommunication investments and full time employees, and as output variables telecommunication income. Moreover, Yang and Jia (2007) measured the TE of 28 Asian countries between 1994 and 2003 by using panel data and SFA. As input variables they used full time employee number, average annual telecommunication investment and number of total subscribers (*mobile cellular subscriptions and fixed line subscriptions*), and as output variables total telecommunication income.

In this context, as in our study, annual telecommunication investment has been considered as investment to fixed line telephone and mobile phones; number of total subscriber has been considered as the number of internet users, the number of mobile cellular phone subscribers and the number of fixed line telephone subscribers.

4. EMPIRICAL STUDIES

4.1. Data and Methodology

In this study, we have investigated the efficiency levels of the European telecommunication sector in the period 2010-2011. In this regard, the DEA approach has been applied on the European telecommunication sector data. For the present study, a specific version is output-oriented DEA, which is the CCR model and BCC model. We have made production and revenue efficiency analysis for the European countries' telecommunication sector for the period 2010-2011. DMUs have been selected that include 32 European countries that have been submitted for DEA analysis for the period 2010-2011.

Conversely, most of the input and output data are taken from ITU, EUROSTAT, World Bank and OECD. Table 2 presents the descriptive statistics of the input and output measures used in the empirical study.

Table 2. Descriptive Statistics for Input and Output Measures of European Telecommunication Sector in the period 2010-2011

Years	Parameters	Mean	Standard Deviation	Maximum	Minimum
2010-2011	Mobile phone investment (10*3)	490,221	724,683	3,261,477	6,573
	Fixed line telephone investment (10*3)	622,732	1,082,539	4,707,974	1,330
	Full time employees	34.5	67	341	1.1
	Fixed line telephone subscribers (10*3)	6,034.5	10,149.5	44,533	192
	Mobile cellular subscribers (10*3)	16,311	24,035	94,853.5	342.5
	Internet user (10*3)	32,966	66,065	340,678.5	338
	Total investment (10*3)	1437083	2148384	8528008	38,434.5
	Total subscribers(10*3)	55,312	89,001.5	409,102.5	873
	Mobile phone revenue (10*3)	4,765,652	7,102,029	28,327,944	99608
	Fixed line telephone revenue (10*3)	3,901,608	7,225,489	32,140,438	58,297.5

We have established two efficiency models as production and revenue efficiencies. To measure production efficiency, we have utilized three outputs and three inputs in the analyses. In addition, we have measured the output by subscribers, which are fixed line telephone subscribers, mobile phone subscribers and internet users.

Conversely, to measure revenue efficiency, we have configured a revenue function that uses two outputs and three inputs. We have evaluated the output by mobile phone and fixed line telephone revenue in the telecommunication sector. The three inputs are labor (full time employees), annual investment and total subscribers, which include fixed line telephone subscribers, mobile cellular subscribers and internet users. Thus, we have established two models as production and revenue efficiency to evaluate telecommunication sector circumstances of European countries.

Table 3. Input and Output for Production and Revenue Efficiency

Efficiency Model	Input Variables	Output Variables
Production Based Model	Mobile Investment	Fixed Line Telephone Subscribers
	Fixed Line Investment	Mobile Subscribers
	Total Employee	Internet Users
Revenue Based Model	Total Subscribers	Mobile Revenue
	Full time employee	Fixed Line Revenue
	Annual Investment	

Table 3 illustrates efficiency models used in the empirical studies. As capital and labor, capital has been measured as annual telecommunication investment (USD) and telecommunication infrastructure development has been measured with total number of users (Koski & Majumdar 2000). Labor is

represented by the number of full time employees in the telecommunication sector and annual telecommunication revenues have been taken as an economic indicator.

When we have measured the efficiency of the telecommunication sector, we have chosen data on sector outputs and inputs. Similar to Symeou (2011), Lam and Shiu (2010), Giokas and Pentzaropoulos (2008), Koski and Majumdar (2000), Yang and Jia (2007) and Lien and Peng (2001) used number of employees in the telecommunication sector in their studies.

Similar to Symeou (2011), Yang and Jia (2007) and Lien and Peng (2001) used annual telecommunication investments, Lam and Shiu, (2010), Giokas and Pentzaropoulos (2008). Yang and Jia (2007) and Lien and Peng (2001) used annual telecommunication revenues. Symeou (2011), Lam and Shiu (2010), Giokas and Pentzaropoulos (2008) and Koski and Majumdar (2000) used number of mobile cellular and fixed line telephone subscribers and internet users in their studies.

Generally, telecommunication sector efficiency of the countries has been analyzed by using capital and labor force as inputs, and revenue and number of subscribers as outputs. The inputs and outputs used in this study are similar to those used in the above studies and support our models.

4.2. Findings

4.2.1. Efficiency Results for the Production Model

This section presents the results that were obtained using the approach described above for the CCR output oriented model and the BCC output oriented model. The selected production efficiency scores are summarized in Table 4.

Table 4. Telecommunication Efficiency Scores of the Production Model of 32 European Countries in the period 2010-2011

Country	2010			2011		
	TE Score	PTE Score	SE Score	TE Score	PTE Score	SE Score
Albania	1.000	1.000	1.000	1.000	1.000	1.000
Armenia	1.000	1.000	1.000	1.000	1.000	1.000
Austria	1.000	1.000	1.000	1.000	1.000	1.000
Bosnia and Herzegovina	0.697	0.701	0.994	0.684	0.685	1.000
Bulgaria	0.952	1.000	0.952	1.000	1.000	1.000
Cyprus	0.626	0.634	0.987	0.637	0.647	0.984
Czech Republic	0.427	0.436	0.979	0.482	0.517	0.931
Denmark	0.731	0.733	0.997	0.682	0.685	0.996
Estonia	0.657	0.667	0.985	0.640	0.688	0.930
Finland	0.389	0.392	0.993	0.303	0.305	0.993
Georgia	1.000	1.000	1.000	1.000	1.000	1.000
Greece	0.867	0.870	0.997	0.815	0.819	0.995
Hungary	0.613	0.622	0.984	0.667	0.667	0.999
Iceland	1.000	1.000	1.000	1.000	1.000	1.000
Ireland	0.544	0.547	0.995	0.589	0.594	0.991

Italy	0.725	1.000	0.725	0.730	1.000	0.730
Latvia	0.675	0.682	0.989	0.467	0.473	0.988
Lithuania	1.000	1.000	1.000	0.598	0.604	0.989
Luxembourg	0.679	0.788	0.861	0.535	0.598	0.896
Malta	1.000	1.000	1.000	0.601	0.794	0.757
Moldova	0.790	0.822	0.961	0.603	0.605	0.997
Poland	0.661	0.675	0.979	0.516	0.559	0.923
Portugal	1.000	1.000	1.000	1.000	1.000	1.000
Romania	0.844	0.844	1.000	0.729	0.889	0.820
Russia	1.000	1.000	1.000	0.929	1.000	0.929
Slovak Republic	0.691	0.718	0.963	0.609	0.615	0.990
Slovenia	0.838	0.841	0.996	0.827	0.828	1.000
Spain	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	1.000	1.000	1.000	1.000	1.000	1.000
Switzerland	0.771	0.773	0.997	0.653	0.655	0.996
Turkey	1.000	1.000	1.000	1.000	1.000	1.000
United Kingdom	0.954	1.000	0.954	0.682	1.000	0.682
Average Score	0.817	0.836	0.978	0.749	0.788	0.954

Besides, the UK and Italy are efficient in the BCC-O models in the period 2010-2011 and Romania showed SE in 2010. Six countries showed growth in both performance scores in comparison with 2010-2011, namely Bulgaria, Cyprus, Czech Republic, Hungary, Ireland and Italy.

DEA analyses have revealed that all European countries in 2010 had noticeably better efficiencies compared to 2011 based on the production-based model. In this regard, it has been determined that 12 countries in 2010 and 10 countries in 2011 had SE.

In the studies performed, the potential improvement ratios of input and output variables are crucial. In this context, in Table 5 the average improvement ratios for the input and output variables are shown considering the projection values obtained from performed analyses through the CCR and BCC models.

As in Table 5, the CCR-O model shows that operators should increase fixed telephone subscribers, mobile phone subscribers and internet users by a ratio of between 31% and 83.1% in 2010. According to the results for 2011, the outputs should be increased from 47.3% to 111.1%. Table 5 indicates the average improvement ratios within the context of BCC analysis.

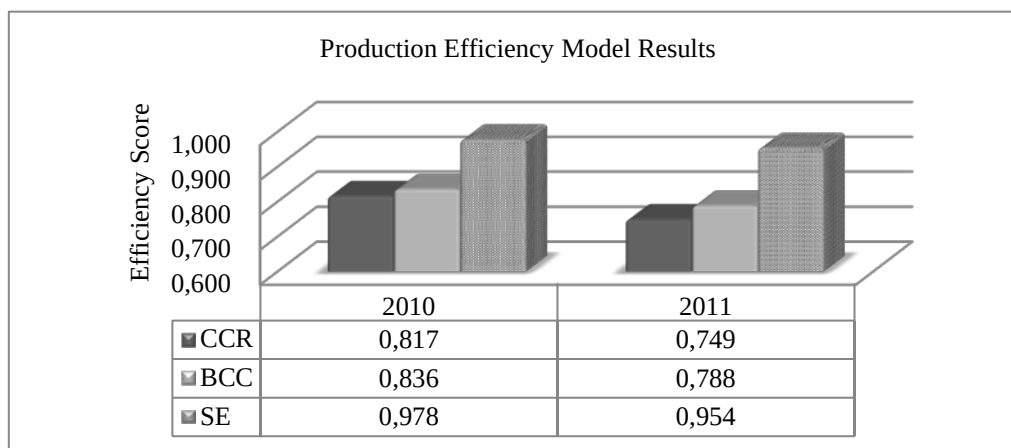
Table 5. The Average Improvement Ratios for Production-Based Efficiency Models in the period 2010-2011

Input and Output Variables	2010		2011	
	CCR Model	BCC Model	CCR Model	BCC Model
Mobile phone investment	-	-0.003	-0.009	-0.019

Fixed line telephone investment	-0.116	-0.102	-0.252	-0.203
Full time employees	-0.000	-	-	-0.005
Fixed line telephone subscribers	0.310	0.287	0.473	0.397
Mobile cellular subscribers	0.831	0.389	1.111	0.533
Internet user	0.651	0.656	0.835	0.845

In this context, according to the BCC model results for 2010, the outputs of countries should be raised by a ratio of between 28.7% and 65.6%. In addition, input values should be decreased by a ratio of between 0 and 0.3%.

Fig. 2. Comparison of DEA Efficiency Scores of the Telecommunication Sector for European Countries in the period 2010-2011



As shown in Fig. 2, it has been found that European countries have demonstrated higher production efficiency scores with respect to the BBC model and CCR model in 2010 than in 2011. European countries showed an 8.32% efficiency decrease in 2011 in terms of CCR analysis, and a continuously 5.74% efficiency decrease in 2011 in terms of BCC analysis. However, European countries showed a 2.45% efficiency decrease 2011 in terms of SE analysis. Examining these scores, we have observed that the following percentages of European countries demonstrated higher performances in comparison with the average efficiency scores. In this regard,

- 53.13% of European countries in the CCR model, 56.25% of European countries in the BCC model and 81.25% of European countries in the SE model for 2010,
 - 40.63% of European countries in the CCR model, 53.13% of European countries in the BCC model and 71.88% of European countries in the SE model for 2011
- have been observed.

Hence, we may conclude that European countries showed higher average DEA scores in 2010 than average DEA scores in 2011.

Table 6. Summary Efficiency Scores of the Production Model in the period 2010-2011

Parameters	2010			2011		
	TE Score	PTE Score	SE Score	TE Score	PTE Score	SE Score
Average	0.817	0.836	0.978	0.749	0.788	0.954

Maximum	1.000	1.000	1.000	1.000	1.000	1.000
Minimum	0.389	0.392	0.725	0.303	0.305	0.682

As shown in Table 6 the average BCC scores are higher than the average CCR scores in every year, which is consistent with the DEA theory that BCC scores are always higher than CCR scores. These are due to CCR efficiency combining both TE and SE while the BCC model only measures TE without regard to SE.

4.2.2. Efficiency Results for the Revenue-Based Model

Table 7 shows the efficiency scores from revenue model in each country calculated for the period 2010-2011.

Table 7. Telecommunication Efficiency Scores of Revenue Model of 32 European Countries in the period 2010-2011

Country	2010			2011		
	TE Score	PTE Score	SE Score	TE Score	PTE Score	SE Score
Albania	0.522	0.538	0.970	0.372	0.407	0.912
Armenia	0.441	0.449	0.982	0.414	0.479	0.864
Austria	1.000	1.000	1.000	1.000	1.000	1.000
Bosnia and Herzegovina	0.426	0.437	0.975	0.448	0.471	0.951
Bulgaria	0.449	0.476	0.945	0.402	0.406	0.990
Cyprus	0.725	0.809	0.897	0.786	0.924	0.851
Czech Republic	1.000	1.000	1.000	0.710	0.731	0.971
Denmark	0.643	0.643	1.000	0.646	0.649	0.995
Estonia	1.000	1.000	1.000	0.830	1.000	0.830
Finland	0.841	0.866	0.971	0.810	0.838	0.967
Georgia	0.419	0.428	0.978	0.278	0.309	0.898
Greece	0.790	0.792	0.997	0.782	0.839	0.932
Hungary	0.732	0.732	1.000	0.718	0.723	0.992
Iceland	0.446	1.000	0.446	0.640	1.000	0.643
Ireland	1.000	1.000	1.000	1.000	1.000	1.000
Italy	1.000	1.000	1.000	1.000	1.000	1.000
Latvia	0.435	0.484	0.898	0.411	0.440	0.935
Lithuania	0.793	0.797	0.994	0.634	0.667	0.951
Luxembourg	1.000	1.000	1.000	0.929	1.000	0.929
Malta	0.659	1.000	0.659	0.607	0.877	0.692
Moldova	0.259	0.265	0.977	0.189	0.204	0.923
Poland	0.653	0.739	0.884	0.674	0.684	0.986

Portugal	0.788	0.829	0.950	0.799	0.818	0.977
Romania	0.633	0.678	0.934	0.566	0.585	0.968
Russia	0.543	0.790	0.687	0.365	0.783	0.466
Slovak Republic	0.836	0.838	0.997	0.697	0.711	0.980
Slovenia	0.758	0.765	0.991	1.000	1.000	1.000
Spain	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	0.994	1.000	0.994	0.839	0.926	0.906
Switzerland	1.000	1.000	1.000	1.000	1.000	1.000
Turkey	0.864	0.866	0.998	0.699	0.699	1.000
United Kingdom	1.000	1.000	1.000	1.000	1.000	1.000
Average Score	0.739	0.788	0.941	0.695	0.755	0.922

Table 7 indicates that Austria, Ireland, Italy, Spain, Switzerland and the UK are efficient overall TE, PTE and SE in the period 2010-2011. Moreover, the Czech Republic, Estonia and Luxembourg had full TE, PTE and SE in 2010 whereas Slovenia showed full TE, PTE and SE in 2011. Furthermore, Estonia, Iceland and Luxembourg were fully efficient in the BCC-O models in 2011 and Sweden and Iceland was PTE in 2010.

Seven countries demonstrated a growth in efficiency scores, namely Bosnia and Herzegovina, Cyprus, Denmark, Iceland, Slovenia, Poland and Portugal. DEA analyses have revealed that all European countries in 2010 had noticeably better efficiencies compared to 2011 according to production models. In this regard, it has been revealed that nine European countries in 2010 and seven countries in 2011 have shown SE.

Table 8 shows the average improvement ratio recommendations in the input and output variables for the revenue-based efficiency model.

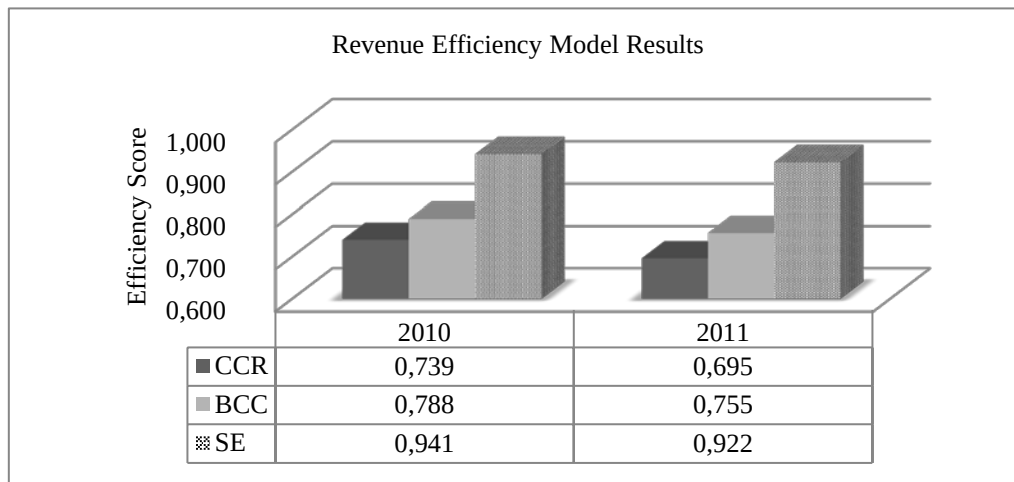
Table 8. The Average Improvement Ratios for the Revenue-Based Efficiency Models in the period 2010-2011

Input and Output Variables	2010		2011	
	CCR Model	BCC Model	CCR Model	BCC Model
Total investment	-0.010	-0.001	-0.011	-0.006
Full time employees	-0.081	-0.188	-0.095	-0.147
Total subscribers	-0.249	-0.185	-0.241	-0.185
Mobile revenue	0.539	0.708	0.423	0.591
Fixed revenue	1.000	0.988	0.852	0.850

Table 8 presents the results of CCR analysis for the period 2010-2011. According to the results for 2010, the outputs for European countries should be increased by a ratio of between 53.9% and 100%. The input values should be decreased by a ratio of between 1% and 24.9% according to the CCR model. However, the results for 2011 show that the outputs for European countries should be increased by a ratio of between 42.3% and 85.2% according to the CCR model. Furthermore, the BCC

model results for 2010 outputs of European countries should be raised by a ratio of between 70.8% and 98.8% and the outputs should be increased from 59.1% to 85% in 2011.

Fig. 3. Comparison of DEA Efficiency Scores of the Telecommunication Sector of European Countries in the period 2010 - 2011



As shown in Fig. 3, it has been found that European countries demonstrated higher revenue efficiency scores with respect to the BBC model and the CCR model from 2011 to 2010. European countries have demonstrated a 5.95% efficiency decrease in 2011 in terms of CCR analysis and a continuously 4.19% efficiency decrease 2011 in terms of BCC analysis. However, European countries have shown a 2.02% efficiency decrease 2011 in terms of SE analysis. In addition, the average efficiency scores have also been taken into consideration. Our analysis of the mentioned scores:

- 53.13% of European countries in the CCR model, 62.5% of European countries in the BCC model and 78.13% of European countries in the SE model for 2010,
- 56.25% of European countries in the CCR model, 53.13% of European countries in the BCC model and 71.88% of European countries in the SE model for 2011

have shown higher performance in comparison to the average efficiency score. Therefore, in 2010, European countries have supported better efficiencies than 2011 according to the CCR and BCC models.

Table 9. Summary of Efficiency Scores of the Revenue Model in the period 2010-2011

Parameters	2010			2011		
	TE Score	PTE Score	SE Score	TE Score	PTE Score	SE Score
Average	0.739	0.788	0.941	0.695	0.755	0.922
Maximum	1.000	1.000	1.000	1.000	1.000	1.000
Minimum	0.259	0.265	0.446	0.189	0.204	0.466

As shown in Table 9, the average BCC scores are higher than the average CCR scores in every year, which is consistent with the DEA theory that BCC scores are always higher than CCR scores.

5. CONCLUSION

In this study, the competition structure of the European telecommunication sector has been analyzed by DEA. In this regard, the telecommunication sector efficiencies of these countries have been investigated both in revenue and production-based efficiency models.

The efficiency levels of the European telecommunication sector have been evaluated and compared using the DEA approach. The TE and PTE levels of 32 European countries have been analyzed by output-oriented DEA models for 2010-2011 data.

The production-based CCR model results of 2010 indicate that 12 European countries can be defined as fully efficient. According to the 2011 results, the CCR scores of 10 European countries have been found fully efficient. Conversely, the revenue CCR efficiency results of 2010 show that nine European countries can be defined as fully efficient. Additionally, the results of CCR analyses for 2011 have shown that seven European countries are found fully efficient. Furthermore, the revenue based CCR model results of 2010 show that nine European countries can be determined as fully efficient. Also, the CCR scores seven European countries can be defined as fully efficient in 2011.

The DEA results have shown that Austria and Spain are fully efficient in terms of TE, PTE and SE in the both models for the period 2010-2011. Due to the circumstances encountered in the European economy, the negative growth rate of the European telecommunication sector incomes has accelerated. For most European operators, the income growth in year 2011 was negative.

The average improvement ratios of the telecommunication sector of European countries can be a significant efficiency reference for financial decision makers and policymakers whose goal is to achieve an optimal level of telecommunication performance.

In this context, operators should have increased their fixed line telephone subscribers, mobile cellular phone subscribers and internet users in order to increase the production efficiency of Europe's telecommunication sector in the period 2010-2011. Like the average improvement ratios of BCC analyses, for 2010, the output values of European countries should be raised and the input values should be lowered.

Finally, the DEA analyses have revealed that European countries showed slightly better efficiencies in 2010 when compared to 2011 results of the *production* and *revenue-based* efficiency models. Consequently, DEA is a worthy mathematical programming technique that is applied to determine the TEs and PTEs of similar DMUs in analyzing the telecommunication sector.

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