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Evaluating the performance of OECD countries in the Covid-19 epidemic by network data envelopment analysis

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Abstract

The outbreak of the coronavirus has caused a recession in most countries, reducing the budgets of organizations in all sectors, including government, business, and academia. After the beginning of the epidemic, countries responded to the disease in various ways. This paper evaluates the performance of OECD member countries using the network data envelopment analysis method. For this purpose, effective financial and health indicators were identified. Unfavorable and flexible data were identified in various stages and a suitable model was presented. The results of the implementation of the model provide a good insight into the financial and health policies of the above countries.

Keywords: Data Envelopment Analysis, Network, Performance Evaluation, Health.

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1. Introduction

For months, people around the world have been waking up with a nightmare called Covid-19. In the midst of all these worries, some countries have been able to control this crisis to some extent with proper management and technology and prevent the further spread of this disease. Most businesses around the world have been affected by the outbreak of the Corona virus, and many offices, factories and companies have closed, and the corona has not only taken the lives of many people, but also weakened the pulse of some businesses. As predicted, the epidemic has caused a recession around the world and reduced the budgets of organizations in all sectors, including government, business and academia. The issue of budget cuts has also become a problem around the world, and governments are facing budget cuts due to the outbreak of the disease, which is why some countries are considering cutting funding for innovation and technology projects. Therefore, evaluating the performance of different countries in the response to the Covid-19 epidemic is very important. The Covid-19 virus has affected the entire world, so we have witnessed many challenges in all areas in this short time, among which one can refer to the economic, tourism industry, education, social, etc. areas. These challenges have changed the conduct of governments in the confrontation with these problems. Having strategic plans, all countries create platforms to confront such an epidemic and use these platforms and facilities in confrontation with such an epidemic. Laying the groundwork for public education and raising the level of people's knowledge takes place via creating hospitals and beds, medical equipment, training specialized doctors, investing in medical research centers, etc.

When an epidemic occurs in a country, it is necessary to use the facilities properly to be able to resist it. The main purpose of this study is to compare the member countries of the Organization for Economic Cooperation and Development (OECD) in creating the bases and facilities and the impact of these facilities in confrontation with the Covid-19 epidemic. For this purpose, data envelopment analysis technique is used. This technique is able to calculate the relative efficiency of countries using multiple input and output indicators and to do this, it obtains a model in society by comparing relative decision-making units. In the second part of this article, the preliminaries of the forthcoming discussion on data envelopment analysis and density are stated. In the third part, the research question and modeling will be stated. In the fourth part, the presented method is introduced in a numerical example, and in the fifth part, the conclusion is presented.

2. History

Covid-19 is a highly infectious respiratory disease caused by a new coronavirus. The disease was discovered in China in December 2019 and then spread around the world, causing an unprecedented public health crisis. Covid-19 pandemic has affected the lives of children and their families around the world. Covid-19 is an infectious respiratory disease caused by a newly discovered virus called SARS-CoV-2. "CO" stands for Corona, "VI" for the virus and "D" for the disease.

The OECD stands for the Organization for Economic Co-operation and Development. The union includes 37 countries in Europe, America and the Pacific. Its members and major partners make up 80% of global trade and investment. Majority of the 37 OECD members are from Europe. They include Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland and the United Kingdom. There are four countries from the American continent: Canada, Chile, Colombia, Mexico and the United States. The four members from the Pacific are Australia, Japan, Korea and New Zealand. The two countries from the Middle East are Israel and Turkey.

Data Envelopment Analysis (DEA) is a mathematical technique for evaluating the performance of decision units (DMUs) with multiple inputs and outputs, first introduced in the paper by Charnes et al. (1978). In DEA, each DMU is evaluated in the best conditions, therefore, if a DMU is inefficient, it should not be efficient in any other way [1].

Data Envelopment Analysis (DEA) measures the efficiency of decision-making units with multiple inputs and outputs by assigning weights to them and by the ratio of the total weighted outputs to the total weighted inputs. Network Data Envelopment Analysis (NDEA) is an extension of the Data Envelopment Analysis (DEA) model that does not suffer from the problems of traditional models in considering internal structure and ignoring intermediate indicators (Kao, 2008). These models have recently found many applications in performance appraisal due to their differentiation power from traditional models [2]. We note that an independent decision maker at each stage of the network maximizes its technical efficiency regardless of other components and the network as a whole. For this reason, network models are useful models for modeling the whole network. The advantage of DEA network models is their ability to accurately reflect the internal operations of the DMU as well as their combination of relationships and dependencies. Therefore, they provide more complete and more accurate results than conventional DEA models and provide us with more information about the sources that cause inefficiency. As discussed in many DEA studies, DMUs can have a two-stage structure that uses first-stage inputs to generate outputs, which become second-stage inputs. In the second stage, these inputs are used to generate output. The two basic analyses of the dominant literature methods related to the two-stage DEA are the Kao and Huang multiplication method [3] and the additive method of Chen et al. [4]. The two methods consider the same definitions of stage performance but differ fundamentally in defining the performance of the whole system as well as in the decomposition methods. In the multiplication efficiency decomposition method, the overall efficiency is defined as the product of the multiplications of the steps, while in the additive efficiency analysis method, the overall efficiency is defined as a weighted average of the phase performances.

The first article to discuss this idea is probably Charnes et al. The simplest case divides the entire operation into two processes, see, for example, Charnes et al. [5] and Wang et al. [6]. Early papers that discussed the stages of the decision-making components are Far and Grosskopf [7], Wang et al. [8], and Far and Grosskopf [9].

Cook, Liang, and Zho [10] reviewed a number of models for the main two-stage system in which the system connects only two processes in series, and the second stage uses all the outputs of the first stage for production. Castelli, Pesenti , Ukovich [11] reviewed common, multilevel network models and some networks.

In DEA modeling, a two-stage network from the perspective of performance analysis, both multiplicative performance analysis and additive performance analysis are proposed depending on changes in structures and two-stage assumptions with constant returns to scale and variable returns to scale. Kao and Huang [3] proposed a relational model that is able to decompose the overall efficiency by multiplying the two-stage efficiency by assuming a constant return to scale. Liang et al. [12] developed multiplicative efficiency analysis using the concept of game theory. Studies have been performed in the analysis of multiplicative efficiency. For example, Chen et al. [13], and Zho and Liang [14] analyzed the overall performance into multiplication of the performance of the steps. Chen et al. [15] decomposed the overall performance into the weighted average of the two step efficiencies, while a constant- returns to scale was not required.

Additive performance analysis has its own computational problems as shown by Gao et al. [16]. Chen et al. [4] showed that additive performance decomposition can be solved by second-order cone programming. Many articles have been published that use basic two-step network DEA models to solve real-world problems. For example, Tsolas [17] discussed 19 construction companies in Greece. Based on the relationship model proposed by Kao and Huang [18], Cao and Yang [19] measured the marketability and profitability of 40 Internet companies. Chen et al. [13] evaluated the design performance of 534 airlines from more than 20 manufacturers aiming for less environmental impact. Kao and Huang [3] used a two-step process for 24 non-life insurance companies in Taiwan. Chen et al. [4] mentioned a model that can also be used for variable returns to scale. They mentioned the efficiency of the overall two-step process as the weighted average of the two separate steps. Wang and Chen [8] developed the Chen et al model [4] by introducing relative weights for two separate steps.

Today, network data envelopment analysis is widely used in everyday life. In this paper, this method is used to identify the performance structure of OECD countries based on network data envelopment analysis technique to deal with the Covid-19 epidemic, and a special data analysis modeling is presented via identifying indicators affecting their performance.

According to the above discussion, the innovation of this research is as follows:

- Identification of indicators affecting the performance of countries in coping with the Covid-19 epidemic.
- Identification of the performance structure of countries based on data envelopment analysis technique.
- Modeling specific data analysis with network structure.
- Development of network model with undesirable outputs.

The structure of this article is as follows. In the second part, the basic concepts are discussed. In the third part, modeling and model implementation and in the fourth pert, analysis of results are studied. Finally, in the fifth part, conclusions and suggestions are presented.

3- Basic concepts

Suppose there are n decision makers. The j-th decision unit uses the input vector $X_j = \left(x_{1j},\ldots,x_{mj}\right)^t$ to generate the output vector $Y_j = \left(y_{1j},\ldots,y_{sj}\right)^t$ and $X_j \neq 0$ and $X_j \geq 0$ and $Y_j \neq 0$ and $Y_j \geq 0$. Charnes et al. (1979) proposed the following model for calculating relative efficiency.

$$
\begin{aligned}
z_p^* = Max \quad & \sum_{r=1}^{s} u_r y_{rp} && (1)\\
s.t \quad & \sum_{i=1}^{m} v_i x_{ip} = 1 \\
& \sum_{r=1}^{s} u_r y_{rp} - \sum_{i=1}^{m} v_i x_{ip} \leq 0, \quad i = 1,\ldots,m \\
& u_r, v_i \geq \varepsilon , \quad i = 1,\ldots,m \ , \ r = 1,\ldots,s.
\end{aligned}
$$

Where the vectors v and u are the corresponding weights of the input and output vectors, respectively. z_p^* the scalar is in the distance $\left(0,1\right]$. If $z_p^* = 1$ then

DMU_p is called relative efficiency and if $0 < z_p^* < 1$ then DMU_p is called relative inefficiency. The amount z_p^* is of DMU_p relative efficiency.

Model (1) can be used for the case where the final production takes place in one step. If production occurs during stages (more than one stage), then model (1) cannot calculate the efficiency of the stages. For this purpose, we define the two-step structure as follows. Suppose $X_j = \left(x_{1j},...,x_{mj}\right)^T$ the input vector and $Z_j = \left(z_{1j},...,z_{kj}\right)^T$ the intermediate product vector and $Y_j = \left(y_{1j},...,y_{mj}\right)^T$ the output vector is DMU_p and و $Z_j \neq 0, Z_j \geq 0$ و $X_j \neq 0, X_j \geq 0$. $Y_j \neq 0, Y_j \geq 0$ The model developed to calculate the relative efficiency DMU_p is obtained by solving the following problem.

$$
\begin{aligned}
z_p^* = Max\ & \frac{uY_p}{vX_p} && (2)\\
s.t\quad & \frac{uY_j}{vX_j} \leq 1, && i = 1,...,n,\\
& \frac{uY_j}{wZ_j} \leq 1, && i = 1,...,n,\\
& \frac{wZ_j}{vX_j} \leq 1, && i = 1,...,n,\\
& (v, w, u) \geq 1\varepsilon.
\end{aligned}
$$

Considering that in model (2) the first category with the presence of the second and third constraints is redundant, so the corresponding linear model (2) is as follows.

$$
\begin{aligned}
z_p^* = Max\ & \sum_{r=1}^{s} u_r y_{rp} && (3)\\
s.t\quad & \sum_{i=1}^{m} v_i x_{ip} = 1\\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{t=1}^{k} w_t z_{tj} \leq 0 \quad, && i = 1,...,n,\\
& \sum_{t=1}^{k} w_t z_{tj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, && j = 1,...,n,\\
& u_r, v_i, w_t \geq \varepsilon,\ i = 1,...,m\ ,\ r = 1,...,s\ ,\ t = 1,...,k.
\end{aligned}
$$

If $\left(V^*, W^*, U^*\right)$ the optimal answer is model (3), then $\left(E^a\right)$ the overall efficiency, $\left(E^1\right)$ the efficiency of the first stage and $\left(E^2\right)$ the efficiency of the second stage are calculated from the following equation.

$$
E^a = z_p^* = \frac{\sum_{r=1}^{s} u_r^* y_{rp}}{\sum_{i=1}^{m} v_i^* x_{ip}},
$$

$$
E^1 = \frac{\sum_{t=1}^{k} w_t^* z_{tp}}{\sum_{i=1}^{m} v_i^* x_{ip}}, \qquad (4)
$$

$$
E^2 = \frac{\sum_{r=1}^{s} u_r^* y_{rp}}{\sum_{t=1}^{k} w_t^* z_{tp}}
$$

Given relations (4) it is obvious $E^a = E^1.E^2$

Hence $E^a = 1$ if and only if $E^1 = E^2 = 1$. Otherwise, if the first or second stage is inefficient, then DMU_p will be overall inefficient.

The envelopment form of model (3) is as follows:

$$\min \theta \qquad (5)$$

$$s.t$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ip}, \; i = 1,...,m,$$

$$\sum_{j=1}^{n} \mu_j y_{rj} \ge y_{rp}, \; r = 1,...,s,$$

$$\sum_{j=1}^{n} \lambda_j z_{tj} - \sum_{j=1}^{n} \mu_j z_{tj} \le 0, t = 1,...,k,$$

$$\lambda_j \ge 0, \mu_j \ge 0, \qquad j = 1,...,n.$$

Based on equations (4) by variable changing the linear model first step is

$$E^1 = \max \sum_{t=1}^{k} \omega_t z_{tj} \qquad (6)$$

$$\begin{aligned} s.t. \quad & \sum_{i=1}^{m} v_i x_{io} = 1 \\ & \theta_o^* = \sum_{r=1}^{s} u_r y_{ro} \\ & \sum_{t=1}^{k} \omega_t z_{tj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{t=1}^{k} \omega_t z_{tj} \le 0 \\ & v_i \ge 0, u_r \ge 0, \omega_t \ge 0 \end{aligned}$$

and the linear model the second step becomes

$$E^2 = \max \sum_{r=1}^{s} u_r y_{ro} \qquad (7)$$

$$\begin{aligned} s.t. \quad & \sum_{t=1}^{k} \omega_t z_{tj} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \theta_o^* \sum_{i=1}^{m} v_i x_{ij} = 0 \\ & \sum_{t=1}^{k} \omega_t z_{tj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{t=1}^{k} \omega_t z_{tj} \le 0 \\ & v_i \ge 0, u_r \ge 0, \omega_t \ge 0 \end{aligned}$$

4- Modeling

In this study, OECD countries are compared based on the creation of the necessary infrastructure to deal with the Covid-19 epidemic and the impact of these structures on society. The technique used is multi-step data envelopment analysis.
The number of OECD countries whose data are visible in the 03/08/2021database is 37. All information from this database was extracted on 03/08/2021.
Indicators affecting the performance of countries in coping with the Covid-19 epidemic were selected as follows.

- Health costs (percentage of GDP): Percentage of total health costs of countries relative to GDP
- Population
- Population density: is the number of people per square kilometer in a country
- Physician density: The number of physicians per 1000 population of a country
- Number of hospitals: The number of active hospitals in a country at the time of data collection
- Hospital bed density: The number of hospital beds per 1,000 population in a country
- Number of active covid-19 patients: The number of people in a country who became infected with Covid-19 but did not improve or die at the time of data collection.
- Number of improvements: The number of people in a country who became infected with Covid-19 and improved at the time of data collection.
- Number of deaths: The number of people in a country who became infected with Covid-19 at the time before data collection and died at the time of data collection.
- Number of people infected with Quaid-19: The number of people in a country who have been infected with the Quaid-19 virus at one time before data collection.

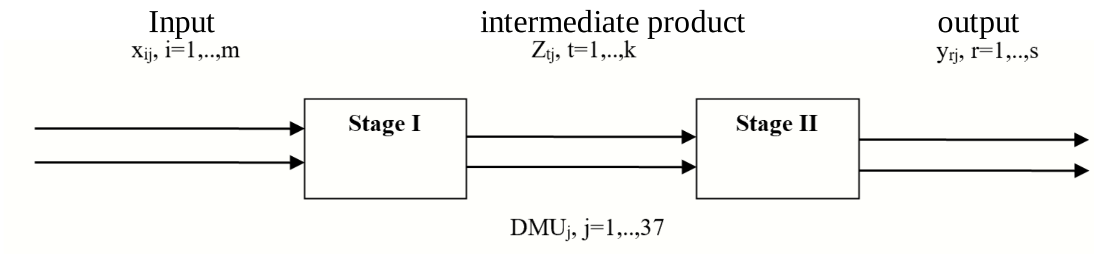

Figure1. two-step structure

Since the necessary infrastructure is needed to be designed and implemented in each country to deal with any type of epidemic, and in the event of an epidemic, this infrastructure can be used to deal with the epidemic and can also use specialists and equipment available to treat the affected. A two-step structure for evaluating countries' performance during the Covid-19 epidemic is designed as Fig 1.

Figure 1 shows a two-step structure for comparing countries. In the first stage, countries are obliged to create the necessary infrastructure to deal with the Covid-19 epidemic. In the second stage, the impact of these infrastructures on the prevalence and spread of the Covid-19 virus and the effectiveness of the infrastructure can be seen.

The indexes for input and output in the steps are shown in Table 1.

The values of inputs and outputs considered at the time of data collection (08/03/2021) are shown in Table 2.

Table 1. Input and output indexes of two-stage structure

	indexes
Input indexes	Health costs (percentage of GDP)
	Population
	Population density
Intermediate indexes	Physician density
	Number of hospitals
	Hospital bed density
Output indexes	Number of active patients
	Number of improved
	Number of people deaths

Table 2. Indexes values

DMUs	X			Z			Y		
	Health expenditures (percentage of GDP)	population	Population density	Number of hospitals	Physician density	Hospital bed density	Number of people deaths	Number of improved	Number of active patients
AUSTRALIA	10.4	25466460	3.29	1327	3.29	3.8	909	2582	1853
AUSTRIA	9.2	8859449	105.63	264	5.17	7.4	6.641	349215	20937
BELGIUM	10.3	11720716	383.93	174	3.07	5.7	19.936	45744	592975
CANADA	10.6	37694084	3.78	715	2.31	2.5	16.707	545971	8167
CHILE	9	18186770	24.05	353	2.44	2.1	16.974	595799	20608
COLOMBIA	7.2	49084840	43.1	1800	2.11	1.7	36019	1181753	62715
CZECH REPUBLIC	7.2	10702498	135.7	256	4.07	6.6	12.8	651814	144987

DENMARK	10.1	5869410	98.86	54	4.01	2.6	1.517	149346	27634
ESTONIA	6.4	1228624	27.17	30	3.46	4.7	270	22124	10143
FINLAND	9.2	5571665	16.48	241	3.81	3.3	586	31	6482
FRANCE	11.3	67848160	105.39	3042	3.26	6	67.431	201286	2478418
GERMANY	11.2	80159664	224.52	3084	4.25	8	40.401	1494100	360638
GREECE	8	10607051	80.38	271	5.48	4.2	5.195	9989	12831
HUNGARY	6.9	9771827	105.04	165	3.34	7	10.44	18.449	140854
ICELAND	8.3	350734	3.41	8	3.98	3.1	29	5704	134
IRELAND	7.2	5176569	73.66	86	3.29	3	2.327	23364	110193
ISRAEL	7.4	8675475	395.47	85	3.48	3	3.596	408753	65008
ITALY	8.8	62402660	207.08	1059	3.98	3.2	77.911	1589590	570389
JAPAN	10.9	125507472	332.11	8372	2.41	13.1	3.857	213737	47705
KOREA	7.6	51835112	519.81	3924	2.36	13.2	1.1	49324	17575
LATVIA	6	1881232	29.13	62	3.19	5.6	801	34268	12713
LITHUANIA	6.5	2731464	41.83	95	4.83	6.6	2.119	87963	66457
LUXEMBOURG	5.5	628381	242.99	10	3.01	4.7	527	44482	2735
MEXICO	5.5	128649568	65.49	4629	2.38	1.5	132069	1134877	240985
NETHERLANDS	10.1	17280396	415.96	549	3.61	3.3	12.171	0	846743
NEW ZEALAND	9.2	4925477	18.32	165	3.47	2.7	25	2101	62
NORWAY	10.4	5467439	16.89	75	2.83	3.6	472	46611	7393
POLAND	6.5	38282324	122.43	1276	2.38	6.6	30.574	1104599	230472
PORTUGAL	9	10302674	111.88	230	5.12	3.4	7.59	360181	98938
SLOVAK REPUBLIC	6.7	5440602	110.95	130	3.42	5.8	2.788	14149	56886
SLOVENIA	8.2	2102678	103.72	29	3.09	4.5	2.947	110925	22757
SPAIN	8.9	50015792	98.97	782	3.87	3	51.874	0	1998486
SWEDEN	11	10202491	22.66	100	3.98	2.2	9.433	0	480038
SWITZERLAND	12.3	8403994	203.6	281	4.3	4.7	8.23	3176	152153
TURKEY	4.2	82017512	104.67	134	1.85	2.8	22.45	2182145	102986
UNITED KINGDOM	9.6	65761116	269.94	1910	2.79	2.5	79.833	1364821	1512818
UNITED STATES	17.1	332639104	33.83	6210	2.61	1.4	378.149	13259949	8818804

Table 3. efficiency results

DMUs	total efficiency	first stage efficiency	second stage efficiency
AUSTRALIA	0.009969	1	0.009969
AUSTRIA	0.148853	0.512336	0.290538
BELGIUM	0.310616	0.310616	1
CANADA	0.179158	0.521601	0.343478
CHILE	0.238114	0.374288	0.636179
COLOMBIA	0.249006	0.787362	0.316253
CZECH REPUBLIC	0.135125	0.544236	0.248284
DENMARK	0.059524	0.199153	0.298883
ESTONIA	0.044588	0.621049	0.071795
FINLAND	0.019823	0.719754	0.027542
FRANCE	0.419167	0.814655	0.514533
GERMANY	0.123931	0.591223	0.209619
GREECE	0.089796	0.572351	0.15689
HUNGARY	0.09622	0.40878	0.235383
ICELAND	0.023531	1	0.023531
IRELAND	0.106848	0.383775	0.278413
ISRAEL	0.107075	0.281458	0.380432
ITALY	0.299507	0.299507	1
JAPAN	0.013139	1	0.013139
KOREA	0.00529	0.97916	0.005402

LATVIA	0.074754	0.863622	0.086558
LITHUANIA	0.144677	0.902088	0.16038
LUXEMBOURG	0.166128	0.802383	0.207043
MEXICO	0.465803	1	0.465803
NETHERLANDS	0.274777	0.487439	0.563716
NEW ZEALAND	0.001242	0.551274	0.002252
NORWAY	0.02263	0.316557	0.071488
POLAND	0.192875	0.513924	0.375299
PORTUGAL	0.081277	0.542752	0.14975
SLOVAK REPUBLIC	0.085941	0.564902	0.152134
SLOVENIA	0.231443	0.419721	0.55142
SPAIN	0.418805	0.418805	1
SWEDEN	0.280506	0.280506	1
SWITZERLAND	0.087579	0.523593	0.167266
TURKEY	0.293965	0.293965	1
UNITED KINGDOM	0.286744	0.444859	0.644573
UNITED STATES	1	1	1

In this section, modeling is performed to calculate the efficiency of countries based on a two-stage structure.
By implementing the mentioned models for the desired data, the result is presented in the table 3.
Note that the higher the output of the second stage, i.e. the number of patients, the worse the situation in the country is, so this output is undesirable. On the other hand, the number of active people and the number of deaths, which are the final outputs of the two-stage structure, are also undesirable outputs.
It is clear from the table that the total efficiency is obtained by multiplying the efficiency of the steps. In the first stage, Australia, Iceland, Japan and Korea, and in the second stage, Belgium, Sweden, Turkey, and the United States are efficient. The efficiency of the whole system is also presented.

5. Conclusion

With the outbreak of Covid-19 disease and its spread in all countries, the ways to deal with it have always been on the carpet. This article evaluates OCED countries in this category.
To evaluate the two-stage network with the indicators set for the inputs, the middle stage and the outputs, which are three, three and three, respectively, are considered.
The evaluation results show that Australia, Iceland, Japan and Korea are efficient in the first stage and Belgium, Sweden, Turkey, and the United States are efficient in the second stage.

References

[1] Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2:429–444.

[2] Despotis K. D, Koronakos G, Sotiros D. (2014) Composition versus decomposition in two-stage network DEA: a reverse approach. J Prod Anal.

[3] Kao C, Hwang S-N (2008) Efficiency decomposition in two-stage data envelopment analysis: an application to non-life insurance companies in Taiwan. Eur J Oper Res 185:418–429.

[4] Chen Y, Cook WD, Li N, Zhu J (2009) Additive efficiency decomposition in two-stage DEA. Eur J Oper Res 196:1170–1176.

[5] Charnes, A. Cooper, W.W. Golany, B. Halek, R. Klopp, G. Schmitz, E. Thomas, D. (1986) Two phase data envelopment analysis approach to policy evaluation and management of army recruiting activities: tradeoffs between joint services and army advertising. Research Report CCS no. 532, Center for Cybernetic Studies, The University of Texas, Austin, Texas.

[6] Wang, C.H. Gopal, R. Zionts, S. (1997) Use of data envelopment analysis in assessing information technology impact on firm performance. Ann. Oper. Res. 73, 191–213.

[7] Fare R, Grosskopf S (1996) Productivity and intermediate products: a frontier approach. Econ Lett 50:65–70.

[8] Wang Y.M, Chin K, S, (2010) Some alternative DEA models for two-stage process. Expert sys.Appl. 37(12) 8799-8808.

[9] Fare, R. Grosskopf S., (2000) Network DEA. Soc. Econ. Plann. Sci. 34(1), 35–49.

[10] Cook W.D, Liang L, Zhu J, (2010) Measuring performance of two-stage networkstructures by DEA: a review and future perspective, Omega 38 423–430.

[11] Castelli L, Pesenti R, Ukovich W (2010) A classification of DEA models when the internal structure of the decision making units is considered. Ann Oper Res 173:207–235.

[12] Liang, L. Cook, W.D. Zhu, J. (2008)DEA models for two-stage processes: game approach and efficiency decomposition. Nav. Res. Logist. 55, 643–653.

[13] Chen Y, Cook WD, Kao C, Zhu J (2013) Network DEA pitfalls: =divisional efficiency and frontier projection under general network structures. Eur J Oper Res 226:507–515.

[14] Zha, Y. Liang L., (2010) Two-stage cooperation model with input freely distributed among the stages. Eur. J. Oper. Res. 205, 332–338.

[15] Chen Y, Cook WD, Zhu J (2010) Deriving the DEA frontier for two stage DEA processes. Eur J Oper Res 202:138–142.

[16] Guo, C. Shureshjani R.A., Foroughi A.A, Zhu, J. (2017) Decomposition weights and overall efficiency in two-stage additive network DEA. Eur. J. Oper. Res. 257(3), 896–906.

[17] Tsolas, I.E. (2013) Modeling profitability and stock market performance of listed construction firms on the Athens Exchange: two-stage DEA approach. J. Construct. Eng. Manag. 139, 111–119.

[18] Kao C, Hwang S-N (2011) Decomposition of technical and scale

efficiencies in two-stage production systems. Eur J Oper Res 211:515–519.

[19] Cao, X. Yang, F.Measuring the performance of Internet companies using a two-stage data envelopment analysis model. Enterp. Inf. Syst. 5(2), 207–217 (2011).