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LPI Based Two Stage Network DEA Model to Measure Logistics Efficiency: An Application on OECD Countries

Mahmut Burak ERTURAN [a] **Fahriye MERDİVENCİ** [b]

[a] Akdeniz University, Institute of Social Sciences, Department of Econometrics, Antalya, Turkey. burak.erturan@gmail.com.
[b] Akdeniz University, Faculty of Applied Sciences, Department of International Trade and Logistics, Antalya, Turkey. fahriye@akdeniz.edu.tr.

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ABSTRACT

Purpose – Measuring logistics efficiency is important to understand the strengths and weaknesses of a country's logistics operations and to be able to do necessary improvements. A common practice in the literature is applying Data Envelopment Analysis (DEA) with World Bank's logistics performance index (LPI) values for measuring logistics efficiency of countries. While DEA is a powerful methodology for relative efficiency measurement, a more sophisticated branch of DEA models is Network DEA (NDEA), especially for processes with inner sub-processes. The purpose of this study is to present a novel NDEA model for measuring logistics efficiencies and sub-efficiencies of countries.

Design/methodology/approach – This study presents a relational two-stage network data envelopment analysis model to measure relative efficiency of a country's logistics process. For the first time in literature, total logistics process of a country is divided into two sub-processes as production and service stages.

Findings – Proposed Network DEA model utilizes international LPI scores and macroeconomic indicators to measure OECD countries' logistics efficiencies for bi-yearly periods between 2010 and 2018. Obtained results favors 3 countries out of 37 with high logistics efficiencies. Also, by grouping the countries in terms of development level, results show that although developed countries have better logistics outputs in terms of LPI index, most logistically efficient countries are developing economies in general.

Discussion – This study with proposed NDEA model is open for further research and development. The model could be varied with different capital and labor measures, also could be improved by adding some domestic LPI or other logistics indicators.

1. INTRODUCTION

In a globalizing world with rising competitiveness among countries and corporations, logistics plays a vital role. In a governmental perspective, logistics of a country effects international trade, economic growth, prosperity and therefore is a key element for a country's economy (Marti et al., 2017: 170). Because logistics is a significant factor of economy, efficiency measurement of logistics processes is a very important task. Efficient logistics of a country decreases costs, increases trade volume, provides easier access to international markets and boosts the competitive advantage of the country over other countries (Andrejić and Kilibarda, 2016: 733). Since logistics process includes all phases of flow and storage of goods and services from source to consumption (Bramel and Simchi-Levi, 1997: 1-3), it is a multivariate, multilateral and multistage process. Therefore, performance measurement of logistics operations need to be a sophisticated one such that it should measure the performance in different aspects.

A significant performance measurement is done by World Bank with Logistics Performance Index (LPI) starting from 2007. LPI covers 167 countries and is based on survey feedbacks of global freight forwarders and express carriers. Logistics performance of countries are evaluated in terms of six criteria: customs, infrastructure, ease of arranging shipments, quality-competence of logistics services, tracking-tracing and timeliness. Customs index is about customs and border management clearance. Infrastructure indicator is the measure of trade and transport infrastructure quality. Ease of arranging shipments deals with the pricing of the shipments. Quality-competence of logistics services includes competence and quality of the services

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presented. Tracking-tracing is, as the name suggests, the ability to track and trace consignments. Lastly, timeliness indicator concerns whether the shipments reach consignees within scheduled delivery times. For detailed information about LPI and corresponding parameters, see Arvis et al. (2018).

The six performance indicators of LPI shows how successful a country on those criteria. In addition, a country ranking is constructed using the average of those six criteria. On the other hand, an important research area is the logistics efficiency of the countries. Since efficiency is the ability to get maximum output using minimum input, to be able to measure logistics efficiency on country level, one needs inputs, outputs and a mathematical approach. There are parametric and non-parametric approaches to measure efficiency. Different from nonparametric methods such as data envelopment analysis (Charnes et al., 1978) and free disposal hull (Deprins et al., 1984); in parametric efficiency measurement methods like deterministic frontier analysis (Aigner and Chu, 1968) and stochastic frontier analysis (Aigner et al., 1977; Meeusen and van Den Broeck, 1977), production function is described with explanatory variables and error terms. In nonparametric methods, computations are easier, data could be in qualitative format or in ordinal ranking and there are fewer restrictive assumptions comparing with parametric methods. On the other hand, nonparametric approaches do not use all the information in the sample and that causes lesser efficiency than parametric approaches. One of the highly anticipated efficiency measurement model is data envelopment analysis (DEA). DEA is a non-parametric model that measures relative efficiency of decision-making units, which does not require a priori knowledge of the production function and is useful for evaluating efficiency from different aspects (Markovits-Somogyi and Bokor, 2014: 137).

In literature, there are studies to measure country level logistics DEA efficiency by using LPI indicators. Markovits-Somogyi and Bokor (2014) measures the logistics efficiency of 29 European countries by using a DEA-PC (pairwise comparison) model and compares the results with classical DEA model. Some of domestic and international LPI indicators are included in the model with others. Andrejić and Kilibarda (2016) uses PCA-DEA (Principal Component Analysis – DEA) approach for logistics efficiency of 8 countries. Model has 11 inputs and 4 outputs among international and domestic LPI indicators. In another important study (Mariano et al., 2017) the efficiency in the relationship between LPI and CO2 emission of transport sector is evaluated for 104 countries. Model takes CO2 emissions of transport sector as the only input, and 6 LPI components and gross domestic product (GDP) as the outputs. In the paper of Rashidi and Cullinane (2019), SOLP (Sustainable Operational Logistics Performance) methodology is presented. SOLP is created using data envelopment analysis approach, and with the integration of LPI, a sustainable logistics performance index (SLPI) is presented. DEA model consists of 1 input and 3 outputs, where input is energy use and the outputs are greenhouse gas emission, logistics activity and rate of job creation.

An important contribution to the literature comes from the study of Marti et al. (2017). In their work, a synthetic DEA-LPI logistics performance index is proposed for countries. The six main LPI indicators is divided into two groups. First group is related with regulatory policies and consists of customs, infrastructure and logistics quality-competence. On the other hand, timeliness, shipments and tracking-tracing are in the second group as they are all service delivery outcomes. The first group of indicators are inputs and the second ones are the outputs of a DEA process, which is applied to 140 countries around the globe.

The classification and the input-output relations of the LPI indicators presented in Marti et al. (2017) shed light to a new perspective about country level logistics performance measurement. Since the second group of indicators are the outputs and the first group of indicators are inputs of a service process, a beforehand production process is existed on a country level. Therefore, inputs of the service stage would be the outputs of a production stage, which has country level (macroeconomic) inputs. This two-stage model has main macroeconomic level inputs of a country and three main outputs as timeliness, shipments and tracking tracing. Other three indicators of LPI, customs, infrastructure and logistics quality-competence are the intermediate inputs/outputs.

At this stage, an important task is to determine the main macroeconomic inputs of country level logistics performance. In literature, there are numerous studies comparing country level efficiencies of different processes using DEA methodology. A common practice in the literature is taking a measure of labor and capital as country level inputs, since any production process should have capital and labor force as inputs. Studies use different capital and labor measures. Some of the researches focus on capital stock (Fa̋re et al., 1994), while others use government spending (Tsai et al., 2016) as capital input measure. Since the intermediate inputs of this study, which are the outputs of the production stage, are mostly related directly to governmental policy making, government spending is used as capital input. On the other hand, studies use employment (or unemployment) rate (Lovell et al., 1995) or labor force (Faïre et al., 1994) as labor input measure. In this study, total labor force of the countries is used as input measure. Because LPI indicators are grades changing 1 to 5, inputs used are calculated as per capita value using population numbers, instead of using total spending or total labor size of the country. Therefore, two main inputs chosen are government spending per capita and labor force per capita for this study.

Data Envelopment Analysis handles the decision making unit (DMU) as a whole, in other words as a black box where inputs are provided to produce outputs. On the other hand, in some cases DMU may have some component or sub processes which should be studied (Kao, 2014: 1). Identifying the inner structure of the black box could give more information about the source of inefficiencies. The inner structure of a DMU might be a simple two stage process, or a more complicated one with series and/or parallel processes. In general, Network DEA (NDEA) is the approach to measure the efficiency of network structured systems. By so, NDEA models allow researchers to study the inside of the classical black box DMU.

NDEA models are applied to a wide range of subject areas. Finance and banking sector (Seiford and Zhu, 1999), tourism (Chiu and Huang, 2011), academics-teaching (Kao, 2012), retail stores (de Mateo et al., 2006) are some examples. Although there is not any country level logistics studies, logistics is a popular application area of Network DEA. Efficiency analysis with NDEA is applied to railways (Yu, 2008), airlines (Yu and Chen, 2011), bus transportation (Sheth et al., 2007) and supply chains (Yang et al., 2011).

Since the introduction of the Network DEA concept (Färe and Grosskopf, 1996), researchers have developed numerous NDEA models. Some main NDEA models are two stage, series, parallel, mixed, hierarchical and dynamic models. For a comprehensive review of NDEA models, see Kao (2014). One of the common NDEA models is relational two stage NDEA. In relational models, weights of the inputs or outputs do not change according to different processes (Kao, 2014: 4). In two stage NDEA models, a DMU is thought of a two-stage process. In literature, one of the most common practices of dividing a DMU into two stages is production-consumption (service) division of the black box (Yu, 2008; Yu and Chen, 2011).

This study presents a NDEA model to measure countries' logistics performance benefited from international LPI index indicators of World Bank. A two stage relational NDEA model is constructed, where, system is divided into production and service processes. Government spending per capita (GSPC) and labor force per capita (LFPC) are the main inputs, where, three of the LPI indicators; timeliness, shipments and tracking-tracing are the main outputs. Other three LPI indicators; customs, infrastructure and logistics quality-competence are intermediate products which are the outputs of the production stage as well as the inputs of the service stage. Proposed NDEA model is applied to 37 OECD countries to measure relative efficiency values. The rest of the paper is as follows. Section 2 presents the proposed NDEA model with network structure. Section 3 explains the data used as inputs, outputs and for comparison purposes. In Section 4 obtained results of the application are presented. Finally, Section 5 discusses the results of the application and concludes with future research recommendations.

2. METHOD

2.1. Proposed Network DEA Model

The ability to measure relative efficiencies of a multi-input multi-output DMU in a non-parametric manner makes Data Envelopment Analysis a prominent methodology. Since the introduction of the Data Envelopment Analysis in the study of Charnes et al. (1978), a vast amount of models and approaches has been developed under the title of DEA. First developed DEA model is constant returns to scale (CRS) model, which is also called CCR model (Charnes et al., 1978). In CRS model, the assumption is that, the output changes by same proportions with the inputs. On the other hand, variable returns to scale (VRS) model proposed in Banker et al. (1984), also called BCC model, assumes increasing, decreasing or constant returns to scale may be present. After these basic models of DEA, some extensions in DEA literature has been developed. A non-radial additive model, also called Pareto-Koopmans model, is presented in Charnes et al.(1985). In the work of Tone (2001), a slack based measure (SBM) of DEA model is presented. Also, cross efficiency (Sexton et al., 1986) and super efficiency (Andersen and Petersen, 1993) are some examples of these developments.

An important progress in DEA literature is the introduction of Network DEA by Färe and Grosskopf (1996). Different from traditional DEA approaches, Network DEA takes the inner activities of the DMU into account. Other than the main inputs and outputs, each sub-processes of the DMU has its own inputs and outputs. Opening up the main DMU, also called black box, helps the researcher to analyze the sub-process inefficiencies, and therefore to pinpoint the source of the inefficiency of the main DMU. There are many models and approaches of Network DEA. For a comprehensive review on NDEA models one can refer to Kao (2014).

In this study a relational two stage Network DEA is used to measure relative logistics efficiencies. In Figure 1, the proposed network DEA model with corresponding inputs and outputs is shown. The inputs and the outputs of the main DMU are X_1, X_2 and Y_1, Y_2, Y_3 respectively. Z_1, Z_2, Z_3 are the intermediate products, which are the outputs of the production sub-process as well as the inputs of the service sub-process. The Network DEA model applied in this study is a two stage relational model, which also a basic series model presented in Kao (2009). In relational models, input or output weights do not change according to different processes. For example, in Figure 1 the weight of the input X_1 is the same for calculating the whole DMU efficiency and for production stage efficiency.

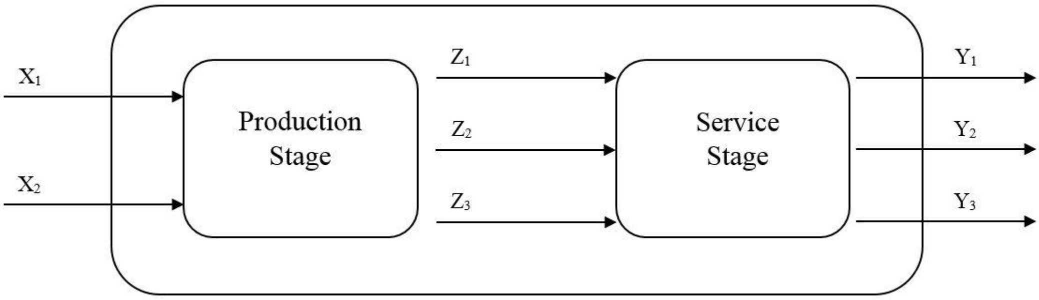


Figure 1. Proposed Network DEA Model

The system efficiency of the relational two stage network of DMU k in Figure 1 is calculated using the generalized form in Kao (2009) by the following model:

$$E_k = max \sum_{r=1}^{s} u_{rk} Y_{rk} \tag{1.1}$$

$$s.t. \quad \sum_{i=1}^{m} v_i X_{ik} = 1 \tag{1.2}$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \qquad j = 1, \dots, n \tag{1.3}$$

$$\sum_{p=1}^{q} w_p Z_{pj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \qquad j = 1, \dots, n \tag{1.4}$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{p=1}^{q} w_p Z_{pj} \leq 0, \qquad j = 1, \dots, n \tag{1.5}$$

$$u_r, v_i, w_p \geq \varepsilon, \tag{1.6}$$

$$r = 1, \dots, s, \quad i = 1, \dots, m, \quad p = 1, \dots, q. \tag{1.7}$$

X_{ij}, Y_{rj} and Z_{pj} are the inputs, outputs and the intermediate products of the system respectively. Number of the inputs is m, number of the outputs is s and the number of the intermediate products is q. v_i is the weight of i'th input, u_r is the weight of r'th output and w_p is the weight of p'th intermediate product. Also, n is the number of the DMUs to be compared and ε is a non-Archimedean number.

The number of constraints of this model is equal to multiplication of the number of DMUs and the number of processes in the system. Following the solutions for optimal weights (u_r*, v_i*, w_p*), the efficiency of the main DMU and sub-DMU's can be calculated as:

$$E_k = \frac{\sum_{r=1}^{s} u_r^* Y_{rk}}{\sum_{i=1}^{m} v_i^* X_{ik}} \tag{2.1}$$

$$E_k^{prod} = \frac{\sum_{p=1}^{q} w_p^* Z_{pk}}{\sum_{i=1}^{m} v_i^* X_{ik}} \quad (2.2)$$

$$E_k^{serv} = \frac{\sum_{r=1}^{s} u_r^* Y_{rk}}{\sum_{p=1}^{q} w_p^* Z_{pk}} \quad (2.3)$$

E_k is the system efficiency, where, E_k^{prod} and E_k^{serv} are the production and service stage efficiencies respectively. It can be seen from equations (2.1-2.3) that, the system efficiency is the product of production and service efficiencies. Therefore, system efficiency would be low if one of the sub-process is inefficient, and high only both sub-process efficiency is high. Also, for an efficient system (E_k=1) both sub-processes should be efficient.

Model (1) stated in eqns. (1.1)-(1.7) is an output oriented CRS (or CCR) model. In fact, if constraints (1.4) and (1.5) is removed, then the conventional output oriented CCR model is obtained. In addition, constraints (1.4) and (1.5) together are equal to constraint (1.3), therefore constraint (1.3) is redundant and can be left out. The efficiency calculated from model (1) cannot exceed the efficiency calculated from conventional CCR model by omitting the sub-processes, because model (1) has more constraints (Kao, 2009: 952).

2.2. Data

In the proposed model for logistics efficiency comparison of OECD countries, there are 2 inputs, 3 outputs, 3 intermediate products and a total of 8 performance indicators used. Descriptions of the data used according to network shown at Figure 1 are as follows:

- Government Spending Per Capita (X_1): The total government spending in billion USD over total population in millions. Abbreviated as GSPC, calculated yearly and taken the average of two years.
- Labor Force Per Capita (X_2): Total labor force in millions over total population in millions. Abbreviated as LFPC, calculated yearly and taken the average of two years.
- Customs (Z_1): Bi-yearly rating of customs and border management clearance from international LPI. Abbreviated as CUST.
- Infrastructure (Z_2): Bi-yearly rating of the quality of trade and transport infrastructure from international LPI. Abbreviated as INFR.
- Logistics Quality and Competency (Z_3): Bi-yearly rating of the competence and quality of logistics services (trucking, forwarding, and customs brokerage) from international LPI. Abbreviated as LQ&C.
- Shipments (Y_1): Bi-yearly rating of the ease of arranging shipments with competitive prices from international LPI. Abbreviated as SHIP.
- Tracking and Tracing (Y_2): Bi-yearly rating of the ability to track and trace consignments from international LPI. Abbreviated as T&TR.
- Timeliness (Y_3): Bi-yearly rating of the timeliness of the shipments reaching consignees from international LPI. Abbreviated as TIME.

Table 1. Descriptive Statistics (GSPC and GDPPC are in thousands of USD)

		GSPC	LFPC	CUST	INFR	LQ&C	SHIP	T&TR	TIME	GDPPC
	No of Data Points	37	37	37	37	37	37	37	37	37
2010	**Min**	0,79	0,34	2,48	2,59	2,69	2,54	2,75	3,10	5,76
	Max	17,99	0,59	4,04	4,34	4,32	3,83	4,27	4,58	104,08
	Median	7,53	0,51	3,47	3,62	3,64	3,30	3,83	4,12	36,54
	Mean	7,30	0,50	3,36	3,54	3,53	3,28	3,69	4,04	35,51
	Std. Dev	4,53	0,05	0,46	0,54	0,46	0,31	0,43	0,36	21,55
2012	**Min**	1,03	0,36	2,38	2,52	2,64	2,69	2,66	3,08	7,68
	Max	21,05	0,59	3,98	4,26	4,14	3,86	4,14	4,32	111,26
	Median	7,58	0,50	3,42	3,74	3,57	3,43	3,67	4,01	39,20
	Mean	7,81	0,50	3,34	3,55	3,53	3,35	3,58	3,86	39,13
	Std. Dev	4,98	0,04	0,44	0,51	0,43	0,34	0,43	0,34	24,35

2014	**Min**	1,16	0,37	2,59	2,44	2,64	2,71	2,55	2,87	8,16
	Max	21,46	0,60	4,21	4,32	4,19	3,82	4,17	4,71	116,22
	Median	8,04	0,51	3,54	3,67	3,66	3,45	3,68	4,06	39,28
	Mean	7,93	0,50	3,50	3,62	3,62	3,41	3,61	3,98	40,01
	Std. Dev	5,10	0,04	0,39	0,45	0,35	0,27	0,38	0,34	24,68
2016	**Min**	0,88	0,38	2,21	2,43	2,67	2,55	2,55	3,23	6,02
	Max	17,23	0,61	4,12	4,44	4,28	4,24	4,38	4,80	102,83
	Median	7,28	0,51	3,48	3,75	3,70	3,58	3,82	4,03	36,66
	Mean	6,98	0,50	3,49	3,66	3,62	3,51	3,76	4,03	36,04
	Std. Dev	4,31	0,04	0,41	0,48	0,42	0,35	0,39	0,32	21,76
2018	**Min**	0,98	0,40	2,61	2,67	2,69	2,74	2,79	2,88	6,52
	Max	18,63	0,62	4,09	4,37	4,31	3,99	4,32	4,41	111,98
	Median	7,67	0,51	3,47	3,69	3,71	3,43	3,75	3,96	40,07
	Mean	7,64	0,51	3,42	3,59	3,60	3,41	3,67	3,93	39,65
	Std. Dev	4,73	0,04	0,41	0,47	0,42	0,33	0,41	0,36	23,51

Input data sets (X_1 and X_2) are calculated from the data published in www.theglobaleconomy.com, whereas, all other data is gathered from https://lpi.worldbank.org/. In this study a bi-yearly relative efficiency analysis of countries is made, since international LPI is published bi-yearly. Although, first international LPI publishing was in 2007, first publishing has more than 6 indicators and took 3 years to publish another issue. After year 2010, international LPI became a regular bi-yearly publication with 6 indicators. Therefore, in this study bi-yearly efficiency analysis is run from 2010 to 2018. Additionally, this study uses gross domestic product per capita (GDPPC) data for comparison purposes of final efficiency scores. Data set is gathered from www.theglobaleconomy.com, and calculated for bi-yearly averages. Descriptive statistics of the data used are at Table 1.

3. FINDINGS

In this study, the relative logistics efficiency of 37 OECD countries is calculated using a Network DEA model. Proposed NDEA model divides the overall logistics process into production and consumption sub-processes. Production stage consumes government spending per capita and labor force per capita to output logistics products related with regulatory policies, namely, customs, infrastructure and logistics quality-competence. On the other hand, service stage uses the outputs of production stage to produce final outputs: shipments, tracking-tracing and timeliness. The efficiency analysis is done for bi-yearly periods from 2010 to 2018, a total of 5 periods.

The optimization problem stated in eqns. (1.1) to (1.7) is solved using MS Excel Solver add-on to find optimal weights. For each DMU, by using optimal weights, overall and sub-process efficiencies are calculated using eqns. (2.1)-(2.3). In Table 2, logistics efficiency scores of countries are tabulated. Table 3 shows the efficiencies of sub-processes, production and service. Top five countries for each period for total logistics efficiency is in Table 4. In addition, top five countries according to production and service efficiencies are at Table 5 and Table 6.

Table 2. Logistics efficiency scores (E_k) of OECD countries (in percentage)

COUNTRY	2010	2012	2014	2016	2018	COUNTRY	2010	2012	2014	2016	2018
Australia	73,61	66,71	66,33	73,92	74,77	**Korea**	72,27	70,65	64,41	72,67	78,19
Austria	75,65	73,21	67,57	82,13	82,08	**Latvia**	70,58	54,94	66,86	70,43	64,26
Belgium	87,99	86,61	84,76	96,53	93,49	**Lithuania**	70,21	61,59	61,1	75,87	74,58
Canada	67,69	65,86	63,68	72,2	72,46	**Luxembourg**	80,93	78,45	81,64	90,91	75,56
Chile	84,77	73,53	73,04	77,89	82,55	**Mexico**	100	99,58	100	100	99,7
Colombia	97,23	95,34	97,13	100	100	**Netherlands**	70,99	73,53	68,01	78,7	77,08
Czech Rep.	71,85	60,67	69,89	78,86	85,2	**New Zealand**	66,16	62,8	66,77	65,81	74,71
Denmark	69,49	73,23	71,09	73,54	81,88	**Norway**	71,16	66,47	68,69	72,24	76,67
Estonia	65,1	55,22	63,61	69,68	74,06	**Poland**	80,83	72,62	71,61	77,88	90,33
Finland	75,95	78,6	70,36	79,22	89,77	**Portugal**	62,86	67,21	67,28	72,1	87,01
France	81,59	82,67	79,91	86,93	90,67	**Slovak Rep.**	67,98	59	65,6	73,28	69,72
Germany	76,61	73,02	71,17	80,45	84,5	**Slovenia**	59,31	67,08	64,76	69,74	76,54
Greece	67,62	61,62	65,01	77,42	83,9	**Spain**	73,97	72,63	69,33	79,67	87,32
Hungary	70,06	74,09	75,08	79,27	89,9	**Sweden**	74,4	68,27	70,06	81,13	75,5
Iceland	53,68	53,24	52,09	57,3	55,17	**Switzerland**	70,03	62,4	61,31	68,76	73,85
Ireland	75,38	70,76	75,16	84,33	77,91	**Turkey**	98,44	94,74	90,68	97,76	100
Israel	71,76	71,84	75,47	80,38	77,8	**United Kingd.**	75,94	73,41	70,7	79,79	84,87
Italy	86,88	85,9	84,18	93,94	96,47	**United States**	76,77	75,54	73,14	81,07	84,67
Japan	74,35	72,98	68,31	76,93	81,45						

Table 3. Production (E_k^{prod}) and consumption (E_k^{serv}) stage efficiencies of OECD countries (in percentage)

	2010		2012		2014		2016		2018	
	Prod	**Serv**	**Prod**	**Serv**	**Prod**	**Serv**	**Prod**	**Serv**	**Prod**	**Serv**
Australia	82,44	89,29	73,35	90,95	75,14	88,27	79,15	93,39	82,92	90,18
Austria	80,42	94,07	81,63	89,68	78,06	86,56	86,09	95,41	88,13	93,13
Belgium	100,00	87,99	93,87	92,27	94,82	89,39	100,00	96,53	100,00	93,49
Canada	79,44	85,20	70,71	93,14	74,52	85,44	83,23	86,75	80,24	90,31
Chile	94,29	89,91	75,98	96,78	78,90	92,58	77,89	100,00	91,02	90,70
Colombia	100,00	97,23	100,00	95,34	100,00	97,13	100,00	100,00	100,00	100,00
Czech Rep.	79,65	90,20	67,82	89,46	70,81	98,70	83,36	94,61	89,54	95,16
Denmark	80,68	86,12	81,76	89,57	83,97	84,66	83,78	87,77	90,01	90,97
Estonia	74,06	87,90	55,37	99,74	66,98	94,97	69,68	100,00	77,24	95,88
Finland	90,18	84,22	86,17	91,21	79,10	88,95	92,70	85,45	92,92	96,60
France	94,33	86,49	86,48	95,60	85,52	93,45	95,34	91,18	95,17	95,28
Germany	93,43	82,00	81,46	89,64	89,46	79,56	91,99	87,45	94,06	89,83
Greece	67,62	100,00	61,62	100,00	83,94	77,45	77,42	100,00	83,90	100,00
Hungary	80,40	87,14	74,09	100,00	75,08	100,00	79,27	100,00	92,30	97,41
Iceland	64,18	83,63	60,94	87,36	60,76	85,74	58,56	97,86	56,77	97,18
Ireland	83,59	90,18	75,06	94,28	89,12	84,34	84,76	99,49	84,05	92,69

Israel	81,31	88,25	76,19	94,29	76,59	98,54	84,96	94,61	84,75	91,80
Italy	98,48	88,22	90,04	95,40	89,14	94,43	97,97	95,89	100,00	96,47
Japan	87,88	84,61	79,39	91,93	83,26	82,04	86,00	89,45	91,10	89,40
Korea	79,74	90,64	72,74	97,12	71,45	90,14	77,10	94,25	81,75	95,65
Latvia	70,58	100,00	54,94	100,00	72,51	92,20	73,44	95,90	72,55	88,58
Lithuania	70,21	100,00	61,59	100,00	64,50	94,73	79,42	95,53	74,58	100,00
Luxembourg	100,00	80,93	82,38	95,23	90,52	90,19	92,27	98,52	86,11	87,75
Mexico	100,00	100,00	99,58	100,00	100,00	100,00	100,00	100,00	100,00	99,70
Netherlands	86,75	81,83	78,62	93,52	84,89	80,12	88,68	88,74	88,32	87,28
New Zealand	80,03	82,67	64,94	96,70	70,70	94,44	67,45	97,57	82,69	90,35
Norway	85,81	82,93	69,37	95,81	90,63	75,80	77,66	93,02	80,49	95,25
Poland	80,83	100,00	72,62	100,00	77,08	92,91	81,01	96,14	94,76	95,33
Portugal	74,85	83,99	69,47	96,74	74,34	90,49	76,47	94,28	87,01	100,00
Slovak Rep.	67,98	100,00	64,34	91,70	65,70	99,86	73,72	99,40	76,69	90,92
Slovenia	60,23	98,48	67,52	99,35	72,19	89,71	72,60	96,06	77,69	98,53
Spain	80,65	91,72	75,11	96,69	79,49	87,21	83,61	95,29	93,75	93,15
Sweden	85,29	87,24	75,20	90,79	77,27	90,67	86,36	93,95	88,33	85,47
Switzerland	79,25	88,36	68,64	90,90	68,83	89,07	77,26	88,99	77,07	95,82
Turkey	100,00	98,44	100,00	94,74	100,00	90,68	100,00	97,76	100,00	100,00
United Kingdom	86,43	87,87	79,73	92,08	87,76	80,56	89,86	88,80	90,78	93,50
United States	88,34	86,90	80,55	93,79	84,83	86,21	88,34	91,76	88,88	95,27

Studies show that international LPI scores and development of a country is related. Most of the developed countries show good performance scores, whereas, least developed countries have poor LPI scores (Arvis et al., 2018: 13-14). On the other hand, proposed study is interested in efficiency measurement of logistics of countries under the constraints of capital and labor measures. Therefore, it is possible to investigate the efficiencies of country groups in accordance of development level.

Table 4. Most efficient five countries according to total logistics efficiency scores (E_k) in percentage

2010		**2012**		**2014**		**2016**		**2018**	
Mexico	100,00	**Mexico**	99,58	**Mexico**	100,00	**Colombia**	100,00	**Turkey**	100,00
Turkey	98,44	**Colombia**	95,34	**Colombia**	97,13	**Mexico**	100,00	**Colombia**	100,00
Colombia	97,23	**Turkey**	94,74	**Turkey**	90,68	**Turkey**	97,76	**Mexico**	99,70
Belgium	87,99	**Belgium**	86,61	**Belgium**	84,76	**Belgium**	96,53	**Italy**	96,47
Italy	86,88	**Italy**	85,90	**Italy**	84,18	**Italy**	93,94	**Belgium**	93,49

Table 5. Most efficient five countries according to logistics production efficiency scores (E_k^{prod}) in percentage.

2010		**2012**		**2014**		**2016**		**2018**	
Mexico	100,00	**Colombia**	100,00	**Mexico**	100,00	**Turkey**	100,00	**Mexico**	100,00
Turkey	100,00	**Turkey**	100,00	**Colombia**	100,00	**Belgium**	100,00	**Turkey**	100,00
Colombia	100,00	**Mexico**	99,58	**Turkey**	100,00	**Colombia**	100,00	**Belgium**	100,00
Luxembourg	100,00	**Belgium**	93,87	**Belgium**	94,82	**Mexico**	100,00	**Italy**	100,00
Belgium	100,00	**Italy**	90,04	**Norway**	90,63	**Italy**	97,97	**Colombia**	100,00

Table 6. Most efficient five countries according to logistics service efficiency scores (E_k^{serv}) in percentage. Note: More countries are present in the situations where fifth and following countries have same scores.

2010		2012		2014		2016		2018	
Slovak Rep.	100,00	**Greece**	100,00	**Hungary**	100,00	**Greece**	100,00	**Lithuania**	100,00
Poland	100,00	**Mexico**	100,00	**Mexico**	100,00	**Colombia**	100,00	**Portugal**	100,00
Lithuania	100,00	**Latvia**	100,00	**Slovak Rep.**	99,86	**Hungary**	100,00	**Turkey**	100,00
Greece	100,00	**Lithuania**	100,00	**Czech Rep.**	98,70	**Estonia**	100,00	**Greece**	100,00
Mexico	100,00	**Hungary**	100,00	**Israel**	98,54	**Mexico**	100,00	**Colombia**	100,00
Latvia	100,00	**Poland**	100,00			**Chile**	100,00		

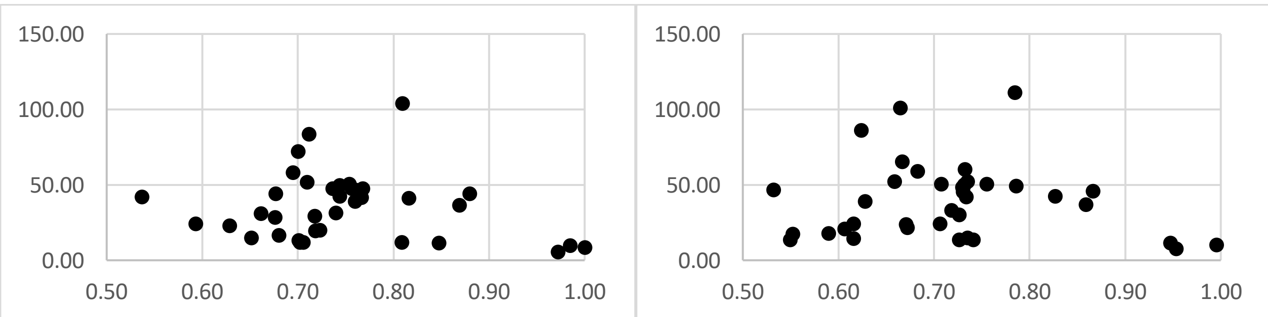
United Nations (UN) publishes World Economic Situation and Prospects (WESP) report yearly. In this publication, countries are classified into developed, developing and in transition economies (UNCTAD, 2020). For 2010-2018 period, Out of 37 OECD members, five countries are in developing economies class: Israel, Chile, Colombia, Mexico and Turkey. Rest of the OECD members are developed countries. It is possible to compare the average efficiencies of developed and developing OECD countries. In Table 7 total logistics, production stage and service stage efficiencies of developed and developing countries of OECD are shown respectively.

Table 7. Average efficiency values of developed and developing countries of OECD (in percentage).

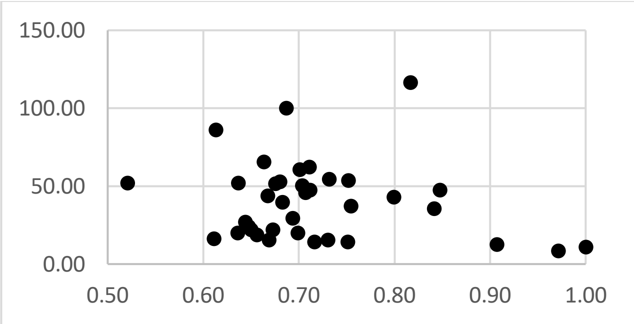
Efficiency Measure	Economies	2010	2012	2014	2016	2018
Total Logistics Efficiency	**Developed**	72,43	69,41	69,36	77,27	80,14
	Developing	90,44	87,01	87,27	91,21	92,01
Logistics Production Efficiency	**Developed**	81,68	73,67	78,51	82,33	85,62
	Developing	95,12	90,35	91,10	92,57	95,15
Logistics Service Efficiency	**Developed**	89,09	94,39	88,70	94,04	93,65
	Developing	94,77	96,23	95,79	98,48	96,44

In Figure 2, distribution graphs of yearly average gross domestic product per capita (GDPPC) with respect to obtained logistics efficiencies of countries are shown in bi-yearly manner. In addition, in Table 8, correlation coefficient (R) between GDPPC and logistics efficiency of countries through five periods 2010-2018 is presented.

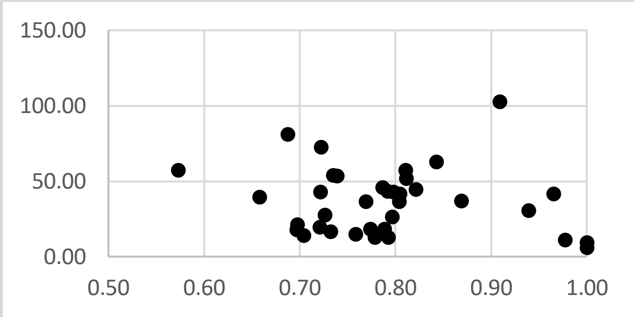
Figure 2. Distribution of average gross domestic product per capita (thousand USD) vs. logistics efficiencies for periods of 2010 (a), 2012 (b), 2014 (c), 2016 (d) and 2018 (e)



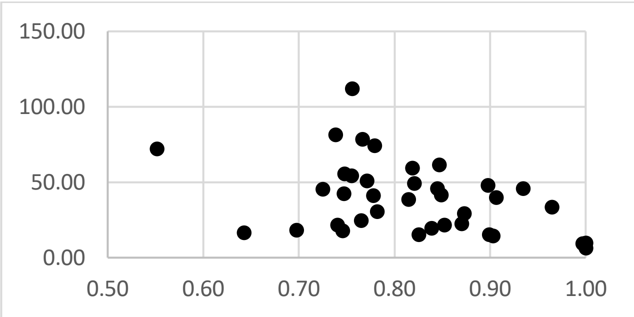
(a) (b)



(c)



(d)



(e)

Table 8. Correlation coefficient (R) between gross domestic product per capita and logistics efficiency values of OECD countries.

Period	Correlation Coefficient (R)
2010	-0,16
2012	-0,09
2014	-0,18
2016	-0,15
2018	-0,42

4. CONCLUSION AND DISCUSSION

In this study, a Network DEA model is presented for measuring relative logistics efficiencies of countries. Main logistics process divided into two, as production and service stages. Two macroeconomic inputs, government spending per capita and labor force per capita are main inputs as well as the inputs of production stage. On the other hand, based on the work of Marti et al. (2017), 3 international LPI indicators are main outputs and the outputs of service stage at the same time. The other 3 International LPI components are intermediate products, which are the outputs of production stage and the inputs of service stage.

Proposed model is applied to 37 OECD countries to measure relative logistics efficiencies. Obtained results show that out of 37 countries, especially three of them, Mexico, Colombia and Turkey shows distinctly high efficiency scores through all five periods. According to the findings, total logistics processes of Mexico is efficient (efficiency over 99,5%) for all five periods. Columbia is efficient for 2016-2018 periods and Turkey is efficient in 2018 period. Although Colombia and Turkey are not fully efficient in all periods, they show a steady high efficiency over 90%. Other than these three countries, Italy and Belgium have relatively high overall logistics performances changing in 84%-97% band. Opening up the black box of main logistics DMU, it can be seen that the top three countries (Mexico, Colombia and Turkey) are fully efficient in production process for all time periods. In addition, Belgium is efficient in production stage for three out of five time periods, while Italy and Luxembourg for one time periods each. On the other hand, service stage efficiency scores indicates a different structure. While Mexico is efficient for all periods, Greece shows full efficiency for four periods out of five. Also, Slovak Republic, Poland, Lithuania, Latvia, Hungary, Portugal, Estonia, Turkey, Colombia and Chile show efficient service stage processes for some periods.

Analyzing international LPI scores shows that there is a relation between development level and LPI indicators of a country, such that the more developed a country is the higher LPI indicator scores (Arvis et al., 2018: 13-14). On the other hand, efficiency is another concept. Efficiency measures the level of output relative to the level of input. Showing higher output levels relative to same input levels, or same output levels for lower input levels brings higher efficiency scores. Therefore, inputs are critically important as constraints for efficiency analysis. Higher efficiency scores of total logistics efficiency means better logistics performance relative to limited capital and labor. On the other hand, to be able to have high total efficiency score, service stage efficiency should also be high. Therefore one need to have relatively high logistics service outputs (timeliness, shipments and tracking-tracing) according to service inputs (customs, infrastructure and logistics quality-competence) to have high total logistics efficiency scores.

Using United Nations country classification of development, OECD countries can be divided into two. There are 32 developed countries with 5 developing countries. Taking average efficiency scores for both classes shows developing countries have better efficiency results than developed countries in average. Also, analyzing the sub-process efficiencies results that developing countries of OECD are superior to developed ones in both production and service stage efficiencies in average. It can be seen by looking at the GDP per capita values of countries that, top three countries having the highest efficiency scores have lowest GDP per capita scores in all periods. On the other hand, Fig. 2.a-2.e and correlation coefficient values in Table 8 shows no distinct evident in relation between GDP per capita and the efficiency scores obtained.

Obtained results show that three countries (Mexico, Colombia and Turkey) out of 37 OECD countries show dominantly high logistics efficiency scores. In addition, these three countries are superior to others especially in terms of production stage efficiency. However, their service stage efficiency values seems to be improvable. Another important finding is that, other than top three countries mentioned; although countries like Belgium and Italy show high production efficiency scores, service efficiency scores favor countries like Poland, Latvia, Lithuania, Greece, Hungary and Slovak Republic. Focusing on the less efficient stage and working on those input and outputs might give a very high overall logistics efficiency for these countries.

This study is open for further research and development. Proposed Network DEA model could be varied with different capital and labor measures like capital stock or employment rate. In this study, international LPI indicators are used and two logistics sub stages are identified. It is possible researching for other sub stages of logistics process and adding some other logistics indicators relevant to these sub processes. It is important to note that because DEA measures the relative efficiency scores, obtained results are relative to application sample, which consists of 37 OECD countries. Therefore, enlarging or narrowing the sample size might alter the efficiency scores. Consequently, applying the proposed two stage structured model on different country groups could help the generalization of the model.

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