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An empirical study on measurement of efficiency of digital transformation by using data envelopment analysis

Mehmet Nuri İnel[a*]

[a]*Marmara University, İstanbul, Turkey*

C H R O N I C L E

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A B S T R A C T

Nowadays digitalization is an important topic for businesses and government agencies. There are important reports publishing about digitalization or digital transformation. This study aims to measure the relative efficiency of digital transformation among EU Countries based on data envelopment analysis (DEA). The necessary data are extracted from Digital Transformation Scoreboard 2018 published by European Commission. DEA is one of popular methods for measuring the relative efficiency of similar units. This study empirically proposes an alternative ranking for countries with respect to digital transformation efficiency by using "enablers and output" approach of Digital Transformation Scoreboard. Digital Infrastructure, Investment and Access to Finance, Supply and Demand of Digital Skills, E-Leadership and Entrepreneurial Culture are considered as input while ICT start-ups and Digital Transformation are considered as the output of DEA model. The results indicate that while some countries like Denmark, Italy and United Kingdom are considered relatively efficient, Netherland and Germany are not very efficient according to our results.

1. Introduction

Digital transformation is an important topic for businesses and countries in this era. Technical improvements and applications enable us to improve digital transformation on both businesses and countries, rapidly. This study investigates the efficiency of digital transformation in this study. The aim of this study is to measure the relative efficiency of digital transformation using data envelopment analysis (DEA). There are many reports about digital transformation and one of them is Digital Transformation Scoreboard 2018 **(**Digital Transformation Scoreboard, 2018) published annually by European Commission. The study data and the application framework are taken from this report. The concept of DEA with different methods and approaches, is used in many studies and practices as one of efficiency measurement analysis. In this study, DEA is implemented to measure of the relative efficiency of digital transformation. The study has three main sections. The first and the second sections include literature of DEA and digitalization. The third section includes application of measurement efficiency and finally section four provides the conclusion of the paper.

* Corresponding author.
E-mail address: mninel@marmara.edu.tr (M. N. İnel)

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The literature review of digital transformation and DEA methods are described in this section. Since the digital transformation is an important topic, we need to measure the effectiveness of the method. There are different studies in the literature that measure the relative efficiency of countries instead of efficiency of digital transformation. Kaynar et al. (2005) measured the relative efficiency of the telecommunication sector located in OECD region using DEA method. Aksu and Gencer (2018) also measured the relative environmental performance in OECD countries using DEA. Raab and Kotamraju (2006) measured the efficiency of high tech economies using DEA in United States. Chodakowska and Nazarko (2017) applied environmental efficiency analysis and evaluated the productivity of European Countries using DEA method.

Ceccobelli et al. (2012) used DEA method to measure the impact of information and communication technology (ICT) on labor productivity on 14 OECD countries. Angeriz et al. (2006) used DEA to assess indices of total factor productivity, technological change and efficiency in Europe countries. Filippetti and Peyrache (2015) also used DEA to assess Labor Productivity and Technology Gap in Europe countries. Mitrovic (2015) used DEA based model to analyze dynamics and the level of the digital information in Western Balkan Countries. Kumar and Russell (2002) used DEA to measure the efficiency technological catch-up in 57 countries. Chetty et al. (2018) measured digital literacy to create some useful index. DEA method was also used for ranking in the literature (Mehrabian et al., 1999)

It is shown that there were significant number of studies, which implement DEA to measure efficiency of countries as macro dimension in the literature. In this paper, we use DEA method to measure the relative efficiency of digital transformation in EU countries.

2. Data Envelopment Analysis

DEA was born first through a study by Farrel (1957). DEA has been one of the most popular methods for measuring the relative efficiency of decision making units developed first by Charnes et al. (1978), which was based on constant return to scale (CCR). According to Melao (2005), DEA basically measures the relative efficiency of multiple outputs and inputs of decision making units. It evaluates decision making units according to efficient frontiers, which gives scores for every units (Shim & Kantor, 1999). There are different assumptions about DEA. The extension of CCR was developed by Banker et al. (1984). They proposed variable returns to scale assumption called BCC model (Banker et al., 1984; Cooper et al., 2007). Both method have output and input oriented approaches. As a mathematical programming approach, objective function for particular decision making units evaluate generally and symbolically (Cooper et al., 2011),

$$\max h_o(u,v) = \frac{\sum_r u_r y_{ro}}{\sum_i v_i x_{io}}. \tag{1}$$

Definition, formulas and assumption details of CCR and BCC were explained by Cooper et al (2011). There are different DEA based approaches in the literature. Because of using CCR and BCC; input and output oriented assumptions in application of study, these assumptions are shortly explained in this section.

3. Digital Transformation

Digital transformation is one of favorite topics nowadays. This topic influences on economic environment as well as businesses and countries. There are many approaches to define digital transformation in the literature. According to Reddy and Reinartz (2012) digital transformation has two definitions and one of these is to use internet and computer to create effective economic value with respect to traditional sense. The other definition wholly states changes of new technology in operation, interaction, configuration and creation of wealth with respect to broader sense. Schallmo et al. (2017) investigated definition of digital transformation and proposed definition of digital transformation for their

digital transformation of business models research. According to Schallmo et al. (2017) digital transformation includes networking business, customers, segments and requires data analysis to reach information used to evaluate options that increases business performance.

Berman (2012) suggested to reshape costumer value and transform operations based on digital technologies to reach grater customer collaboration and interaction for the success of digital transformation. Digitalization of countries can be measured with six key attributes: ubiquity, affordability, reliability, speed, usability and skill (El-Darwiche et al. 2012)

In the literature, Schwarzmüller et al. (2018) investigated how the digital transformation affects the organizations. Majchrzak et al. (2016) performed an investigation on designing for digital transformation. Balyer and Öz (2018) investigated digital transformation on education according to academicians' perspective. Bouwman et al. (2018) investigated generally impacts of digitalization for SMEs. Motta (2016) also investigated impacts of digitalization about socio economic development. Li et al. (2018) investigated capability of SME's for digital transformation. Loonam et al. (2018) investigated some case studies about digital transformation. Digital transformation affects world economy, helps to emergence of concepts such as digital economy (Unctad, 2017).

Westerman et al. (2011) investigated a research on executives about digital transformation. According to executives, digital transformation has three main areas of customer experience, business models and operational process. Every area has elements that have shown in Table 1.

Table 1
A Part of Building Blocks of the Digital Transformation Source: (Westerman et al. 2011)

Customer Experience	Operational Process	Business Models
Customer Understanding	Process Digitalization	Digitally Modified Business
Top Line Growth	Worker Enablement	New Digital Business
Customer Touch Points	Performance Management	Digital Globalization

3.1 Digitalization Index

There are different reports about digitalization or digital transformation. They assess countries with respect to traits of digitalization and one of them published annually by European Commission is digital transformation scoreboard. It especially investigates Europe countries. As the name suggests, the report includes a scoreboard. The scoreboard is a part of digital transformation monitor. The scoreboard contains indicators in two different areas. These are enablers and outputs. Enablers have five categories and outputs have two categories. These indicators assess the development of digital transformation in 28 EU Countries. The seven-category is defined and shown in Fig. 1 (Digital Transformation Scoreboard 2018).

Enablers				
Digital Infrastructures	**Investment and Access to Finance**	**Supply and Demand of Digital Skills**	**E- Leadership**	**Entrepreneurial Culture**
Enterprises possessing and using digital tools	Investments related to digitalization and access to finance	Widespread digital skills	Education and training available to obtain digital skills	People favor entrepreneurial behavior
Integration of Digital Technology Companies are increasingly using digital technologies				
ICT Start-ups The number of start-ups in the ICT sector is increasing				
Outputs				

Fig. 1. Indicator-Based Monitoring of Digital Transformation
Source: Digital Transformation Scoreboard 2018

Digital transformation scoreboard was built in four main (Indicators, survey, real time data, policy analysis) methodological framework shown in Fig. 2.

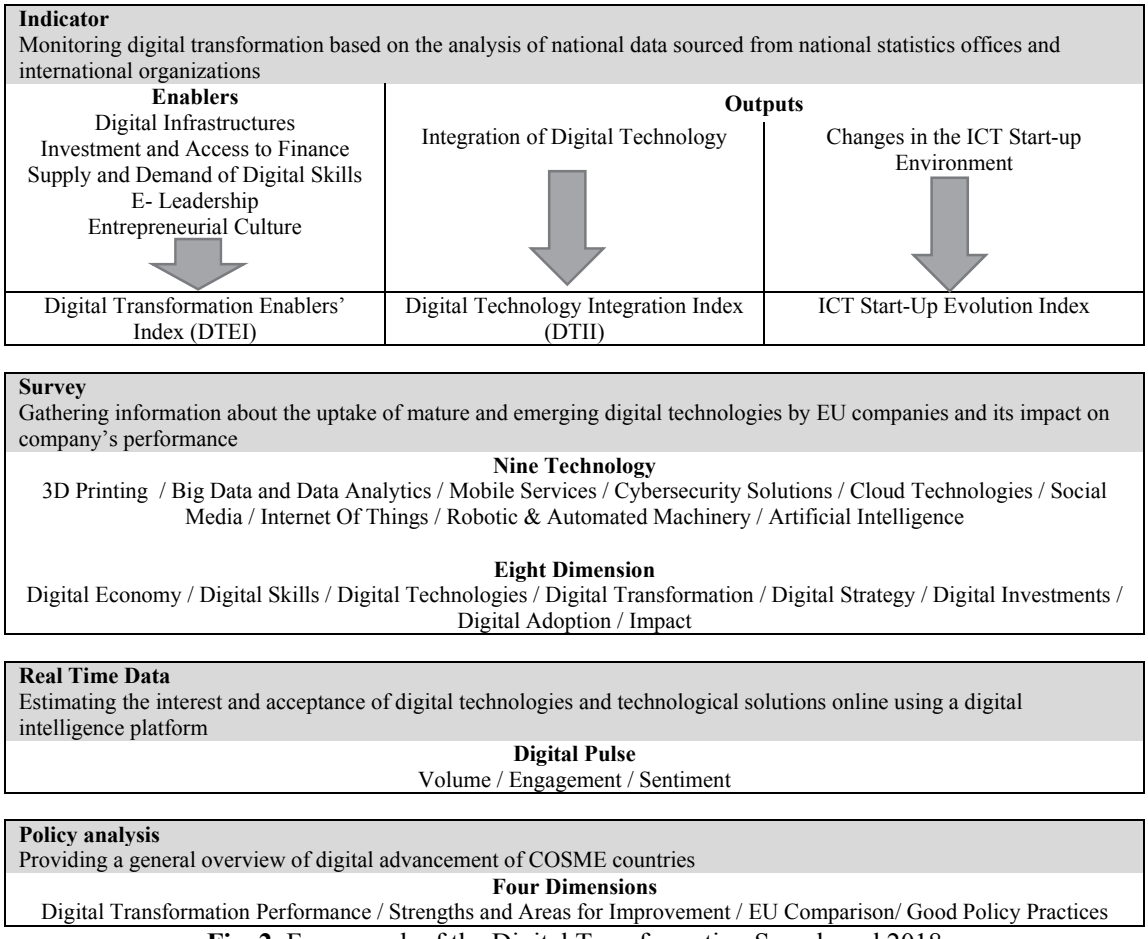

Fig. 2. Framework of the Digital Transformation Scoreboard 2018

Source: Digital Transformation Scoreboard 2018

In this study, we use the indicators of enablers and output to measure efficiency of digital transformation in EU Countries.

4. Application

In this study, the efficiency of digitalization transformation is measured in EU countries by data envelopment analysis. We use indicators of digital transformation scoreboard 2018 to measure effectiveness. EU countries is ranked according to effectiveness scores. In the ranking process, we compare different data envelopment analysis approaches.

4.1 Methods

Data envelopment analysis was used to measure the efficiency. CCR method input and output oriented assumptions and BCC method input and output oriented assumptions are applied and the results are compared by using EMS (Efficiency Measurement System: A Data Envelopment Analysis (DEA) Software, Link: http://www.holger-scheel.de/ems/). Digital infrastructure, investments and access to finance, supply and demand of digital skills, e-leadership, entrepreneurial culture, ICT start-ups, digital transformation data of 27 European countries are used in data envelopment analysis. Romania is not analyzed due to lack of data. Data of 27 European countries are obtained from digital transformation scoreboard 2018 report for year 2017.

4.2 Data Envelopment Analysis Application

In this study, data are analyzed to measure the efficiency of digital transformation by EMS program created according to the model of this study that is shown in Fig. 3. Inputs and outputs are determined according to digital transformation scoreboard approach, because the scoreboard proposed a model for measuring digital transformation (Digital Transformation Scoreboard 2018). Each European country was designed as a decision-making unit for data envelopment analysis.

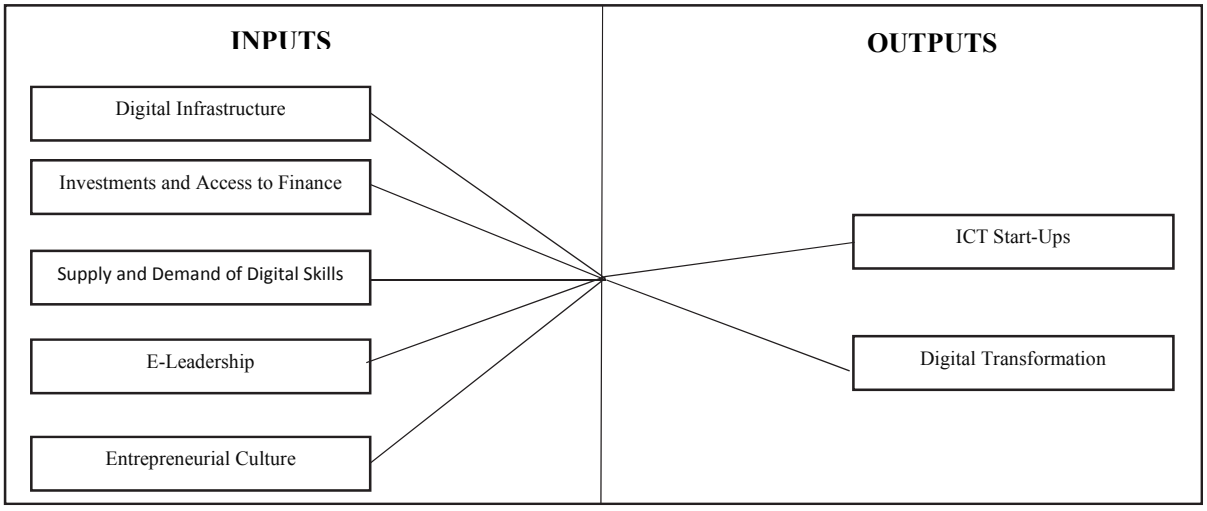

Fig. 3. The Model of Study

Data consist of inputs and outputs of model for 27 European Countries are collected and organized to calculate in EMS program shown in Table 2. We have also calculated super efficiency for both CCR and BSS methods. Thus, eight different calculations have been applied by EMS program. These are input, output, super efficiency input, super efficiency output approaches for CCR method; input, output, super efficiency input, super efficiency output approaches for BCC method.

Table 2
Index Scores of Digital Transformation Framework

Countries	Digital Infra-structure	Investments And Access To Finance	Supply And De-mand Of Digital Skills	E-Leadership	Entrepreneurial Culture	ICT Start-Ups	Digital Transfor-mation
Finland	76	80	83	97	51	60	37
Belgium	76	77	65	84	77	24	52
Sweden	70	76	86	76	75	76	42
Luxembourg	80	74	65	86	60	65	44
Netherlands	85	71	89	65	100	32	40
Austria	59	69	55	76	33	35	39
Germany	57	68	53	51	72	22	35
France	52	68	58	60	77	34	56
UK	46	68	66	70	58	71	54
Czech Republic	42	67	34	47	71	41	41
Greece	23	55	24	19	58	27	43
Malta	67	53	55	57	71	75	30
Hungary	14	51	38	35	70	45	24
Estonia	35	51	47	54	78	68	32
Denmark	78	48	84	78	46	71	62
Italy	45	47	27	33	62	29	56
EU	48	46	45	55	68	43	37
Poland	16	45	20	36	60	48	48
Portugal	66	40	34	38	96	70	22
Spain	67	39	55	72	77	33	46
Ireland	60	37	94	86	76	35	24
Lithuania	59	34	21	64	79	79	23
Bulgaria	13	34	30	41	78	67	22
Slovenia	48	19	34	69	79	52	30
Latvia	16	16	18	37	80	54	33
Croatia	24	14	24	54	91	38	35
Cyprus	52	13	53	67	80	34	34

4.3 Results and Discussion

The efficiency scores of DMUs have been analyzed according to CCR method. The results for comparing and efficiency scores are shown in Table 3. The most efficiency countries for digital transformation according to data and the model of study are empirically countries that are highlighted in bold (100%) in first and second columns. Especially, it is stated that efficiency scores vary according to inputs or outputs size. For example Bulgaria has the highest input super efficiency score (152,71%) but when we look at Table 2, Bulgaria has maintained the lowest input values in some categories. The other countries like Germany (for example) has performed poorly according to efficiency score (51,16%) but when we look at Table 2, Germany has maintained some high input values. This efficiency measure empirically proposes that countries can possess higher output. If a country has low efficiency score, it can be stated that higher outputs can be achieved with the same input scores or vice versa. This is also related to the size of the country and the level of digitization. Especially these scores have been calculated with only 5 inputs and 2 output indicators (according to scoreboard) but countries can have very different indicators for the measurement of digital transformation. The efficiency scores of DMU have been analyzed according to BCC method. The results of comparing and efficiency scores are shown in Table 4. The most efficiency countries for digital transformation according to data and the model of study are empirically countries shown in bold color (100%) in first and second columns. Scores of some countries are "big" because of higher scores in third and fourth scores columns.

Table 3
Efficiency Scores According to CCR Method

DMU	Score Input Approach	Score Output Approach	Score Input Super efficiency Approach	Score Output Super efficiency Approach
Denmark	**100,00%**	**100,00%**	148,53%	67,33%
France	77,92%	128,34%	77,92%	128,34%
Italy	**100,00%**	**100,00%**	118,42%	84,44%
UK	**100,00%**	**100,00%**	110,25%	90,70%
Belgium	65,59%	152,45%	65,59%	152,45%
Poland	**100,00%**	**100,00%**	152,66%	65,51%
Spain	80,65%	123,99%	80,65%	123,99%
Luxembourg	84,92%	117,76%	84,92%	117,76%
Greece	**100,00%**	**100,00%**	141,67%	70,59%
Sweden	87,71%	114,01%	87,71%	114,01%
Czech Republic	69,18%	144,56%	69,18%	144,56%
Netherlands	46,85%	213,44%	46,85%	213,44%
Austria	91,13%	109,73%	91,13%	109,73%
Finland	80,56%	124,13%	80,56%	124,13%
Germany	51,16%	195,48%	51,16%	195,48%
Croatia	**100,00%**	**100,00%**	115,06%	86,91%
Cyprus	**100,00%**	**100,00%**	107,87%	92,70%
Latvia	**100,00%**	**100,00%**	152,68%	65,50%
Estonia	91,34%	109,49%	91,34%	109,49%
Malta	**100,00%**	**100,00%**	103,45%	96,67%
Slovakia	**100,00%**	**100,00%**	129,35%	77,31%
Slovenia	90,70%	110,26%	90,70%	110,26%
Ireland	46,83%	213,55%	46,83%	213,55%
Hungary	82,92%	120,59%	82,92%	120,59%
Lithuania	**100,00%**	**100,00%**	129,57%	77,18%
Portugal	**100,00%**	**100,00%**	112,73%	88,71%
Bulgaria	**100,00%**	**100,00%**	152,71%	65,49%

Finally, this study has aimed to measure empirically the relative efficiency of digital transformation. When compared methods, CCR method can be more convenient for ranking purposes because of scores according to data. Most countries, has efficiency of 100% and scores are similar to BCC method. Some countries have extreme scores according to BCC method. In this study, the digital transformation history of the countries was not taken into account and only it was calculated according to 2017 data of countries. Different results will be obtained by taking into account the past investments and different indicators in the digital transformation of the countries.

Table 4
Efficiency Scores According to BCC Method

DMU	Score Input Approach	Score Output Approach	Score Input Super efficiency Approach	Score Output Super efficiency Approach
Denmark	**100,00%**	**100,00%**	big	big
France	88,46%	102,27%	88,46%	102,27%
Italy	**100,00%**	**100,00%**	209,52%	84,16%
UK	**100,00%**	**100,00%**	147,39%	90,12%
Belgium	67,32%	115,38%	67,32%	115,38%
Poland	**100,00%**	**100,00%**	212,05%	big
Spain	82,78%	116,56%	82,78%	116,56%
Luxembourg	88,63%	113,12%	88,63%	113,12%
Greece	**100,00%**	**100,00%**	175,28%	big
Sweden	**100,00%**	**100,00%**	big	98,94%
Czech Republic	78,67%	125,65%	78,67%	125,65%
Netherlands	60,49%	150,67%	60,49%	150,67%
Austria	**100,00%**	**100,00%**	142,73%	big
Finland	86,92%	120,35%	86,92%	120,35%
Germany	75,95%	166,23%	75,95%	166,23%
Croatia	**100,00%**	**100,00%**	123,66%	big
Cyprus	**100,00%**	**100,00%**	110,89%	big
Latvia	**100,00%**	**100,00%**	168,87%	big
Estonia	91,76%	103,45%	91,76%	103,45%
Malta	**100,00%**	**100,00%**	106,09%	95,79%
Slovakia	**100,00%**	**100,00%**	163,64%	big
Slovenia	97,22%	109,98%	97,22%	109,98%
Ireland	83,77%	194,95%	83,77%	194,95%
Hungary	**100,00%**	**100,00%**	105,83%	big
Lithuania	**100,00%**	**100,00%**	big	73,98%
Portugal	**100,00%**	**100,00%**	123,03%	87,92%
Bulgaria	**100,00%**	**100,00%**	258,79%	big

5. Conclusion and Recommends

This study has empirically proposed to measure the relative efficiency of digital transformation using DEA method. It has empirically shown that DEA can be applied to measure the efficiency of digital transformation. Efficiency scores can vary according to data. Denmark, Italy, UK, Poland, Greece, Croatia, Cyprus, Latvia, Malta, Slovakia, Lithuania, Portugal, Bulgaria were detected efficient countries according to both methods according to both BCC and CCR methods. Approximately 50% of countries analyzed, are efficient in digital transformation according to two methods. We may apply input, output approach of this study for businesses to measure the efficiency of digital transformation. For further research, properties of data envelopment analysis like benchmarking of decision making units or sensitivity analysis can applies. This efficiency measurement method of digital transformation can be applied for businesses or different countries.

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