Modeling the Education Supply Chain with Network DEA Model: The Case of the European Union

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Abstract

This study evaluates the effectiveness of the educational supply chain in 27 EU states using the relational network DEA. The education system consists of three interconnected stages: primary, secondary, and tertiary education. The overall system efficiency reflects the combined efficiencies of each stage, demonstrating the interconnection between these stages. This allows for a comprehensive evaluation of the entire education system while also assessing each stage individually. This approach is important because it helps identify specific subsystems responsible for any inefficiencies within the entire educational system, highlighting areas that need improvement. By addressing these inefficiencies at their source, targeted strategies can be implemented to improve the overall effectiveness of the education system. The results indicate that the inefficiency of primary education explains a significant part of the inefficiency of the entire education system.

Key words: education, efficiency, network DEA, European Union
J.E.L. classification: I21, C61

1. Introduction

Education serves as a fundamental driver for enhancing individuals' livelihoods and fostering societal advancement. Education has a profound and multifaceted impact on individuals, communities, and society as a whole. The significance of education extends beyond the mere acquisition of knowledge; it encompasses economic growth, social development, health improvements, and the fostering of civic engagement. (Dincă et al, 2021)

The concept of an educational supply chain can be likened to a traditional supply chain, where inputs are transformed into outputs through a series of stages. In the context of education, this involves students' progression through various educational stages, supported by a range of resources, processes, and stakeholders.

Applying industrial models to the services sector, including education, aims to make them more efficient. Education can be considered a supply chain where human, physical, and financial resources are the inputs of the whole system. In general, this chain can be structured as follows: the outputs of primary education will be the inputs for secondary education or the labor market, and the outputs of secondary education will be the inputs for tertiary education or the labor market. Tertiary graduates will either continue their education throughout life or enter the labor market. (Ramzi, 2019) The education supply chain encompasses the entire process of delivering educational services and resources from the initial input to the final output. This process involves several key components, stakeholders, and activities that ensure the effective functioning and delivery of education. (Pasztori, 2023)

The current study's purpose is to evaluate the EU's education system using the well-known mathematic program of data envelopment analysis (DEA).

Efficiency appears when education results, such as scores in testing or value-added outcomes are achieved with a rather low level of financial resources.

2. Literature review

Education is the most attractive sector for DEA development and expansion. A large number and variety of applications of DEA have been made to evaluate the performance of this sector and detect its inefficiency. They consider two types of DMUs to assess the level of efficiency. The first group is the micro-education level (university, school, etc), and the second group is the macro level where countries are selected as DMUs. Most of the work considers the micro level, and few of them use countries as selected DMUs.

Table no. 1. Literature

Level	Author, title	Content
Micro level	Tran et al, 'Measuring efficiency of Vietnamese public colleges: An application of the DEA-based dynamic network approach'	The overall efficiencies of Vietnam, public colleges are, on average, 0.741 while the average efficiencies of the financial and academic operations are 0.722 and 0.760, respectively.
	Kashim et al, 'Measuring Efficiency of a University Faculty Using a Hierarchical Network Data Envelopment Analysis Model'	An improved DEA model based on a network structure that accounts for more activities in a university is proposed to measure faculty overall efficiency.
	Chen et al, 'Operating efficiency in Chinese universities: An extended two-stage network DEA approach'	An extended two-stage network DEA approach for measuring operating efficiency of 52 Chinese universities.
	Nazarko & Šaparauskas, 'Application of DEA method in efficiency evaluation of public higher education institutions'	The paper describes a comparative efficiency study of 19 Polish universities of technology.
	Lee & Johnes, 'Using network DEA to inform policy: The case of the teaching quality of higher education in England'	This study contributes to the existing literature by employing a network data envelopment analysis model that truly reflects the production process of HEIs and incorporates qualitative and quantitative data drawn from the UK Teaching Excellence Framework (TEF) to capture the effects from teaching quality and the graduate employment outcomes.
	Yang et al, 'Measuring the inefficiency of Chinese research universities based on a two-stage network DEA model'	The study investigates the inefficiency and productivity of Chinese research universities.
	Guijarro, 'Assessing the Efficiency of Public Universities through DEA. A Case Study'	Efficiency study of Colombian public universities in 2012
	Shamohammadi, 'Measuring the efficiency changes of private universities of Korea: A two-stage network data envelopment analysis'	This study investigated trends in the teaching and research performance of Korean private universities.
	Tavares et al, 'A proposed multistage evaluation approach for Higher Education Institutions based on network Data envelopment analysis: A Brazilian experience'	A network DEA approach is proposed for higher education efficiency evaluation.
Macro level	Koçak et al, 'Efficiency Measurement with Network DEA: An Application to Sustainable Development Goals 4'	The study examines the efficiency of educational systems in OECD countries, considering their characteristics related to SDGs.

Level	Author, title	Content
	Yi-Chun Lin, Ming-Miin Yu, 'Performance evaluation of compulsory education system in Taiwan: A modified dynamic network data envelopment analysis approach'	Examines education efficiency in Taiwan with a modified SBM-DNDEA model.
	Flegl, et al, 'A State-Level Analysis of Mexican Education and Its Impact on Regional, Economic, and Social Development: Two-Stage Network DEA Approach'	This paper examines academic efficiency at primary and secondary levels and the dimensions of human development – including long and healthy life, knowledge, and a decent standard of living – at the state level.

Source: Authors' work

3. Research methodology

Data Envelopment Analysis (DEA) began as a theoretical framework and became used in a wide range of applications. DEA is a method that measures the relative efficiency of decision-making units. The main strength of this methodology is its ability to capture the interplay between multiple inputs and outputs. One of the limitations of these models is that they do not consider the internal structure of decision-making units. The network DEA model was developed to take into account the internal structure of DMUs using link variables. It accounts for both the efficiency of a system and the system's interrelated substages.

This study utilizes the relational network DEA model, which consists of a series of three substages under the assumption of constant return to scale and output orientation. The goal is to increase output rather than reduce inputs, revealing that the output-oriented model is the appropriate tool for enhancing efficiency in the educational economy. The overall efficiency of the entire education system is the result of the individual efficiency attributed to primary, secondary, and tertiary education. This emphasizes the interconnection between the three processes within the global system. It allows for the evaluation of the entire education system as well as the evaluation of its components at the same time. This breakdown enables the identification of the subsystem responsible for the inefficiency of the entire educational system and considers it as a potential source of improvement in the future.

The data used are taken from the OECD database, and the World Bank for the year 2022 for the 27 EU states. The DMUs are the 27 European states. Three categories of variables are used for the model, namely input variables (x1, x2, x3), intermediate variables (z1, z2), and output variables (y1).

The input variables are:

- (x1) Government expenditure per pupil, primary (% of GDP per capita).
- (x2) Government expenditure per pupil, secondary (% of GDP) 2022
- (x3) Government expenditure per pupil, tertiary (% of GDP per capita) 2022

Government expenditure per student refers to the average general government expenditure (including current, capital, and transfers) per student at a particular education level, presented as a percentage of GDP per capita. The two intermediate variables used to link primary, secondary, and tertiary education are:

- (z1) Pisa science performance (mean): measures the scientific literacy of a 15-year-old. Scientific literacy is the ability to utilize scientific knowledge to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions about science-related issues.
- (z2) Employment rate for upper secondary level

The output variable of the tertiary education subsystem but also the entire educational system is:

- (y1) The employment rate for tertiary level

This indicator displays employment rates based on different education levels: below upper secondary, upper secondary non-tertiary, or tertiary. The employment rate is calculated as the percentage of working-age people who are currently employed. The employed are defined as individuals who work for pay or profit for at least one hour per week, or those who have a job but are temporarily not working due to illness, leave, or industrial action. This indicator calculates the proportion of employed individuals aged 25-64 out of all individuals aged 25-64.

4. Findings

In terms of efficiency evaluation, the efficiency scores of the entire education system (Ek) and individual stages (Ek(1), Ek(2), and Ek(3) are shown in Table 2 and Figure 1. None of the 27 European states performs efficiently in the three stages, therefore, none is characterized by an overall efficient education system. The overall efficiency of E_k is the product of the three stages efficiency $E_{k1,}$ $E_{k2,}$ and E_{k3}, every E_k is lower than its corresponding $E_{k1,}$ $E_{k2,}$ and $E_{k3.}$

As regards the overall efficiency of the education system, it is noticed that Romania shows the highest efficiency with a score of 0.9641. The second, third, and fourth ranks are Bulgaria, Ireland, and Hungary with efficiency scores of 0.899202, 0.75565, and 0.732027 respectively. Ten of the analyzed countries (Romania, Bulgaria, Ireland, Hungary, Lithuania, Greece, Slovakia, Finland, Czechia, and Germany) are above the average efficiency score.

The overall efficiency and superiority of education in Romania can be explained by several factors, even though education expenditures have been among the lowest in Europe. The efficiency and superiority of the education system in Romania can be attributed to high academic standards, qualified educators, cultural values, supplementary education, a competitive environment, resource efficiency, policy reforms, and strong parental involvement. These factors collectively contribute to a robust educational framework, even with relatively low financial expenditures.

In the first stage of evaluating the efficiency of primary education, Romania stands out as the only country that performs efficiently. Twelve countries are above average in efficiency, namely Bulgaria, Ireland, Hungary, Lithuania, Finland, Czechia, Malta, Greece, Slovakia, France, Germany, and Austria. Conversely, fourteen countries fall below the European average in terms of primary education efficiency. This assessment highlights Romania's unique position in achieving efficient primary education outcomes despite financial constraints. The comparative efficiency of other countries also reflects a diverse range of educational practices and resource utilizations across Europe. Understanding the factors contributing to Romania's efficiency can provide valuable insights for other nations aiming to enhance their primary education systems.

In the second and third stages of evaluating educational efficiency for secondary and tertiary education, distinct patterns emerge across different countries. In the second stage, which evaluates the efficiency of secondary education, three countries stand out as efficient: Bulgaria, Croatia, and Sweden. These countries have managed to optimize their educational systems to achieve high performance and outcomes at the secondary level. In the third stage, focusing on tertiary education efficiency, three different countries are noted for their efficiency: Romania, Italy, and Luxembourg. These countries excel in optimizing resources and outcomes at the tertiary education level, ensuring effective higher education systems.

These stages of evaluation reflect a nuanced understanding of educational efficiency, highlighting that different countries may excel at different educational levels. Efficiency in secondary and tertiary education involves a combination of factors such as resource allocation, curriculum design, teaching quality, and support systems that vary by educational stage and country.

Another remark to be noted is that most of the countries have a smaller efficiency score in primary education E_{k1} compared to the efficiencies of secondary and tertiary education (E_{k2} and E_{k3}).

By looking at the ranks of the efficiency scores attributed to the 27 countries, we remark that some of the countries have similar ranks in $E_{k1,}$ $E_{k2,}$ and $E_{k3.}$ for example Romania, Bulgaria, Ireland, Hungary, and Lithuania, This means that the overall performance of the whole education supply chain is attributed to the performance of its three stages. (primary, secondary, and tertiary education).

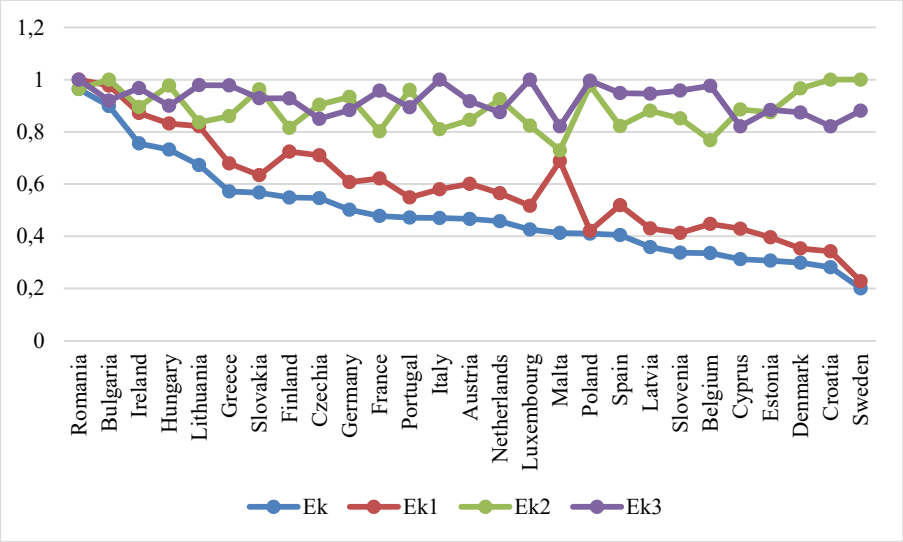
It is also clearly noticed from the ranking results of the efficiency scores and Figure no. 2, a high similarity between the ranks of E_k and E_{k1} for all analyzed countries. This means that an important part of the inefficiency of the whole education system in these countries is explained by the inefficiency of primary education.

Table no. 2. Efficiency scores

Country	E_k	E_{k1}	E_{k2}	E_{k3}
Romania	0.9641	1	0.9641	1
Bulgaria	0.899202	0.9775	1	0.9199
Ireland	0.755665	0.8722	0.8954	0.9676
Hungary	0.732027	0.832	0.9776	0.9
Lithuania	0.67315	0.8219	0.8365	0.9791
Greece	0.571688	0.6794	0.8603	0.9781
Slovakia	0.567252	0.634	0.9631	0.929
Finland	0.548485	0.7243	0.8154	0.9287
Czechia	0.546088	0.7102	0.9044	0.8502
Germany*	0.501333	0.6074	0.934	0.8837
France*	0.477659	0.6218	0.8022	0.9576
Portugal*	0.471328	0.5486	0.9608	0.8942
Italy	0.469939	0.5801	0.8101	1
Austria	0.466417	0.6009	0.8459	0.9176
Netherlands	0.457659	0.5652	0.9253	0.8751
Luxembourg	0.425792	0.5168	0.8239	1
Malta	0.412437	0.6883	0.7295	0.8214
Poland	0.40995	0.4209	0.9777	0.9962
Spain*	0.404873	0.5191	0.8223	0.9485
Latvia	0.358639	0.4299	0.8813	0.9466
Slovenia	0.336958	0.4129	0.8515	0.9584
Belgium*	0.335216	0.4471	0.7678	0.9765
Cyprus	0.312136	0.4289	0.886	0.8214
Estonia	0.306291	0.3958	0.8753	0.8841
Denmark	0.298489	0.3532	0.9666	0.8743
Croatia	0.281083	0.3422	1	0.8214
Sweden	0.200516	0.2276	1	0.881

Source: Authors' calculation based on OECD and The World Bank's databases

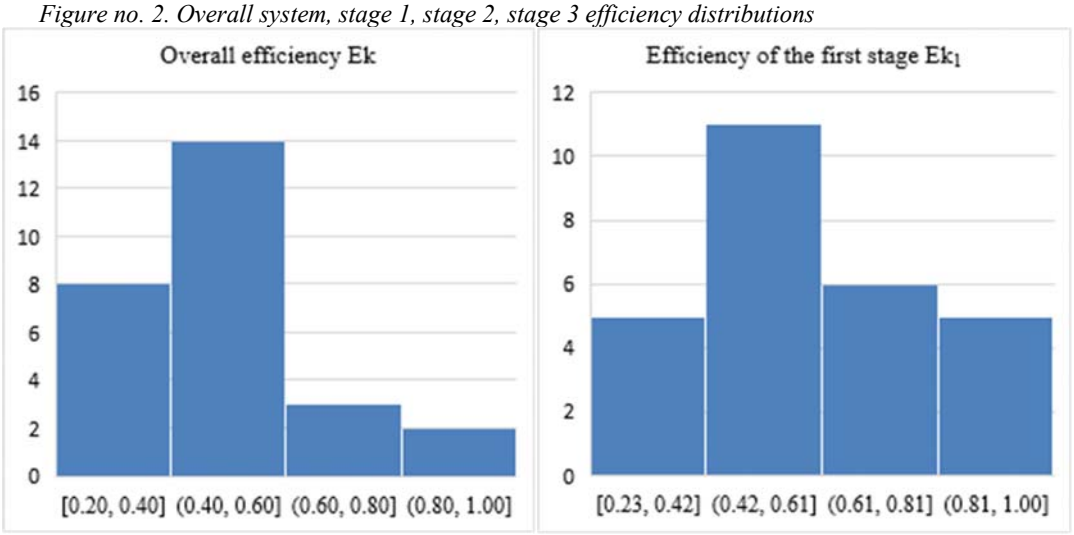
Figure no. 1. Variation curves of Ek, Ek_1, Ek_2, Ek_3

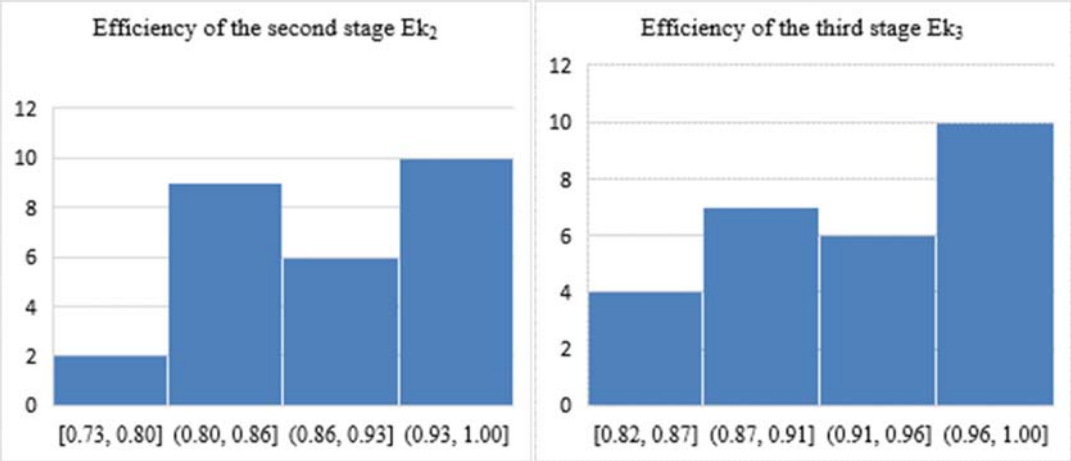


Source: Author representation of the data

The distribution of the efficiency scores for the overall education system, stage 1, stage 2, and stage 3 is provided in Fig.2. For the whole education system, one can observe that none of the countries is overall efficient. This result is not rare with network DEA. (Ramzi, 2019). More than half of the countries have overall efficiency scores less than the average 0.48. This result is mainly due to the inefficiency in the first stage.

Figure no. 2. Overall system, stage 1, stage 2, stage 3 efficiency distributions





Source: Author representation of the data

5. Conclusions

Although education is considered one of the earliest areas in which DEA was applied, little has been done to model an education supply chain using network DEA. This paper assesses the efficiency of 27 European Union states educational supply chains using the relational network DEA. The education system is subdivided into three interrelated substages (primary education, secondary education, and tertiary education). The overall efficiency of the entire education system can be understood as the product of the individual efficiencies attributed to primary, secondary, and tertiary education levels. This highlights the interconnection between these three stages within the global system, enabling a comprehensive evaluation of the whole education system while also assessing each component individually.

These stages of evaluation reflect a nuanced understanding of educational efficiency, highlighting that different countries may excel at different educational levels. Efficiency in secondary and tertiary education involves a combination of factors such as resource allocation, curriculum design, teaching quality, and support systems that vary by educational stage and country.

The overall efficiency and superiority of education in Romania can be explained by the fact that education expenditures, inputs of the system have been among the lowest in Europe and the outputs were maximized. The efficiency and superiority of the education system in Romania can be also attributed to high academic standards, qualified educators, cultural values, supplementary education, a competitive environment, resource efficiency, policy reforms, and strong parental involvement. These factors collectively contribute to a robust educational framework, even with relatively low financial expenditures.

The estimation results of the efficiency scores demonstrate that most of the countries have similar ranks in the three stages. This result proves that the performance improvement of the educational supply chain is achieved by the development and interconnectedness of primary, secondary, and tertiary education.

It is essential to enhance the alignment of primary, secondary, and tertiary education to ensure that students are adequately prepared at each educational stage, leading to seamless transitions and success throughout their academic journeys.

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