

## DATA ENVELOPMENT ANALYSIS OF HIGHER EDUCATION PUBLIC EXPENDITURE EFFICIENCY: A SYSTEMATIC REVIEW

By Kenichi Kagatani

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Supervisor: Kata Orosz

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Signature: Kenichi Kagatani

## Abstract

This current study provides the first systematic review in the literature applying Data Envelopment Analysis (DEA) to measure the efficiency of public spending on Higher Education (HE). First, this paper explores different concepts of efficiency and DEA's history, assumptions, types, and advantages /disadvantages regarding its application in HE. Next, it looks at past systematic reviews on institutional-level DEA studies and concludes that none of them measures efficiency in HE at the national-level. Afterward, based on a systematic review of 11 national-level DEA studies published between 2005 and 2019, it documents the overview of used variables, techniques, challenges, and results. The findings reveal that the selected studies face a lack of consensus regarding variables and methodological difficulties, which causes biases in their results. Finally, it offers a conceptual framework and recommendations to help researchers and policymakers mitigate the biases and better measure, interpret, and improve the national-level efficiency in higher education.

#### Keywords: review, DEA, efficiency, higher education, public spending

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## List of Abbreviations

Abbreviation	Definition
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMUs	Decision-Making Units
EMIS	Education Management Information Systems
ERIC	Educational Resources Information Center
EU	European Union
GDP	Gross Domestic Product
HE	Higher Education
HEIs	Higher Education Institutions
IGOs	Intergovernmental Organizations
KS	Knowledge Society
OECD	Organization for Economic Co-operation and Development
OVB	Omitted Variable Bias
SFA	Stochastic Frontier Analysis
SSE	Slack-based Super Efficiency
VRS	Variable Returns to Scale

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## Introduction

Higher Education (HE), the final stage of formal learning, is an inevitable part of the Knowledge Society. Together with the introduction of the Knowledge Society, which aims to create a scientific and technological community, measuring the efficiency of Higher Education became increasingly important.

After World War II, the manufacturing-based economy was changed by the knowledgebased economy. From then on till now, goods and services have been mainly produced through knowledge-intensive activities. (Jessop 2017). To meet the increased global competition and rapid technological change, the Knowledge Society (KS) policy discourse has required Higher Education to produce highly skilled individuals with specialized knowledge (Drucker 1994). To meet the demands of attracting the best talent and strengthening research excellence, universities require adequate and sustainable funding (European Commission 2003). However, increasing public funds, one of the possible HE funding sources, will not be enough and sustainable. Therefore, many nations, including the United States (US), Japan, and the Member States of the European Union (EU), have begun to seek how to improve the efficiency of public spending on HE.

When considering the challenges of HE, the COVID-19 pandemic has accelerated the growing literature on the efficiency of HE. The pandemic negatively impacted HE through school closures, students' productivity loss, and ultimately, slower economic growth, leading to a 1.5% loss of future GDP (Eric and Woessmann 2020). Alleviating the pandemic impacts requires a continued public expenditure on HE, including spending on educational Information and Communications Technology (ICT) resources. However, according to the Organization for Economic Co-operation and Development (OECD) report (2020), economic stagnation followed by the pandemic is reducing public spending on HE as funds are delivered to the health

sector and other economic measures. Therefore, the pandemic reinforces the importance of the study on how governments can distribute limited public spending on HE efficiently, generating better outcomes without increasing expenditures. Even though various scholars conducted research in this field, a rapid increase in studies of education efficiency led to a lack of consensus regarding variables and techniques applied in the most used method: Data Envelopment Analysis (DEA). Moreover, DEA studies face many methodological challenges causing bias in their results.

Thus, this research aims to provide an overview of the DEA-related techniques, findings, and challenges based on a systematic review of DEA literature evaluating the efficiency of public spending on HE. The research offers not only a summary of DEA studies but also a comprehensive conceptual framework to help future researchers and policymakers understand key variables and strategies to mitigate the biases when measuring, interpreting, and improving the government-level efficiency in HE.

## **Conceptual Framework**

#### What is Efficiency?

Efficiency comes from the discipline of economics and plays a vital role in the context of public management, especially for educational activities. Education is labor-intensive, and technological innovation cannot fill the gap between infinite educational demands and finite resources. Thus, this gap needs to be solved by improving the efficiency of resource allocation (Hashino 2013). Education efficiency is based on education production function theory which explains the relationship between inputs and outputs of the educational process (Hanushek 2007). According to the theory, increasing school inputs can have moderate impacts on achievement (cognitive, social, and physical). However, the theory also tells that how much outputs you can gain given the inputs depends on the efficiency of resource allocation. Therefore, a more efficient organization/country can produce more outcomes within the same level of inputs or reduce the number of resources to produce the same level of outputs (Witte 2017). The standard inputs used in educational activities are public expenditures, the number of students and professors, and the teaching experience. On the other hand, the outputs often include enrollment rates, graduation rates, average test scores, and a number of publications. (Witte 2017).

There is widespread confusion regarding the differences between effectiveness and efficiency. Effectiveness refers to doing the right thing, namely, creating the desired outcome (Lockheed 2006). Achieving the effectiveness of public education expenditure means that a nation produces a socially optimal level of various educational outcomes. On the other hand, efficiency means doing things right; desired outcomes are generated without increasing costs, or higher outputs are produced with the same level of inputs (Lockheed 2006). Thus, improving the efficiency of public spending on education means that a nation provides higher educational

outputs (e.g., completion rates or test scores) within the same level of resources compared to other countries. This paper considers the efficiency side of public spending. The concept of efficiency tends to get more attention from policymakers than effectiveness as they aim to provide more impacts within a limited budget (Mehdi 2016). Speaking about the research on efficiency, the total number of studies on education efficiency is 10,300, and it has been dramatically growing in recent years (Mehdi 2016). However, policymakers/researchers lack a shared understanding of the efficiency concept due to its diverse contents and implications. Therefore, before exploring the literature on education efficiency, this paper first offers the conceptual basement for clarifying efficiency in the context of education.

While the concepts of efficiency are complex and elusive, some researchers have tried to organize the types of efficiency discussed so far in the educational literature. Hashino (2013) categorizes the four concepts of efficiency: *saving, standardization, technical, and allocative efficiency. Saving efficiency* is discussed in the literature of American educational administration studies in the first half of the twentieth century. At that time, the American education system faced the issue of high educational costs due to rapid increases in school numbers and enrolment rates. Embracing scientific management methods, the educational administration literature considers efficiency as cost-saving in dealing with financial issues. *Standardization efficiency* holds the elements of rationalizing and modernizing schoolwork based on scientific management methods. Thus, the pursuit of standardization efficiency is a technical terminology that extends the primitive efficiency definition of input-output ratio and has been accepted in education policy research since the 1980s.

Kosor (2013) also explains efficiency using 4 categories: technical, allocative, price, and exchange. *Technical efficiency* investigates the resources and time applied to produce a certain output level. *Price efficiency*, the extended idea of technical efficiency, takes account of the relative prices of inputs. In addition, *exchange efficiency* examines to what extent education provides positive external impacts on economy and society. Lastly, *allocative efficiency* examines how a particular output level is achieved with the best combination of inputs, given the prices of the inputs. Thus, it seeks to maximize outputs within a certain level of input.

There are some differences and similarities among the six concepts of efficiency explained above. Hashino (2013) argues that the significant difference is whether efficiency is an objective itself or a criterion for achieving an objective. The concepts of saving efficiency lie in the former because the concept functions as the end purpose, often contrasting with adequate budget allocation. On the other hand, standardization, technical, and allocative efficiency belong to the latter. For example, technical and allocative efficiency can be regarded as a criterion for achieving the objectives, such as a higher enrolment rate, because these concepts ask how a high enrollment rate can be performed under limited resources. Hashino (2013) also introduces the difference about whether efficiency assessment includes comparisons among options (which options are efficient in achieving certain objectives) or among organizations (which organizations manage efficiently). While all the concepts can belong to both kinds of assessments, technical and allocative efficiency are used mostly for comparisons among organizations. In terms of similarities, Kosor (2013) says that allocative efficiency encompasses the meaning of exchange efficiency as it examines educational outcomes, including positive external impacts on markets and society. In addition, the technical efficiency and price efficiency are considered similar/same in education studies because price efficiency is an extended version of the technical one with the consideration of relative price.

While there are various efficiency concepts, many researchers confirm that technical and allocative efficiency are the most dominant concepts in education literature. For example, Zimmer (2002) considers technical efficiency as to what extent academic achievement can be improved without increasing costs or how much cost can be reduced without deteriorating outcomes. Thus, the technical efficiency defined by Zimmer (2002) is very similar to the definition by Hashino (2013) and Kosor (2013). Regarding allocative efficiency, Zimmer (2002) thinks it is essential to choose the optimal combination of inputs to minimize the production cost, which is slightly different from the definition by Kosor (2013) as Blank's definition focuses on the cost aspects without considering the external benefits. On the other hand, Hoxby (1996) and Barr (2000) have a similar definition of allocative efficiency to that of Kosor (2013). They consider the positive externality, defining allocative efficiency as the achievement of the equilibrium between the marginal social cost and the marginal social benefit.

Although technical and allocative efficiency definitions differ slightly among researchers, most of the definitions can be traced back to the conceptual framework developed by Farrell (1957) in his article, 'The Measurement of Productive Efficiency.' He provides a clear definition of efficiency in the social sciences by extending the primitive efficiency definition of the input-output ratio. According to him, technical efficiency can be divided into input-oriented and output-oriented. The former is interested in minimizing input to achieve a given output level, while the latter tries to maximize output under a given input level. On the other hand, allocative efficiency seeks the optimal combination of inputs to minimize the production cost given the prices of the inputs. Therefore, the efficiency concept indicated by Farrell (1957), consisting of technical and allocative efficiency, provides the fundamental base to address what efficiency means in the context of education.

To sum up, this section introduces many efficiency concepts and analyzes definitions of the most dominant concepts in education, technical and allocative efficiency. It is found that these definitions slightly differ among researchers, but most of them can be related to the original concept presented by Farrell (1957). Thus, this paper treats Farrell's definition of efficiency as the general terminology in education literature.

While efficiency is often discussed in the social science field, this paper should acknowledge the general difficulties of analyzing efficiency in (higher) education. First, education has no clear set of outcomes (Cooze 1991). It has diverse purposes, including cognitive skills, socialization, and critical thinking, causing a lot of direct and indirect impacts on individuals, the economy, and society. Thus, it does not have a "single well-defined indicator of output" (Cooze 1991). Moreover, many educational outputs cannot be quantifiable in market prices, including personality growth, civic responsibility, teacher quality, and student creativity (Lockheed 2006). Simply measuring quantifiable outputs, such as enrollment rate and test scores, may fail to assess the actual efficiency of public spending on education. For example, some nations focus on expanding the enrollment rate of higher education, neglecting the education quality aspect. On the other hand, other countries prioritize using funding for improving teaching and research quality which often cannot be quantified. Thus, efficiency analysis results will differ depending on the choice and availability of educational outputs. Especially in the case of higher education, the lack of available information imposes a critical issue (Lockheed 2006). For example, higher education does not have standardized tests, unlike primary and secondary education, as HE contains diverse subjects and purposes. Thus, assessing the learning outcomes as output is difficult, leading to the oversimplified efficiency analysis. The misleading results of efficiency analysis can make policymakers neglect/overemphasize investment in a particular aspect of higher education. Therefore, policymakers should take a holistic approach based on both econometrics and qualitative studies to analyze the efficiency to make appropriate educational policies.

#### What is Data Envelopment Analysis?

There has been significant development in the techniques to estimate efficiency in education despite the difficulties of efficiency analysis. The most popular methods are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). According to Hashino (2013), the DEA and SFA were developed from the concept of efficiency by Farrell (1957) and remain the standard methods for measuring and analyzing efficiency until today. DEA takes "a non-parametric linear programming technique to compute a technical efficient production frontier formed by the most efficient units" (Bollou 2006, 2). On the other hand, SFA applies "the parametric regression-based approach to estimate the parameters of a specific functional form for the production or cost frontier" (Ferro 2020, 143). This paper focuses on DEA since it is more widely used in education efficiency studies than SFA as it has less strict assumptions, which is more appropriate in the context of (higher) education. According to Rhaiem (2017), 83% of selected studies on education efficiency evaluation apply DEA instead of SFA.

DEA was developed by Charnes, Cooper, and Rhodes (1978) to meet the political demand for the empirical analysis of efficiency in the field of public policies, including higher education. In the 1970s, the Coleman Report, a well-known study published by the US Government in 1966, denied the policy effects of schooling. In response to the controversial argument from the report, several educational production function studies in the 1970s tried to analyze the relationship between educational policy and educational outcomes quantitatively. Still, they did not necessarily produce consistent findings on the effects of policy inputs (Hashino 2013). Due to the inconsistency of results, policymakers began to demand more solid and empirical techniques to measure the efficiency in education, leading to the DEA establishment (Hashino 2013). Since its embryonic phase in the 1970s, the initial DEA model has undergone several developmental extensions to reflect realistic assumptions, becoming the most popular approach in education efficiency measurement (Hashino 2013). Therefore, the

conceptual establishment by Farrell (1957) and the methodological development of DEA by Charnes (1978) prompted a flurry of empirical analyses of efficiency in education policy research in the West, particularly in the USA, from the 1980s onwards.

The DEA is a mathematical multifactor technique to measure the relative efficiency of any number of decision-making units (DMUs), such as countries, companies, and organizations (Al-Bagoury 2018). DEA applies "a non-parametric linear programming technique to compute a technical efficient production frontier formed by the most efficient units" (Bollou 2006, 2). It can offer the relative technical efficiency score of each DMU by calculating the input-output data and the distance of each production unit to the efficient frontier made by the best practice DMUs. The score "reflects its ability to produce maximum output attainable from a given set of inputs" (Bollou 2006, 3). The score value ranges from 0-1.00, where 1.00 signifies the most efficient DMU on the frontier, compared to other inefficiently selected DMUs under the frontier (Figure 1).



Figure 1 Efficient Production Frontier (Wong 2010)

Several DEA types exist, such as output or input-oriented approaches with different returns to scale models. The input-oriented approach asks how much inputs can be reduced to produce the same level of outputs. It assumes that "for the public sector, it is easier to control the inputs than the outputs, which are also hardly measurable" (Ahec et al. 2018, 6). On the other hand, the output-oriented approach examines how much outputs can be increased within the same level of inputs. It assumes that the "government should maximize output in each sector given a fixed amount of input expenditure" (Fonchamnyo et al. 2016, 203). If an input-oriented approach shows that a country is inefficient, the country is also inefficient from an outputoriented perspective. Many education policymakers find the output-oriented approach more relevant because society demands more educational outputs while financial deficit makes it challenging to increase inputs (Commonwealth of Australia 1997). As for returns to scale, Constant Returns to Scale (CRS) predicts that "output will change by the same proportion as inputs are changed" (Marakkath 2013, 20). Variable Returns to Scale (VRS), on the other hand, assumes that "one unit of input can result in output ranging from less than one unit to more than one unit" (Bollou 2006, 3). If the size of the decision-making units has a vital role in producing outputs, VRS is more appropriate than CRS. This is because less restrictive assumptions of VRS can deal with the different scales of countries/organizations when calculating the efficiency scores (Commonwealth of Australia 1997).

DEA contains a relaxed set of assumptions that researchers must be aware of. It embraces a deterministic method instead of a statistical technical method, meaning that DEA is susceptible to measurement errors (Commonwealth of Australia 1997). While the parametric regression-based approach, such as SFA, tries to control the effect of outliers by the error term in the estimation, non-parametric DEA does not have an error term and lets outliers affect all other organizations equally (Commonwealth of Australia 1997). For example, if one nation has a highly overrated/underrated completion rate of higher education, the outliers will dramatically change the shape of the frontier and improve/reduce the efficiency scores of other nations. Therefore, researchers need to check the existence of outliers in the collected data before applying DEA.

DEA's less restrictive assumptions are also sensitive to Omitted Variable Bias (OVB). DEA can only show the correlation between inputs and outputs, not the causal relationship, as it cannot control unobserved confounding variables (Witte 2017). OVB happens when uncontrolled observed /unobserved confounding variables affect independent and dependent variables. Most education studies with the application of DEA tend to be susceptible to this OVB due to three reasons. First, DEA in education literature often suffers from the curse of dimensionality as they cannot gather many observations necessary for a large number of inputs and outputs (Witte 2017). Second, DEA cannot include many omitted variables due to its computational burden as the non-parametric DEA models "let the data speak for themselves" (Witte 2017, 15). Lastly, the education dataset used in DEA cannot control adequate variables as there are too many environmental factors, which are often unavailable, in the context of education (Witte 2017). Therefore, policymakers should encourage holistic data collection in education to enable DEA to control observed heterogeneity as much as possible to avoid OVB and provide more accurate results.

Despite these limitations, DEA is an appropriate technique to measure efficiency in education because of its many advantages. For example, DEA can incorporate multiple possible inputs and outputs compared to "other statistical efficiency measurement methods" (Bollou 2006). DEA's ability to include various variables is particularly beneficial in education as there are diverse sets of educational inputs/outcomes. Furthermore, thanks to the non-parametric aspect, DEA does not need to provide a solid presupposition regarding normal distribution in the data and, thus, can accommodate wide-ranging behaviors (Commonwealth of Australia 1997). Providing strong assumptions about the production technology and efficiency

distribution is also unnecessary. In other words, "it does not necessarily require relating inputs to outputs" (Fonchamnyo et al. 2016, 203). Moreover, it only needs quantitative information on outputs and inputs without requiring the price of variables (Commonwealth of Australia 1997). On the other hand, SFA requires a stringent parametric form, relatively complete price data, and distributional assumptions that are difficult to be met in educational research due to the lack of available data (Commonwealth of Australia 1997). Therefore, compared to the parametric approach, the fact that DEA is imposing fewer data restrictions is especially suitable for estimating education efficiency because the educational field often has multiple variables, unclear input-output relationships, and unmonetizable inputs/outputs.

DEA can also show the technical efficiency scores of public education spending, giving policymakers beneficial information. As defined above, technical efficiency examines the Decision-Making Units (DMUs) success in minimizing inputs for a given set of outputs or maximizing outputs from a given set of inputs (Farrell 1957). Input-oriented DEA model can calculate the former part of technical efficiency, allowing the policymakers to determine whether they should reexamine their investment in education policies or not (Farrell 1957). An output-oriented DEA model shows the latter part, enabling policymakers to assess their countries with the most efficient nation and decide if they should formulate alternative development policies to achieve higher efficiency. Moreover, DEA can discompose the technical efficiency into "scale effects, the effects of unwanted inputs which the agency cannot dispose of, and a residual component" (Commonwealth of Australia 1997, 21). The allocative efficiency DEA model can also investigate the DMU's success in choosing the best combination of inputs to achieve cost minimization. However, DEA education studies usually do not measure allocative efficiency due to the lack of monetizable variables (Watkins 2014). Therefore, DEA can provide insightful information for education policymakers by revealing the technical efficiency scores of their budget allocation.

There are several complicated ways to present DEA's equation, depending on assumptions and types of DEA model (Commonwealth of Australia 1997). However, most DEA studies involve the most straightforward general formula explained below. The assumptions of the formula contain Variable Returns to Scale (VRS) and the goal of maximizing outputs from a given set of inputs (output-oriented model).

maximize  $\boldsymbol{\theta}_{n}$  with respect to  $\lambda_{1}, \dots, \lambda_{n}, \theta_{n}$ 

Subject to:

$$\sum_{j=1}^{n} \lambda_j X_{ij} \le X_{i0}; i = 1, 2, 3, \dots, m$$
$$\sum_{r=1}^{n} \lambda_j Y_{rj} \ge \theta Y_{r0}; r = 1, 2, 3, \dots, s$$
$$\sum_{j=1}^{n} \lambda_j = 1$$
$$\lambda_i \ge 0, j = 1, 2, \dots, n$$

The model signifies  $\theta$  efficiency scores, *m* inputs, and *s* outputs for *n* Decision-Making Units (e.g., countries).  $n_0$  represents one of the n countries under evaluation, and  $x_{i0}$  and  $y_{i0}$ stand for the *i*-th input and *r*-th output of the country  $n_0$ .  $\lambda$  is "an *n*-dimensional vector of constants that measures the weights used to compute the location of an inefficient country (DMU) if it were to become efficient" (Fonchamnyo et al. 2014, 204). The formula tells that the efficiency score for each DMU needs to be maximized subject to several constraints. When the n<sup>th</sup> linear program is calculated, these weights can decide the most productive way to maximize country n's outputs (Commonwealth of Australia 1997). The relative efficiency score of country n's,  $\theta_n$ , will be the largest number meeting the three sets of constraints formulated above (Commonwealth of Australia 1997). This process of answering the programing problem repeats N times for each observation n until DEA measures the efficiency scores of all the observations. As mentioned above, if  $\theta = 1.00$ , the country is considered the most efficient located on the efficiency frontier, whereas  $\theta < 1.00$  means inefficient governments under the frontier (Fonchamnyo et al. 2014). By solving the above mathematical programming formula, DEA can present optimal input/output and potential improvements in output given set of inputs and illustrate one nation's education current states regarding efficiency.

Finally, the different extensions and advancements of the DEA technique enable researchers to improve its accuracy of efficiency analysis. The two-step DEA procedure is used to identify influential factors in efficiency calculated by the first-step DEA (Agasisti 2009). It applies the Tobit estimation technique to regress the efficiency scores of each DMU against environmental factors (Agasisti 2009). Compared to traditional ordinary least-squares estimation, Tobit regression is more appropriate because the efficiency score lies in a value between 0 and 1 and does not present normal distribution (Agasisti 2009; Fonchamnyo et al. 2014). Moreover, the Tobit model assumes that the inputs used in the first step-DEA and determinants in the second step should be uncorrelated (Agasisti 2009). The widely used determinants for education efficiency are GDP growth, corruption, and financial management at the national level and gender, age, and parental education at the intuitional/individual level (Ferro 2020). The main advantage of the two-step DEA procedure is that statistical tests can be applied to understand the direction and strengths of the relationship between efficiency level and environmental factors (Commonwealth of Australia 1997). Therefore, the two-step DEA procedure can identify the most influential determinants for efficiency and offer evidence-based action plans to improve one nation's education system.

## **Measuring Efficiency of Education: A Review of Literature**

This section outlines the literature review on DEA studies evaluating HE efficiency. First, it looks at university-level DEA studies comparing the efficiency of universities in multiple or single nations. Then, it examines the past systematic literature review summarizing DEA studies in terms of their used variables, techniques, and pros/cons.

The methodological development of DEA led to a wave of empirical analyses of efficiency in education policy research. While there are different types of DEA studies in the educational field, the most used Decision-Making Units (DMUs) in the DEA studies are institutions (i.e., universities) (Rhaiem 2016). Many DEA university-level studies compare the efficiency of universities in more than one nation. For instance, Agasisti, Tommaso, and Johnes (2009) investigates the technical efficiency of universities in Italy and the United Kingdom (UK) and show that UK universities utilize their resources more efficiently than Italian universities. They also conduct the two-step procedure using Tobit regression to identify influential factors in the calculated efficiency scores. They conclude that the science industries' employment rate in the surrounding university area is positively associated with efficiency. Wolszczak-Derlacz and Parteka (2011) also examine 259 universities in European nations by using the two-step DEA. Scholars show that the number of different departments and the number of female academic staff are the most influential positive factors of inefficiency.

Unlike the university-level study comparing multiple nations, some researchers focus on universities within the same country. For example, Johnes (2006) investigates the technical efficiency scores of universities in England by using total operating cost as input and the number of undergraduates, competitive-based grants, and income from other services as outputs. They find that many universities can increase the number of undergraduates by 20-27% without increasing operational costs, showing the space for improvement. Nazarko, Joanicjusz, and Jonas Šaparauskas (2014) also employ DEA to investigate Polish universities' efficiency levels. They use the number of academic staff and government grants as input and the percentage of students with university scholarships and employer references for hiring alumni as outputs. Through the two-step procedure, they also find that the population size of the surrounding city of the university is positively associated with efficiency. On the other hand, the percentage of students with need-based financial aid is negatively related to efficiency. It should be noted that there is confusion in used inputs and outputs among DEA studies. For instance, Johnes (2006) considers public grants as output, while Nazarko (2014) uses them as input. Nazarko (2014) also fails to address the strong association between determinants of efficiency and output regarding students with scholarships, which may cause bias in the efficiency scores.

To sum up, many past DEA studies calculate the efficiency scores of HE in single or multiple nations at the university level. Their results tell university managers/policymakers if they should formulate alternative policies to achieve higher efficiency in tertiary education. Most studies also apply a two-step procedure to examine the influential determinants of inefficiency, which can help university managers/policymakers identify the areas they should prioritize to invest for a more efficient environment.

In response to a growing literature on the efficiency of education with the application of DEA, some literature reviews offer an overview of various approaches and their results. Gralka (2018) and Ferro (2020) provide a systematic review of the literature applying DEA and SFA to assess higher education institutions' efficiency, highlighting the methodologies' advantages and disadvantages. Ferro (2020) identifies the frequently used variables in university-level DEA studies. The most commonly used inputs are the number of students and academic staff, the number of non-human resources, such as computers, and their operational costs. On the other hand, the most common outputs are degrees (teaching outcomes), publications, and patents. Finally, most applied determinants include students' intellectual, economic, and social backgrounds. Worthington (2001) also provides an empirical survey of a few studies applying DEA to measure the efficiency of education and determinants of efficiency at the institutional level. He introduces the limitation of university-level DEA studies in controlling adequate inputs and outputs of university performance, such as cognitive skills and critical thinking. In addition, Worthington emphasizes the importance of investigating the explaining factors of efficiency, such as parental socioeconomic situations, by using the two-step procedure because a lot of evidence shows that these determinants strongly affect educational achievement. However, he warns that some studies employing the two-step procedure fail to avoid the strong correlation between inputs and determinants of efficiency, which leads to the bias of the DEA efficiency scores because these scores would reflect both inputs and environmental factors.

Witte and López-Torres (2017) also provide an overview of applied variables and techniques to measure efficiency at the university level. They reveal that many studies fail to identify and include important determinants of efficiency in two-step DEA procedures, which may result in the omitted variables bias. Similar to Worthington (2001), they also point out that many researchers fail to differentiate inputs from determinants, leading to the issue of a strong correlation between inputs and determinants. For example, some studies use attendance rate and public grants as inputs, but others include them in the determinants. Policymakers must be careful of this inconsistency when interpreting the DEA efficiency scores and the second step's results, as they could be biased. They explain how past studies try to overcome these issues by applying techniques like bootstrapping, robust conditional estimators, and Malmquist Index.

Rhaiem (2016) also reviews the 102 studies that apply DEA to investigate the efficiency of universities at the institutional level. He emphasizes the importance of creating a framework that can help researchers make a better and more consistent choice of inputs, outputs, and determinants for efficiency in DEA. The framework will lead to the accumulation of consistent results from many DEA studies, which finally helps university administrators and policymakers to identify the specific areas they should invest in to develop more efficient universities.

To sum up, the already conducted systematic reviews summarize DEA studies in terms of their used variables, techniques, and pros/cons. They also provide some recommendations to improve the DEA's two-step procedures. However, they only focus on the institutional-level studies using universities as Decision-Making Units for efficiency analysis, while excluding the country-level studies employing governments as DMUs.

## Methodology

While most systematic literature reviews analyze studies measuring the efficiency of higher education at the institutional level, none of them systematically review the country-level studies measuring the public spending efficiency on higher education. Summarizing the literature on higher education efficiency at the country level is crucial to help policymakers compare their nations with other best countries and efficiently invest in their higher education system. Moreover, although the literature review pointed out the limitations of the two-step DEA and some techniques, no review gives specific investigations into the second stage regression regarding its variables and techniques to overcome the limitations. As the two-step DEA has an essential role in revealing the most influential factors for efficiency, it is vital to spotlight its detailed process and offer suggestions for future research in this field. Therefore, based on the systematic review of 11 national-level DEA studies that investigated the efficiency of public spending on higher education, this paper answers the following questions:

(1) What are the general data characteristics in their studies? (Data sources, targets, sample size, etc.)

(2) Which variables, including inputs, outputs, and determinants of efficiency, were utilized in the DEA literature?

(3) Which DEA-related techniques were employed to reduce bias in the results?

(4) What is the overall pattern of findings in the DEA literature measuring the efficiency of public spending on higher education?

Based on the findings, the paper will provide a comprehensive conceptual framework and recommendations to help future researchers and policymakers less biasedly measure, interpret, and improve the efficiency of public spending on higher education. To answer the above research questions, this paper follows the established method by a past systematic literature review (Gralka 2018; De Witte 2012; Rhaiem 2016). This method takes a rigorous and replicable process, analyses data from different high-quality studies, and synthesizes the review's findings. The method is based on four steps; (1) the formulation of inclusion and exclusion criteria; (2) the identification of relevant studies; (3) the evaluation of the studies; and (4) discussion of the findings.

For the review, I have used two leading search engines: Educational Resources Information Center (ERIC) and Google Scholar. ERIC is the world's largest online educational research database. As "the most-frequently-used index for carrying out educational research" (Craciun and Orosz 2018, 14), it offers a holistic and full-text database of education-related studies for researchers, policymakers, and the public. Google Scholar is also used because it functions as a reliable tool for accessing academic literature and is free and available to all. It contains more than 100 billion materials available, including educational research, enabling scholars to collect the existing data in their expert fields comprehensively.

#### The Formulation of Inclusion and Exclusion Criteria

I have selected and evaluated potential references based on five criteria. First, a study had to be quantitative research written in English, relying on primary and/or secondary data to draw findings. Thus, non-English, conceptual, or theoretical studies were excluded. Second, a study had to be published between 1978 and 2022. 1978 was chosen as the starting point because Charnes (1978) published the seminal paper on DEA. Third, a study also must deal with the efficiency of public spending on higher education. Fourth, a study had to utilize DEA to estimate efficiency scores of public expenditure on higher education. Finally, I excluded the DEA studies measuring the efficiency of universities at the institutional level because they were already reviewed by several past systemic literature reviews.

#### The Identification of Relevant Studies

I conducted the three search strategies, following the techniques by Rhaiem: "(1) an electronic database search based on relevant keywords; (2) a screening in selected electronic journals; (3) a hand-search in the lists of references of the final set of selected articles" (2016, 5). First, relevant keywords ('efficiency', 'education', 'frontier', 'public spending', 'public expenditure', 'higher education, 'universities', 'colleges, 'tertiary education, 'DEA', etc.) were used for electronic database search (See Appendix 1: List of Keywords Used to Identify Relevant Articles for the detailed keywords set). I made various combinations of these keywords using the Boolean operators AND and OR. Eliminating the duplicates within and between search engines, I finally identified 5231 unique studies in total.

#### The Evaluation of the Studies

Next, I applied a screening in selected electronic journals based on the inclusion and exclusion criteria. The screening of potential studies was implemented in several steps. If the articles did not meet the criteria at each step, I eliminated them from the pool of references. If it was uncertain whether the article should be kept in the pool, it was kept until the following step. The keyword search in the ERIC database provided 230 references. After reviewing the title and abstract of each reference, 15 references remained. Finally, after reviewing the full texts of these references, only 1 reference met all the criteria. I also went to google scholar to check if there were other available studies. Keyword search in the Google Scholar database offered 5001 results. After the title review, 756 references remained. However, the abstract review revealed that most studies focused on a single nation and compared their universities' efficiency at institutional levels or public spending efficiency at the different educational levels. Thus, most of them were excluded, and 45 references remained. Finally, the review of full texts offered 7 references.

Finally, I applied a hand-search in the lists of references of the final set of selected articles to find other potential articles that could not be identified in the previous search techniques. This search provided 3 more studies that passed exclusion/inclusion criteria.

To ensure data quality, I used Quality Assurance Guideline for Social Science Research (Meltzoff 2018) to evaluate the identified references according to adequate sample size, criteria measure's reliability, and statistical tests' appropriateness. As a result, I found **11 high-quality studies in total** (Appendix 2: Summary Table of Selected Studies) that use two-stage DEA to measure the efficiency of public spending in higher education.

Zotero was used to organize all the identified references. I also created a Microsoft Excel database to manage the data of identified articles. The data includes the general characteristics (publication year, data sources, sample size, etc.), the set of applied inputs, outputs, and determinants, applied DEA-related techniques, and overall results.

### **Results and Discussion**

This section outlines the main findings of this systematic literature review from multiple angles. First, answering the first research question, it looks at the general characteristics of data on selected studies. Next, it analyzes the applied inputs, outputs, and efficiency determinants, responding to the second research question. Then, it answers the third question, considering the reduction of biases by examining the methodological approaches and techniques the studies utilized to reduce the bias in their results. Finally, it shows the overall pattern of findings in the DEA literature measuring the efficiency of public spending on higher education. This literature review does not intend to compare the efficiency scores among the studies because they use different nations and variables; thus, comparing efficiency values between studies is not meaningful.

#### General Characteristics of DEA Studies on HE Efficiency

Figure 2 shows that the number of published articles on the efficiency of public spending on higher education has gradually increased since 2005. 8 out of 11 studies were published within the past decade, implying that the topic of the governmental level DEA studies on HE is a relatively new research area. This trend comes from the fact that cross-country analysis is becoming more popular "due to the era of internationalization of higher education institutions and growing competition, especially in the European area" (Rhaiem 2016). Thus, compared to the past, more available cross-national data has enabled researchers to analyze the nationallevel efficiency of higher education, although the number of studies is still limited. As 2019 has the largest number of published studies, it is predicted that more studies will focus on this topic in the future. Therefore, this systematic literature review is essential in offering guidelines for future research on this newly established research area. With an average of 27 pages, the selected studies follow the general structure of economic papers. 9 out of 11 studies are less than 20 pages, except European Commission (2009) study with 148 pages which provides an extended conceptual framework and applies several methods. Moreover, 7 out of 11 studies are published in economic journals focusing on the education sector, such as "Education Economics," "Amfiteatru Economic Journal," "Economic Alternatives," and "Journal of Knowledge Management, Economics and Information Technology." The nature of the DEA methodological approach explains this concentration of studies in the economic journal. Although economic papers tend to be concise, some studies are too short of providing the basic theoretical framework to rationalize the selection of used variables. The problem regarding the lack of explanation for applied variables will be described in later subsections.



Figure 2 Number of published articles on the efficiency of the public spending on HE Source: compiled by the author

This systematic literature review also reveals the general data pattern used in selected studies. One can see that 8 out of 11 studies utilize panel data instead of cross-sectional data. Many panel data studies use the average of specific periods' values because some nations do not have available data for certain years. While selected studies measure the efficiency over

four years on average, the data timeframe varies among studies. Aristovnik (2013) contains the longest timeframe of data: 9 years from 1999 to 2007. Some cross-sectional studies use the different years for inputs and outputs to consider the time lag effects. Reflecting specific characteristics of HE data, such as time lag, is important to increase the reliability of results. The following section will explain the necessary points to consider regarding the HE data.

Figure 3 shows that more than half of the data analyzed by the selected 11 studies comes from Eurostat (Statistic database – Research and Development) and OECD (Education at a Glance). It can be noticed that data sources mainly focus on developed nations. In fact, all the studies aim to estimate the efficiency scores in EU nations and OECD countries. This data trend may be explained by the popularity of implementing evidence-based education policies for knowledge society across many European countries and the UK (Rhaiem 2016). With an average of 22 nations, the sample size significantly differs, depending on the studies, from a minimum of 9 to a maximum of 37 nations. Appendix 3: Distribution of the Investigated Countries shows that most studies include the Czech Republic, Hungary, and Poland (evaluated by 11 articles), followed by Bulgaria, Slovakia, and the UK (assessed by 9 articles). Some papers focus on new EU member states from Central and Eastern Europe, while only a few evaluate the efficiency in non-European nations, such as America and Japan.



Figure 3 Organisations used as data sources Source: compiled by the author

#### The Overview of Inputs, Outputs, and Determinants of Efficiency in DEA Studies

This section offers an overview of inputs, outputs, and the determinants of efficiency in selected studies. No past systematic literature review has paid attention to how the variables should be selected and how they can be categorized in groups in the context of this new research area, the national level-efficiency in HE.

#### **Inputs**

This paper classifies the identified inputs into three categories: funding, human resource, and physical capital. It introduces these categories based on the frequency of their usage. With the average number of 2 inputs in each study, this paper finds a relatively consistent pattern of used inputs in each category among the studies.

The most frequent applied input category is funding. All the studies use the related variables in this category, although their funding variables slightly differ from each other. 9 out of 11 studies use the total/public expenditures on tertiary education as a percentage of GDP. They agree on measuring spending as a percentage of GDP to make data comparable between

nations with different incomes and population sizes. However, there is a slight difference in the scope of expenditures on higher education. While some authors focus on public spending (Kosor 2019; Šonje 2018; Aristovnik 2013; European Commission 2009; Tóth 2009), others include spending both from public and private sources (Agasisti 2011; Obadić 2011; Yotova 2017; Velichkov 2019). The latter group of researchers argues that it is impossible to clearly separate the effect of public spending and that of private expenditure on outputs due to the mixed funding system. Researchers/policymakers should be aware of this difference when selected countries have substantially different HE funding mechanisms. Moreover, Gavurová, Halásková, and Koróny (2019) and Kochera (2005) exclusively focus on public research funding as they measure the efficiency of HE public expenditure in the context of research performance.

Human resource is the second most applied input category, with 4 out of 11 studies using a related variable. This category contains diverse types of associated variables. The total number of employees in the HE sector is the most commonly used variable in this category. While European Commission (2009) focuses on academic staff (researchers and professors), Gavurová, Halásková, and Koróny (2019) include both academic staff and administrative staff. These numerical inputs are considered in per capita terms to make the data comparable between countries with different population sizes. Other variables include the total number of students, ratio of students to teaching staff in tertiary educational institutions, net entry rates into tertiary education for each year of age, and population. The last variable, the population of each country, is a questionable input as it is not under the control of the decision-making unit (nations) in the education production function.

The least used input category concerns physical capital. Only one study (Kochera 2005) applies the related variable, namely the number of universities, unlike the institutional level-DEA papers implementing several physical capital variables, such as the number of computers, seats, and library stocks (Rhaiem 2016). The lack of physical capital variables in the national-

level DEA studies can be explained by the difficulty of collecting data at the national level and

the opacity of direct state involvement in physical capital development.

Category	<b>Related variables</b>	Authors
Funding	Public expenditures on tertiary education as a percentage of GDP Total expenditures on tertiary education as a percentage of GDP Expenditures on tertiary education per pupil in the percentage of GDP per capita R&D expenditure in the higher education sector as % of GDP	Agasisti (2011), Aristovnik (2013), European Commission (2009), Gavurová, Halásková, and Koróny (2019), Kochera, Luptacikb, and Sutter (2005), Kosor, Perovic, and Golem (2019), Obadić and Aristovnik (2011), Šonje, A., Deskar- Škrbić, and Šonje, V. (2018), Tóth (2009), Velichkov and Stefanova (2019), Yotova and Stefanova (2017).
Human ResourcesAcademic Staff and Students (in per capita terms) Total number of students per capita The ratio of students to teaching staff in tertiary educational institutions Net entry rates into tertiary education for each year of age		Agasisti (2011), European Commission (2009), Gavurová, Halásková, and Koróny (2019), Kochera, Luptacikb, and Sutter (2005).
Physical	Total number of universities	Kochera, Luptacik, and Sutter (2005).
Capital		

Table 1 Overview of inputs used in the selected studies

Source: compiled by the author

#### **Outputs**

This paper also regroups the identified outputs into five categories: HE attainment, employability, research, the attractiveness of HEIs, and welfare of the population with HE. These categories are described below in the order of most frequently used in the studies. The average number of outputs in the national-level DEA is 3. Like inputs, this paper finds a relatively consistent pattern of employed outputs among the studies despite some variations.

The most employed output category is HE attainment, with 8 out of 11 studies utilizing the related variables. Most studies include the percentage of tertiary graduates in the population (25–34 years old). One should notice that they specify the age group for the variable to

accurately identify the effect of inputs on producing outputs during specific periods. The lower limit, 25 years old, is considered as the age which has at least a Bachelor's degree, and 34 years old represents the lowest possible upper limit based on the available data.

In addition to HE attainment, employment is also the most commonly used category, with 8 out of 11 studies implementing the related variables. Similar to HE attainment, employability is one of the primary teaching outcomes. Most studies utilize employment rates of people with completed tertiary education (%). They use ratio variables instead of an absolute number to make the employment data comparable between nations with different population sizes. While most studies specify age groups to clarify the relationship between outputs/inputs used in specific periods, Obadic (2011) and Aristovnik (2013) fail to limit the age range. The failure to specify age on data could lead to the bias in efficiency scores as the employment rate of all people with HE degrees cannot be produced by specific periods' inputs. In addition, Šonje (2018) and Gavurová (2019) employ a tertiary unemployment rate; however, they also fail to identify the age groups due to the lack of specific data.

The second most used output category is research, although only 3 out of 11 studies use it due to the difficulty of collecting cross-national research output data. They are mainly using the number of publications during certain years. Other measures, such as the number of citations, are also utilized to evaluate the quality aspect of research. However, Agasisti (2011), who intentionally focuses on only teaching outputs, points out the biased results from research outputs due to the lack of comparable data and different actors involved in the total number of publications/citations, such as private companies. Thus, it is difficult to evaluate the research outputs produced only in the context of HE. Policymakers should make an effort to sponsor the collection of comparable data in terms of these outputs because research is one of HE's key objectives. The least used output categories are the attractiveness of HEIs and the population's welfare with HE. Only two studies use related variables in each category (Agasisti 2011; Šonje 2018; Yotova 2017; Velichkov 2019). The former category includes two variables: international students enrolled as a percentage of all students in HE and the World University Ranking list. On the other hand, the latter is measured by the population with tertiary education not at risk of poverty and social exclusion (age group 25-49). The two categories are not universities' direct objectives but indirect outcomes that many studies tend to neglect. However, it is essential to gather these complementary output data in the future to assess the efficiency of public spending on HE holistically.

Category	Related variables	Authors		
HE Attainment	The percentage of tertiary graduates in the population (25–34 years old) School enrolment, tertiary (% gross)	Agasisti (2011), Aristovnik (2013), European Commission (2009), Kosor, Perovic, and Golem (2019), Obadić and Aristovnik (2011), Tóth (2009), Velichkov and Stefanova (2019), Yotova and Stefanova (2017)		
Employment Research	Employment rates of people aged 20-34 with completed tertiary education (%) Labor force with tertiary education (% of total) The unemployed with tertiary education (% of total unemployment) The number of publications Papers 1990–1998 The number of citations	dAgasisti (2011), Aristovnik (2013)yGavurová, Halásková, and Koróny (2019)Obadić and Aristovnik (2011), Šonje, A.nDeskar-Škrbić, and Šonje, V. (2018), Tóth(2009), Velichkov and Stefanova (2019)yYotova and Stefanova (2017).dAgasisti (2011), European Commission(2009), Gavurová, Halásková, and Koróny		
		(2005).		
Attractiveness of HEIs	Foreign students enrolled as a percentage of all students (foreign plus domestic) for total tertiary enrolment Best ranked universities from observed countries in the World University Ranking list	Agasisti (2011), Šonje, A., Deskar-Škrbić, and Šonje, V. (2018).		
The Welfare	Population with higher education	Velichkov and Stefanova (2019),		
of Population with HE	outside of risk of poverty and social exclusion (age group 25-49 years).	Yotova and Stefanova (2017).		

Table 2 Overview of outputs used in the selected studies

Source: compiled by the author

#### **Determinants of Efficiency**

This section describes the overview of applied determinants of efficiency. According to the definition by Gralka (2018), the determinant of efficiency refers to the environmental/nondiscretionary variables which are "neither inputs nor outputs of the production process and/or are outside of the control of the decision-making units but are assumed to influence the producer performance nonetheless" (2018, 15). The determinants of efficiency either increase or decrease the efficiency scores. Agasisti (2011), Tóth (2009), and European Commission (2009) apply the second-stage DEA to measure the influence of the determinants on efficiency. The number of applied determinants varies depending on the studies, with the average variable of 4. These applied determinants are categorized into four groups: HEIs' autonomy, students' intellectual and socioeconomic background, funding mechanism, and organizational characteristics. Whereas input/output categories have fewer variations and frequently applied variables, the authors use a wide range of determinants in each category to provide a concise and clear overview.

The first category of determinants concerns the autonomy of HEIs. The related determinants include various kinds of autonomies in HE: "autonomy to choose the number of admitted students and their profile, autonomy to decide on the level of tuition fees and to raise other funds as well as to decide on the structure of expenditure, autonomy to hire, set the wages, and to dismiss the academic staff, and autonomy to set course content, to offer more diversified studies, and to decide on the (in)existence of constraints associated with numerous clauses" (European Commission 2009, 20). These autonomy levels are based on a cross-country survey data from the minimum score of 0 to the maxim score of 10.

The second category of determinants focuses on students' intellectual and socioeconomic backgrounds. The related determinants regarding students' intellectual levels contain PISA results. As for their socioeconomic background, average household wealth measured by GDP per capita and parental educational attainment levels are employed as related variables. Other students' backgrounds, such as ethnicity, age, and gender, are omitted in the selected studies, showing the lack of theoretically relevant determinants included in the national level-DEA HE studies.

The third category pays attention to the funding mechanism, including funding composition and state approach to HEIs. For instance, the funding rule variable measures to what extent nations offer performance-based funds to universities compared to the traditional input-oriented funds based on university size and historical backgrounds. Other related variables include the percentage of public funding concerning the total resources devoted to tertiary education institutions and expenditure per student.

In addition to the HE funding scheme, the fourth category focuses on HE organizational characteristics, which may significantly differ among selected nations. The related variables include the percentage of students in public universities (versus private ones), the average number of years to complete higher education, and the presence of evaluation system in HEIs. The first two variables above are numerical data, while the last one is an international survey data ranging from 1 to 10.

To sum up, this section gives an overview of inputs, outputs, and determinants of efficiency. Inputs are categorized into three groups: funding, human resource, and physical capital, while outputs have five categories: HE attainment, employability, research, the attractiveness of HEIs, and welfare of the population with HE. On the other hand, determinants of efficiency contain four groups: HEIs' autonomy, students' intellectual and socioeconomic background, funding mechanism, and organizational characteristics. Whereas this paper finds the consistent pattern of the dominant inputs and outputs utilized by all/most studies, there is a diverse set of determinants used in each category. The findings also tell researchers about the importance of measuring spending as a percentage of GDP, applying per capita to numerical

variables, and specifying age groups to make the data comparable between selected nations with different population and income levels.

#### **Applied DEA Techniques**

This section examines the techniques and methodological approaches the studies utilized to reduce the bias in their results. In terms of optimization perspective (Figure 4), most articles (8/11) solely use the output-oriented model, while only one uses the input-oriented model. In addition, Halásková and Koróny (2019) and European Commission (2009) apply both models to conduct the holistic efficiency analysis in HE. The popularity of the output-oriented model comes from the fact that seeking outputs maximization within a limited budget is more realistic in the context of higher education because the knowledge-based society demands more educational outputs while financial deficit makes it challenging to increase inputs.



### Figure 4 Optimization Perspective Source: compiled by the author

As for the techniques used to measure the efficiency, Figure 5 shows that all the studies only or jointly use VRS (variable returns to scale)-DEA model with other methods. Compared to the CRS-DEA model (constant returns to scale), the VRS-DEA model is more appropriate when using countries with many different characteristics as decision-making units because "VRS will take into account the different scales of the individual units and allow different inputoutput ratios to be defined as efficient" (Velichkov 2019, 495). On the other hand, Agasisti (2011) takes VRS-DEA with other models, including CRS-DEA and FDH (another nonparametric method). Using three different models, Agasisti (2011) compares the results and improves their reliability. Similarly, European Commission (2009) also applies both VRS-DEA and SFA (stochastic frontier analysis) to check the robustness of results. Moreover, Halásková and Koróny (2019) take SES + VRS-DEA (Slack-based super efficiency VRS DEA model). This joint model "involves all three possible scenarios for improving decision-making units: larger outputs with fixed inputs or fixed outputs with smaller inputs or larger outputs with smaller inputs" (2019, 240).



Figure 5 Techniques used to estimate the efficiency Source: compiled by the author

With regard to the explanation of determinants of efficiency (Figure 6), 3 out of 11 studies apply two-step DEA procedures to identify the most influential determinants of efficiency (Agasisti 2011; Tóth 2009; and European Commission 2009). All the two-step DEA studies use Tobit regression to "estimate linear relationships between variables when there is either left- or right-censoring in the dependent variable" (UCLA 2020). The rationale for this

censored regression model is that the DEA efficiency score, the dependent variable, is not normally distributed but is truncated at a maximum (= 1).



Figure 6 Explanation of Determinants of Efficiency Source: compiled by the author

Although many studies do not explain determinants of efficiency due to a lack of data, some studies employ different DEA extensions. Mihaljevic Kosor, Malesevic Perovic, and Golem (2019) create the benchmark table to identify the role model nations for inefficient governments regarding public spending on HE. This information helps policymakers select comparable nations they should deeply analyze. Moreover, they also show the efficiency targets for inputs and outputs necessary for countries to achieve total efficiency of public spending on HE. These targets tell policymakers how much they can increase outputs, such as completion and employment rates, under the current level of inputs. In addition, Tóth (2009) applies sensitivity analysis to show which nations have the high elasticity to the change of environmental factors by "calculating the minimum necessary magnitude of change in the variable values to the improvement of the state's position" (2009, 82). Finally, European Commission (2009) applies the Malmquist index to examine the efficiency change over time based on panel data by decomposing "total factor productivity change into efficiency change

and technical change" (2009, 35). The country improves the efficiency of public spending on HE over time when the Malmquist index exceeds 1, and if it is less than 1, the nation's efficiency deteriorates over time. You can refer to the detailed explanation of the Malmquist index by Agasisti and Johnes (2009).

There are also other key strategies to reduce the bias in DEA efficiency results. First, some authors are aware of the delayed effect of inputs on outputs in the education production function (Golem 2019; Stefanova 2017; Aristovnik 2013; Velichkov 2019). For instance, there should be a time difference between public expenditure on HE in one year and observed outputs, such as graduation and employment rates. Thus, it is necessary to use input data collected several years earlier than output data. Moreover, as mentioned above, these researchers also specify age groups to properly measure the effects of input on outputs during certain periods. For instance, public spending on HE in one year should improve HE attainment of specific age groups, not all populations. Therefore, considering lagged effects and target age groups in data is essential to reduce the bias in DEA efficiency measurement.

In addition, some studies also carefully check how many decision-making units (DMUs) and inputs/outputs should be used. According to (Chalos 1997), the number of DMUs (countries in their case) needs to be three times greater than the sum of applied inputs and outputs to avoid the curse of dimensionality. Otherwise, DEA results show most countries as efficient due to many outputs/inputs included in the analysis. Due to the fact that most of the countries are considered as being efficient in terms of public spending in HE, conducting meaningful cross-country comparisons would be impossible. Increasing the number of other countries meeting the criteria is one solution to avoid the curse of dimensionality; however, it is often difficult due to the lack of cross-national data. Moreover, simply reducing inputs/outputs to meet the standard also wastes the advantage of DEA, which can analyze multiple variables together.

Thus, some researchers provide useful solutions that not only fulfill the requirement but also holistically analyze the efficiency in HE.

One solution is to reduce unnecessary inputs/outputs by checking their correlation coefficients. DEA assumes that there should be a positive correlation between inputs and outputs in production function as its objective is not to find the association but to analyze the efficiency of resource allocation. Thus, if there is no statistically significant correlation between inputs and outputs, these variables can be taken out from the DEA. Velichkov (2019) uses classic Pearson correlation coefficients and robust Spearman coefficients to identify key variables and exclude unnecessary ones. Moreover, Halásková and Koróny (2019) also consider the solid theoretical relationship between inputs and outputs when selecting core variables. Therefore, to avoid the curse of dimensionality, researchers can exclude unnecessary inputs/outputs by checking their levels of associations.

The second solution is to use multiple models with different variables. For example, European Commission (2009) builds two DEA models where they apply only one output for each. The first focuses on teaching efficiency by using weighted graduates as output, while the other evaluates research efficiency by applying the number of publications as output. Similarly, Stefanova (2017) and Aristovnik (2013) also utilize different DEA models with different variables. By doing so, they can reduce the number of inputs/outputs in each model to refrain too many nations from becoming efficient. Moreover, producing similar results from different models can improve the reliability of results. Therefore, by applying multiple models, researchers can not only avoid the curse of dimensionality but also check the robustness of results. Policymakers should also be aware of whether studies apply these techniques as some results might deceive them about the status of their HE system due to the delayed effects and the curse of dimensionality.

#### The Overall Pattern of Findings

This section offers the overall pattern of findings in the DEA literature measuring the efficiency of public spending on higher education. This section does not intend to compare the efficiency scores and discuss which nations perform the best. The efficiency scores are highly sensitive depending on selected inputs/outputs, data periods, and nations. Thus, it is not meaningful to compare relative scores across studies. However, many researchers agree that the results of the determinant of efficiency from second-stage procedures can give insights to policymakers/researchers. Table 3 summarizes the direction of each determinant's influence on efficiency by grouping them into three categories: positive (+), negative (-), and no evidence of effect (NA). If a determinant has a statistically significant impact on efficiency at a significance level of 5%, it is categorized as either positive or negative direction, while the determinant with no significant impact is considered as a no evidence of effect.

Table 3 Summary	of the	determinants	and the	direction	of imp	pact on	efficiency
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Determinants	The direction of impact on efficiency
Autonomy of HEIs	
Student selection	NA
Budget decision	NA
Staff hiring policy	+
Course and degree flexibility	-
Students' Intellectual, Economic, and Social Background	
Household wealth by GDP per capita	+
Parental educational attainment level	NA
PISA results	+
Funding Mechanism	
The percentage of performance-based funding (versus input-based one)	+
State support (% of total HE expenditure)	-
Expenditure per student	NA
Institutional Characteristics	
The percentage of students in public universities	NA
The average number of years to complete higher education	-
The presence of evaluation system	NA
Source: compiled by the author	

Overall, half of the identified determinants have statistically significant impacts on efficiency. Regarding HEIs' autonomy, staff hiring policy has a positive association while course and degree flexibility decreases efficiency. The positive result of the staff hiring policy suggests that it could be better for policymakers to allow universities to easily decide when to hire/dismiss academic staff and change their wage. Moreover, the negative effect of course and degree flexibility (autonomy to increase the number of courses and degrees offered) can be explained by the high cost of introducing new programs for HEIs. Therefore, a state may encourage each university to prioritize their expert fields and promote cooperation with other universities to increase the overall efficiency and diversity of disciplines at the national level. Surprisingly, student selection (autonomy to choose the number of students) and budget decision (autonomy to decide tuition fee and expenditure structure), do not have significant influences; however, more future research on these determinants is necessary to accumulate results and enhance reliability and accuracy.

Two out of three students' intellectual and socioeconomic backgrounds positively impact efficiency. Especially the positive direction of PISA results (the average score in each nation) implies the importance of improving the quality of secondary education. In other words, more academically prepared secondary students will enhance the overall HE expenditure efficiency because their enrollment, persistence, and completion rates in HE are likely to be higher. Thus, policymakers should be aware of this strong relationship among different educational levels and improve secondary education, which benefits many children with ripple effects on tertiary education.

Regarding funding mechanisms, the ratio of performance-based funding (versus inputbased funding) and the ratio of state support (% of total HE expenditure) have positive and negative influences, respectively. These results may support the validity of HE neoliberal reforms aiming to improve the funding allocation with more performance-based funding and public expenditure cut. These reforms promote more competition among universities, incentivizing them to efficiently use their budget to produce outputs. Thus, inefficient governments may learn from successful cases of neoliberal approaches in the UK to increase the overall efficiency. Lastly, in the institutional characteristics category, only one determinant, the average number of years to complete higher education, has a significant negative association with efficiency. This negative direction comes from the fact that inefficient governments tend to neglect financial obstacles among students, causing higher dropouts or a longer stay in HE. Similar to HEIs autonomy, these (non) significant determinists should be repeatedly assessed in the future to see the reliability of the current results. Therefore, consistent data collection is crucial to enable researchers to conduct a similar DEA to accumulate the results and contribute to evidence-based HE policies.

### **Recommendations**

Based on the findings, this section reveals the challenges of DEA studies and a set of recommendations for researchers and policymakers, respectively. The comprehensive set of recommendations helps researchers mitigate bias in their results and provide better measures of efficiency. It also enables policymakers to make decisions based on more precise efficiency scores and improve the efficiency of their higher education systems.

#### **Recommendations for Researchers**

While other systematic literature reviews address the issues among institutional-level DEA studies, the governmental-level DEA studies still do not have a clear consensus on which inputs/outputs variables to include and what determinants of efficiency should be applied. Therefore, based on findings, this current study will first offer a comprehensive conceptual framework to help future researchers understand which variables and DEA models they should utilize to investigate the efficiency of public spending on higher education.



Figure 7 Conceptual framework of efficiency of public spending on HE Source: compiled by the author



Figure 8 Key features of DEA models studying efficiency of public spending on HE Source: compiled by the author

This conceptual framework (Figure 7 and Figure 8) gives an overview of identified inputs, outputs, determinants of efficiency, and the key features of DEA models used to measure the efficiency of public spending on HE. The upper block in Figure 7 represents the higher education production function, regrouping inputs and outputs in meaningful categories. The size of each category depends on the frequency of their usage, showing which categories are more prevalent in the country-level DEA studies. The most dominant variables can be found in each category in the Results and Discussion section. The bottom block in Figure 7 shows seven identified determinants of efficiency, which have statistically significant influences. Unlike the consistent pattern of the dominant inputs/outputs utilized by all/most studies, determinants are diverse and scattered without any dominant categories. Thus, this framework does not differentiate the size of determinants based on their popularity but intends to advance knowledge and inform the selection of determinants in future studies.

Figure 8 shows the dominant methodological approach in national-level DEA. Outputoriented VRS-DEA is the most popular and realistic model for HE efficiency research due to several reasons. First, it can show how much HE outputs can be increased under a limited budget, reflecting the key policy goal for many nations in the narratives of knowledge society. Second, it can apply various definitions of efficiency ratio to deal with the different scales of countries as the size of each nation may impact the efficiency. Finally, it can be used with other econometrics methods, including VRS-DEA, SFA, and FDH, to check the robustness of the results. For the second procedure, Tobit regression is most commonly used as the DEA efficiency score is not normally distributed. Other DEA extensions are also shown to help future researchers deepen their efficiency analysis. The detailed explanation for these extensions can be found in the Results and Discussion section.

In addition to the framework, this paper illustrates the challenges of national-level DEA studies and some techniques that researchers must know to reduce the bias in their results.

*First: Heterogeneity among nations.* Different characteristics of selected countries, such as population size and income levels, should be discussed. To avoid the influence of national heterogeneity on their results, researchers should use equivalent indicators across different countries. For example, they can make data comparable by measuring HE spending as a percentage of GDP, applying per capita to numerical variables, and using ratios instead of absolute values. In addition, nations differ in funding mechanisms (public vs. private fund priority) and in the typical configuration of production functions in their higher education systems (unitary vs binary system). For instance, Japan and America may become outliers for EU nations with similar HE funding rules, dramatically changing the efficiency scores of EU nations. Thus, researchers must consider national differences and outliers before choosing their sample nations. The configurational approach introduced by Seeber (2019) enables researchers to identify comparable nations with similar HE traits and improve the validity of the crossnational analysis.

Second: The lack of consideration for data selection. Reasons behind the selection of applied variables should be provided. When determinants are selected on an ad hoc basis, there is no consistent pattern for variables in the second-stage DEA model. Therefore, future researchers must develop theoretical-based data selection, by utilizing the efficiency concepts and a comprehensive conceptual framework, such as the one introduced in this paper, to inform their choice of variables to be included in the models. Moreover, some studies fail to consider the specific age group of people with HE degrees and the delayed effects when selecting inputs/outputs data. These two points are necessary to appropriately capture the efficiency scores. Some studies also suffer from the curse of dimensionality as they include either too many variables or only a few DMUs. Researchers can avoid this issue by excluding unnecessary variables based on correlation coefficients or using multiple models with different variables.

Third: The lack of conceptual clarity between inputs, outputs, and determinants of *efficiency*. This paper finds the same challenge emphasized by the past systematic literature review on the institutional level DEA studies. Although Gralka (2018) clearly defined determinants of efficiency, some authors confuse determinants with inputs/outputs. For instance, one study treats the population of each country as input though it is indeed a determinant, while some studies apply total expenditure per student as a determinant, which should be considered as input. In addition, although many DEA studies use students' backgrounds as determinants, this paper urges debate regarding this group as it can arguably be considered a quality of inputs under the control of decision-making units. Thus, the findings reveal that researchers lack conceptual clarity and make confusion between inputs/outputs and determinants of efficiency, which causes biases in results because it means that relevant variables are omitted or mistakenly reflected in the first/second stage DEA procedures. Therefore, future researchers should be aware of the common confusion explained above to avoid bias. Moreover, they should draw on a clear definition of determinants and dominant inputs/outputs discussed in this paper to justify their choice of variables. Using a theoretically based and more consistent set of variables accumulates the results which are more comparable across studies, leading to increased reliability of HE efficiency analysis.

#### **Recommendations for Policymakers**

While this current study mainly discusses methodological obstacles for DEA researchers, it also offers some insights for policymakers when interpreting DEA results to improve the efficiency of HE systems.

*First: Evaluation of DEA results.* The summary of challenges among DEA studies reveals that efficiency results can often be biased due to heterogeneity between nations, inadequate data selection conditions, and confusion among variables. Therefore, policymakers need to check whether DEA studies make an appropriate selection of

inputs/output/determinants based on theory and whether they apply multiple techniques to reduce biases in their results. Otherwise, some biased results would mislead policymakers to consider their nations as highly inefficient/efficient and neglect/overemphasize investment in a particular aspect of HE. Moreover, policymakers must know that the efficiency results are sensitive to the selection and availability of variables in the DEA method. Thus, they should not formulate their HE policies based on a single DEA study. Instead, they should evaluate multiple DEA studies using the same/different indicators as well as other qualitative data, such as experts' opinions, to improve the accuracy and reliability of their interpretation of efficiency in their HE systems.

Second: The lack of cross-country data. This systematic literature review identifies only 11 cross-national DEA studies. The limited number of studies in this new field results from the lack of comparative datasets, as the past systematic literature reviews also point out (Gralka 2018; De Witte 2012; Rhaiem 2016). Insufficient data leads to ad hoc (not theoretical) based selection of variables and omitted variable bias. In fact, the findings reveal that selected studies analyze only a few simple quantifiable variables, such as enrollment, graduation, and employment rates. The oversimplified efficiency analysis, in turn, prevents policymakers from accurately evaluating the real efficiency of public spending on education. Therefore, policymakers must constantly sponsor the collection of comparable data across different nations. More specifically, they should invest more in helping data collection on research outputs, social outputs of HE, and determinants of efficiency, as the findings show that data in these three fields are mostly absent among the national-level DEA studies. However, this current study also acknowledges the difficulty of quantifying many (HE) outputs, such as research quality, civic responsibility, and student creativity. Therefore, policymakers should financially support researchers/experts in improving data collection methods and promote discussion about how they should/can quantify and gather these outputs.

*Third: No DEA study on developing nations.* Finally, this paper uncovers that no single governmental-level DEA study has focused on developing nations. This exclusion of developing countries comes from the fact that these nations do not have the local statistical capacity to collect and analyze HE data (Gunderman 2021). As developing nations face more challenges in terms of the limited national budget under the pandemic, identifying how to improve the efficiency of public spending on HE could be more important for these nations than for developed ones. Therefore, policymakers in developing countries should build effective education management information systems (EMIS) by strengthening partnerships with IGOs, such as UNESCO, the EU, and OECD. More specifically, they should acquire knowledge and systematic evidence from these IGOs and adopt best practices to improve their EMIS. Such knowledge transfer and capacity development are necessary for policymakers to promote cross-country DEA to strengthen their higher education systems.

## Conclusion

In conclusion, this paper provides the first systematic literature review on the DEA studies measuring the HE public spending efficiency by analyzing 11 studies published from 2005 to 2019. Although it includes a limited number of studies, it advances the knowledge in this new research area by identifying the most appropriate efficiency concept, DEA models, variables, and techniques in the context of HE. The pandemic reinforces the importance of investigating how to improve HE expenditure efficiency to fulfill the demands of the knowledge society. DEA can offer insightful information about the status of the HE system, suggest avenues for alternative policy formulation, and identify the most influential determinants to improve efficiency. However, the findings reveal that DEA studies face a lack of consensus regarding variables and methodological approaches, which causes biases in their results and makes comparisons across nations difficult. Therefore, this paper strongly recommends that researchers and policymakers consider the listed critical points and strategies to mitigate the biases and better measure, interpret, and improve the efficiency of public spending on higher education.

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## **Appendix 1: List of Keywords Used to Identify Relevant Articles**

Topic Keyword	Education Level Keyword	Methodology Keyword
efficiency/education	higher education/tertiary	DEA/data envelopment
economics/public	education/ postsecondary/	analysis/Two-stage DEA/two-
spending/public	university/	step procedure/one-step
expenditure/cross-country	education/college/school/scho	procedure/national-level
efficiency/technical	oling/higher education	DEA/nonparametric/efficient
efficiency/inefficiency/effici	institution	frontier/variable return to scale
ency of public spending		DEA/input-oriented DEA

Source: compiled by the author

CEU eTD Collection

# **Appendix 2: Summary Table of Selected Studies**

Full citation	Data Type	Data sources	Sample size/Targets	DEA models
Agasisti, Tommaso. "Performances and Spending Efficiency in Higher Education: A European Comparison through Non-Parametric Approaches." <i>Journal of Education Economics</i> 19, no. 2 (2011): 199–224.	Panel data	OECD (Education at a Glance)	18 nations (the EU)	Output-oriented VRS-DEA + CRS-DEA + FDH + Tobit regression
Ahec Šonje, Amina, Milan Deskar-Škrbić, and Velimir Šonje. "Efficiency of public expenditure on education: comparing Croatia with other NMS." (2018): 2317-2326.	Panel data	The World Bank database	11 nations (the EU)	Input-oriented VRS-DEA
Aristovnik, Aleksander. "Relative efficiency of education expenditures in Eastern Europe: A non- parametric approach." <i>Journal of Knowledge</i> <i>Management, Economics and Information</i> <i>Technology</i> 3, no. 3 (2013): 1-4.	Panel data	Eurostat, OECD, UNESCO and the World Bank's World Development Indicators database	37 nations (the EU + Croatia)	Output-oriented VRS-DEA
European Commission. Directorate General for Economic and Financial Affairs. "Study on the efficiency and effectiveness of public spending on tertiary education: Third report (second draft)." Publications Office. (2009).	Panel data	OECD (Online Education Database – UOE database), Eurostat, and AMECO	28 nations (the EU + OECD)	Input and Output-oriented VRS-DEA + SFA + Tobit regression
Gavurová, Beáta, Martina Halásková, and Samuel Koróny. "Research and development indicators of EU28 countries from viewpoint of super-efficiency DEA analysis." <i>Journal of Acta Universitatis</i> <i>Agriculturae et Silviculturae Mendelianae</i> <i>Brunensis</i> 67, no. 1 (2019): 225-242.	Panel data	Eurostat (Statistic database – Research and Development) and Scopus database (Scimago Journal & Country Rank)	28 nations (the EU)	Input and Output-oriented VRS-DEA + SES-DEA

Kocher, Martin G., Mikulas Luptacik, and Matthias Sutter. "Measuring productivity of research in economics: A cross-country study using DEA." <i>Socio-Economic Planning Sciences</i> 40, no. 4 (2005): 314-332. https://doi.org/10.1016/j.seps.2005.04.001	Panel data	Journal Citation Reports, Economics Departments, Institutes and Research Centers in the World	21 nations (OECD)	Output-oriented VRS-DEA
Kosor, Maja Mihaljevic, Lena Malesevic Perovic, and Silva Golem. "Efficiency of public spending on higher education: a data envelopment analysis for eu- 28." <i>Journal of Problems of Education in the 21st</i> <i>Century</i> 77, no. 3 (2019): 396-409	Cross-sectional data	Eurostat	28 nations (the EU)	Output-oriented VRS-DEA
Obadić, Alka, and Aleksander Aristovnik. "Relative efficiency of higher education in Croatia and Slovenia: an international comparison." <i>Journal of</i> <i>Amfiteatru Economic Journal</i> 13, no. 30 (2011): 362-376.	Panel data	Eurostat, the IMF, the OECD, UNESCO, and the World Bank's World Development Indicators database	37 nations (the EU + OECD)	Output-oriented VRS-DEA
Tóth, Réka. "Using DEA to evaluate efficiency of higher education." <i>Journal of Applied Studies in Agribusiness and Commerce</i> 3, no. 3-4 (2009): 79-82.	Cross-sectional data	OECD (Education at a Glance)	19 nations (the EU)	Output-oriented VRS-DEA + Tobit regression
Velichkov, Nikolay, Kristina Stefanova. "Comparative Analysis of Higher Education Expenditure Efficiency in European Union Member States from Central agd Eastern Europe." (2019).	Cross-sectional data	Eurostat	9 nations (the EU)	Output-oriented VRS-DEA
Velichkov, Nikokay, Kristina Stefanova. "Comparative Analysis of Higher Education Expenditure Efficiency in European Union Member States from Central and Eastern Europe." (2019).	Panel data	Eurostat database	10 nations (the EU)	Output-oriented VRS-DEA

Source: compiled by the author

Country	Number	Country	Number
Czech Republic	11	Greece	7
Hungary	11	Portugal	7
Poland	11	Croatia	6
Bulgaria	9	Cyprus	6
Slovakia	9	Germany	6
United Kingdom	9	Norway	5
Austria	8	Malta	4
Belgium	8	Switzerland	4
Denmark	8	Turkey	3
Estonia	8	Canada	3
Finland	8	Korea	3
France	8	United States	3
Ireland	8	Australia	3
Italy	8	New Zealand	3
Latvia	8	Japan	3
Lithuania	8	Mexico	3
Netherlands	8	Luxembourg	2
Romania	8	Russia	2
Slovenia	8	Iceland	2
Spain	8	Israel	1
Sweden	8		

## **Appendix 3: Distribution of the Investigated Countries**

Source: compiled by the author