Full research paper

EDUCATION PERFORMANCE OF CZECH PUBLIC HIGHER EDUCATION INSTITUTIONS USING DATA ENVELOPMENT AND PANEL REGRESSION ANALYSIS

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ABSTRACT

The priority goals of the development of Czech higher education include ensuring the quality of its activities, improving the availability and relevance of flexible forms of education, and increasing efficiency in teaching and research. Several professional articles evaluated educational efficiency, but the proposed models did not include unemployed graduate students. The paper assesses education efficiency at public universities in the Czech Republic in 2020-2021 using an extended Data envelopment model with undesirable outputs, non-proportional and non-radial measures of distance from the efficient frontier. The influence of selected economic, social, regional and institutional factors on education efficiency is estimated by a panel regression model using the Feasible generalized least squares method. The results document the level and development of education efficiency and find insufficient reduction of unemployed graduates as a critical problem of inefficiency. More prominent universities achieve higher education efficiency. The main statistically significant factors influencing changes in education efficiency are population density, the unemployment rate, the location of the university in larger urban centres and the number of students per university employee.

KEYWORDS

Czech environment, Data Envelopment Analysis, education efficiency, education factors, panel regression model, public universities

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Highlights

- *Analysis of education efficiency of higher education institutions in the Czech Republic.*
- *Changes in education efficiency as a result of dividing universities into groups.*
- *The effects of selected factors on education efficiency.*

INTRODUCTION

The Czech education system, including higher education institutions (HEIs), has unique characteristics and structure. The structure is as follows:

- Pre-school Education - optional and available for children between the ages of 3 and 6 (the last year is compulsory).
- Primary Education - compulsory for children aged 6 to 15 in two cycles: the first lasts five years and the second 4 years.
- Secondary Education - optional; students can attend various types of secondary schools, such as grammar schools, technical schools, and vocational schools.
- Higher Education Institutions (HEIs) - optional; students can choose from various higher education institutions, including universities, colleges, and institutes. These institutions may be public and private.

The number of students enrolled in tertiary education within the European Union was around 14.3 million in the years 2015-2020, and there was an annual growth of 2.28% in 2021 (Eurostat, 2023a). The development of these students in the Czech Republic decreased since 2013, from 370.6 thousand to 285 thousand students in 2020, and followed an annual growth of 3.36% in 2021 (Eurostat, 2023a). The tertiary education system in the Czech Republic included 26 public universities, two state universities and 53 private universities in 2021. The number of graduates from public and

state universities was 52,328 in 2021 (89%), and for private schools, 5,726 students (11%).
Most HEIs in the Czech Republic are public, which means they receive government funding. Private HEIs operate alongside them, typically funded by tuition fees. The Czech HEIs are subject to quality assurance and accreditation processes to ensure high education standards. The Czech Republic has a National Accreditation Bureau responsible for accrediting programs and institutions. Czech higher education follows the Bologna Process, which aligns with the European Higher Education Area (EHEA). This includes using the three-cycle system (bachelor's - 3 years program (Bc.), master's – 1.5-2 years program (Mgr. or Ing.), and doctoral degrees - 3-4 years program (PhD)) and the European Credit Transfer and Accumulation System (ECTS). Czech HEIs offer various study fields, including humanities, sciences, engineering, and business. Czech universities are involved in research and innovation in various fields. The country has a rich scientific tradition and has contributed to science and technology. There are numerous research centres at the HEIs institutions, and Czech HEIs are active participants in international research collaborations. Many Czech HEIs offer programs mainly in the Czech language. However, there is an increasing number of English programs. Czech higher education is known for its quality and internationalisation. The country attracts students worldwide due to its rich academic tradition, affordable tuition, and diverse study options.
Public and private HEIs in the Czech Republic differ in crucial aspects, including funding, governance, and admission policies. More precisely:

1. Funding - public HEIs in the Czech Republic receive a significant portion of their funding from the government. This funding allows them to offer education at lower tuition fees, primarily to Czech and European Union (EU) or European Economic Area (EEA) citizens. Public HEIs typically have more resources for research and facilities. Private HEIs are funded primarily through tuition fees, research grants, donations, and private investments. Private HEIs have more financial autonomy and rely on student enrollment for revenue.
2. Tuition Fees - tuition fees at public HEIs in the Czech Republic are generally lower, especially for Czech and EU/EEA students. Tuition fees for non-EU/EEA international students vary but are typically higher than for EU/EEA students. Private HEIs often have higher tuition fees for all students.
3. Governance - public HEIs are typically under the authority of the Ministry of Education, Youth, and Sports. They are subject to government regulations and policies, and public sector rules and oversight influence their governance structures. Private HEIs have more autonomy in their governance and decision-making processes.
4. Admission Policies - admission to public HEIs in the Czech Republic is often highly competitive, particularly for popular programs. There are centralised admission procedures for Czech and EU/EEA students. The specific requirements and admission processes vary by institution and program. Private HEIs may have more flexible admission policies and procedures.
5. Programs and Specializations - public HEIs typically offer a wide range of programs and specialisations, including those in high-demand fields. They may have more extensive academic and research resources. Private HEIs may focus on specific fields of study or niche programs. They often tailor their offerings to meet the needs of specific student populations.

It is important to note that public and private HEIs in the Czech Republic are subject to quality assurance and accreditation processes to ensure the quality of education. Nowadays, there are many problems all around the world, especially in the financing of public institutions. To analyse the topic properly with a homogenous group of the HEIs, just the public HEIs are taken, primarily based on the funding.
The Czech higher education system needs more financial resources, especially for public and state universities. Therefore, the critical question is whether the Czech labour market has sufficient capacity to accept university graduates who no longer want to continue their studies, with the growing number of such graduates and the structure of professional orientation. If we follow the unemployment rate of graduates of all universities (*ur_abs*) in the Czech Republic (see Figure 1), it is clear that it decreased from 2013 to 2019 and then oscillated between 4.2% and 4.9%. The figure also shows the difference between public universities (*ur_abs_public*) and private universities (*ur_abs_private*), with lower graduate unemployment rates. The Ministry of Education, Youth and Sports is faced with the question of how to allocate limited financial resources to universities (especially public and state ones), how to evaluate the effectiveness of educational and research activities at universities so that graduates of these universities contribute positively to the development of society and do not burden the social support system unemployed?
The priority goals of the strategic plan for the development of Czech universities after 2021 (MEYS, 2021) include ensuring the quality of their activities, improving the availability and relevance of flexible forms of education, increasing the efficiency and quality of doctoral studies, strengthening strategic management and effective use of capacities in the field of research, teaching and other creative activities, including those of an international nature. Higher education governance should be conceptual, data-driven, and funding-efficient. Therefore, the next part is devoted to evaluating and analysing the education efficiency of universities in the Czech Republic for 2020 – 2021.
This paper proposes a Data Envelopment Analysis (DEA) model to measure and evaluate the efficiency of the educational process at selected universities and analyse the influence of selected economic, social, regional and institutional factors on the development of this efficiency. The proposed DEA model uses the non-proportional directional output distance function (DDF) introduced by Chung et al. (1997), and the DEA model includes undesirable outputs of unemployed college graduates. The goal of the DEA analysis is to find out the leading causes of the failure to achieve effective behaviour of universities. The subject of the investigation will also be the influence of classifying public universities into more homogeneous groups and monitoring group differences. To reveal the influence of

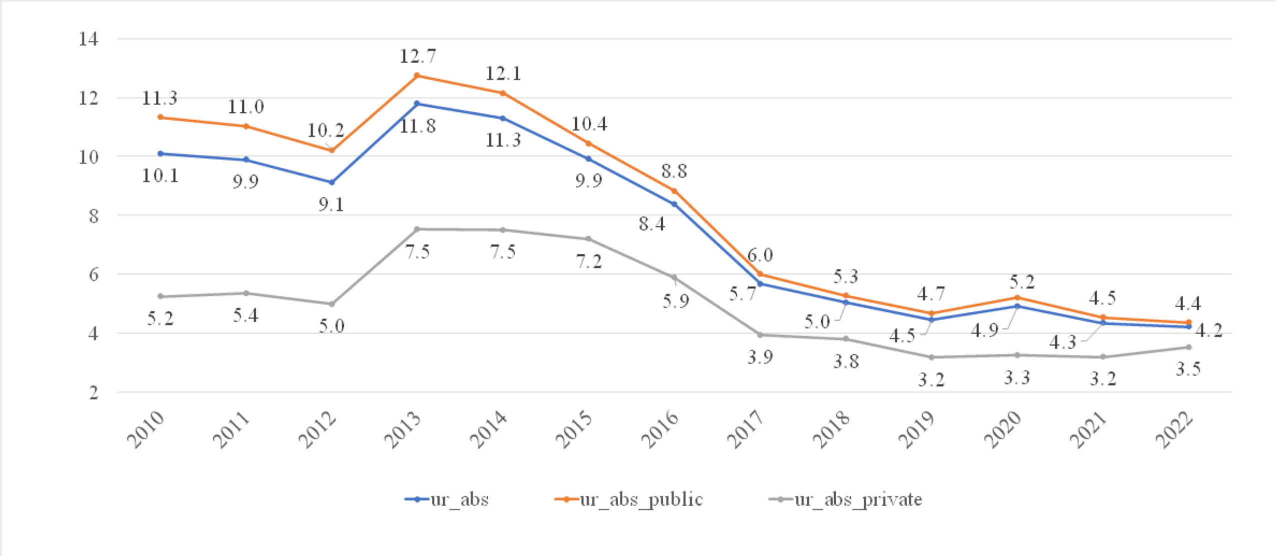

Figure 1: Development of the unemployment rate of university graduates in the Czech Republic, 2010-2022 (data source: Education Policy Center (2022), own calculation)

the factors on the level of education efficiency in the examined period, a panel regression model will be estimated using the FGLS method.

The paper is organised into five sections. Section 2 reviews literature related to the selection of inputs, outputs and the structure of the educational system of universities, the definition of factors affecting the efficiency of the educational process and the specification of the evaluation of education at Czech universities. The description of the input data, the proposal of the new DEA model, and the definition of the methodology for estimating the panel regression model are developed in Section 3. The following section includes the application of the proposed DEA model in the analysis of 26 higher education institutions (HEIs) in the Czech Republic in 2021 and 2021, followed by the estimation of the panel regression model, including the analysis of the results. Section 4 discusses the obtained key results, which are further confronted with other professional literature. Finally, the results are summarised, the limits of the proposed DEA model are defined, and some direction for future research is proposed.

LITERATURE REVIEW

The Bologna Process seeks to ensure the coherence of higher education systems across Europe by creating a European Higher Education Area that facilitates the mobility of students and workers, increases the inclusiveness and accessibility of that education in Europe and strengthens competitiveness on a global scale (European Education and Culture Executive Agency, 2020). A three-level higher education system was introduced: bachelor's, master's and doctoral studies. Conditions were created to ensure the mutual recognition of qualifications abroad and the evaluation of the quality of education. Evaluating higher education, identifying areas for improvement, and ensuring the cooperation of educators and policymakers serve the educational system's effective functioning and sustainable development. Higher education institutions (HEIs) drive economic, social, and regional development. They generate innovation, knowledge creation and human capital formation, all essential for sustainable growth and social progress.

There are different approaches to educational performance assessment. A large group consists of optimisation models of Data Envelopment Analysis, which measure the efficiency of the educational system. Mikušová dealt in the evaluation of educational and research activities at HEIS in both publications, which are discussed below. She used DEA methods, more precisely CRS and VRS model. The first publication (Mikušová, 2015) deals with the DEA applied to Czech public schools from 2013, where academic staff and other costs were used as inputs, whereas graduates and students of bachelor and master programs, and doctoral graduates and students were the outputs of the model. Two analyses were carried out: 1) comparing universities with each other, where the specificities of universities were demonstrated; 2) a comparison of universities divided into three groups with similar cost coefficients, which helps eliminate the high differences in inputs and in outputs led to more accurate results and an understanding of the redistribution of finance at universities in relation to performance. In the second analysis (Mikušová, 2017), an updated analysis with the newest data was performed to confirm the observed division of universities regarding the cost coefficients. The educational system contains academic units (HEIs) that transform inputs into outputs using educational "technologies and processes". The result is finding an efficient boundary where the HEIs with the best practice are identified. For HEIs that are not efficient, the causes of this inefficiency can be identified and quantified. Evaluating higher education's effectiveness can occur at different levels of study programs, departments, faculties, universities, countries, etc. As Mikušová (2017) suggests, it is more appropriate to divide the analysis into smaller and more specific substructures; this helps the condition of better homogeneity of decision-making units, i.e. according to the groups of overall economic difficulty coefficients of the KEN (it is therefore a more specific branch focus). This is more difficult for the Czech Republic to ensure, since there are not so many identical faculties or departments in the Czech Republic. This article focuses on educational units – public HEIs. The key activities of universities are not only education in the sense of teaching but also research and other activities such as lifelong learning, support of the local government or new business of students, etc. This article focuses only on teaching at the bachelor's, master's and doctoral levels.

The global and complex evaluation model of HEIs is documented in the article by Navas et al. (2020). The authors proposed a DEA model for evaluating the performance of 289 HEIs in Colombia from 2010 to 2015. The authors established four models: general and partial models of teaching, employment and research. The average general efficiency of the Colombian HEIs was 0.95. The results were then subjected to a cluster discussion according to various criteria (sub-models, institution size, changes in the number of inputs and outputs). Similarly, the academic effectiveness of 256 study programs was examined in the article by De la Hoz et al. (2021) for 135 public and private universities in Colombia. The study programs were divided into two clusters according to critical competencies. The applied DEA analysis of the effectiveness of the study programs showed that 16% of the study programs were effective. Random Forest and Decision Tree techniques were applied to predict academic effectiveness. Performance assessment in Czech HEIs involves evaluating various dimensions, such as teaching quality, research output, student outcomes, and community engagement. These assessments often inform policy decisions, accreditation processes, and funding allocation. However, the complex nature of HEIs and their diverse range of activities pose challenges for measuring and comparing performance effectively.

In the Czech Republic, Flegl and Vltavska (2013) focused on evaluating the effectiveness of economics faculties in public HEIs comparing 2006-2010 and 2007-2011 periods. The classic output-oriented DEA model was modified by including weighted inputs/outputs. The authors considered three inputs (actual labour costs, number of academic staff, number of students) and one output (research points) The paper evaluates the effectiveness of research and teaching at the Faculty of Economics in public universities in the Czech Republic in two periods (2006-2010 and 2007-2011). The authors use the Data Envelopment Analysis and Index method. Data Envelopment Analysis measures research efficiency according to weighted inputs (average salary of academic staff, number of academic staff and average number of students) to weighted output (RIV points). Teaching effectiveness is measured by weighted performance (average number of graduates). The index approach compares changes between productivity measured in two different ways (RIV points per academic staff, number of students per academic staff) and changes between average wages adjusted for the average rate of inflation. The results of both methods are very similar - for example identifying the "most efficient HEI". However, there are also differences, for example, DEA is considered better in the area of determining efficiency levels and therefore the possibility of compiling a ranking of HEIs according to efficiency and at the same time the possibility of recommendations on how to improve. In contrast, the index method gives the possibility of decomposition and therefore a better understanding of the given area.

Mikušová (2017) also addressed the measurement and evaluation of the effectiveness of public universities in the Czech Republic in 2015. A set of 26 public universities was evaluated using two DEA models assuming (a) constant returns to scale (CCR, Charnes et al., 1978) and (b) variable return to scale (VRS, Banker et al., 1984). The inputs were presented by the number of academic staff, indicator A (number of students in study programs) and indicator K (quality and performance). These indicators are used by the Ministry of Education, Youth and Sports of the Czech Republic when distributing financial resources to universities. Two outputs were presented: the bachelor's and master's graduates and the doctoral graduates. The results show that the average efficiency in the monitored set of HEIs was 0.819 under CRS conditions and 0.885 under VRS conditions. The number of effective HEIs was 50% for the second model. The results were also compared and discussed for three more homogeneous groups divided according to the coefficient of economic difficulties. The main conclusion of this part showed that a higher efficiency of education was achieved in the three more homogeneous groups than in the whole group and that more prominent universities (in terms of number of students) had higher teaching efficiency.

Finally, considering study programs, Flegl, Ticha, and Stanislavska (2013) investigated research efficiency for 29 doctoral study programs at the Czech University of Life Sciences Prague between 2007 and 2011. The DEA model included two inputs (number of PhD students and average length of study) and three outputs (number of graduated PhD students, research quality and a proportion between the number of PhD students and the number of PhD supervisors). The DEA model was based on increasing outputs with given inputs under CRS conditions. It was found that there is a need to improve students' research experiences, provide appropriate conditions for PhD students in departments and improve communication between PhD students and supervisors.

A Literature Search of Used Data

Demosthenous (2017) divided four key factors influencing the educational process – economic, social, cultural and developmental. The author concluded that the measurement and evaluation of the effectiveness of education contribute to the accumulation and growth of human capital and further to the increase of competitiveness on both the micro and macro levels.

Numerous studies have shown a strong correlation between college education and economic development. Economic theory argues that education, as the primary institutional mechanism for the accumulation, production and diffusion of human capital, is also an externality for the spread of market and non-market interests. The importance of education or human capital in the growth process was emphasized by Campbell and Üngör (2020), Fatima et al. (2020), Rossi (2020), Oyinlola and Adedeji (2021) and Braunerhjelm (2022). Similarly, Qi et al. (2022) analysed China's domestic labour market and observed that there was a limited demand for tertiary graduates due to an unbalanced industrial structure, with a weak contribution to economic performance over the past decade. HEIs produce a highly skilled workforce, fostering productivity gains and technological advancements that stimulate economic growth. Research has consistently shown that countries with more college graduates experience higher per capita income, increased labour market participation and reduced unemployment rates (for example the publication by Ferro and Romero (2021)). The main economic factors are labour market needs, innovation and entrepreneurship, economic inequality and industry-academia collaboration.

The effectiveness of public spending on education was analysed by Dufrechou (2016). The study compared the efficiency of 11 upper-middle-income Latin American economies and 24 high-income countries from 1970-2010. Efficiency scores were obtained by applying the DEA model and followed by simulation using bootstrapped truncated panel regressions to estimate the influence of other determinants to explain efficiency. Dufrechou (2016) established one input (real per capita education spending) and two outputs (years of schooling, share of population with secondary education) to evaluate effectiveness, and the basic output-oriented DEA model under VRS was applied. The key conclusion of this study was the finding of a positive trend in the efficiency of public spending, except for an economic slowdown in the years 1973-1990. It has been confirmed that it is necessary to invest in education. The level of globalisation and democracy emerged as the main determinants of efficiency improvement when comparing two groups of countries.

The question of the influence of the *social responsibility* of HEIs on sustainable regional growth and innovation was investigated by Pedro et al. (2022). Effectiveness for 23 public Portuguese HEIs was monitored using teaching and learning, research and technology, and social responsibility activities based on data from semi-structured interviews from 2018-2019. Based on the evaluation of technical efficiency using the output-oriented DEA model under CRS conditions, the influence on sustainable regional growth and innovation intensity of HEIs was determined in the next step using Tobit regressions. The results documented that higher social efficiency was demonstrated by larger HEIs located in large urban centres. Furthermore, the positive effect of teaching and social effectiveness on the regional gross domestic product for peripheral HEIs was proven. Higher education also plays an essential role in the context of social advancement in the form of transformation of individual lives, promoting social mobility and fostering social progress.

Furthermore, HEIs also play a pivotal role in *regional development*, particularly in peripheral or economically disadvantaged areas. They drive regional innovation systems as centres for research, entrepreneurship and collaboration between academia, industry and local communities. Studies have highlighted the positive impact of universities and colleges on local economies, including job creation, increased business activity, and the attraction of external investments, Bukhari et al. (2021). Furthermore, HEIs often contribute to regional development by offering relevant programs tailored to the needs of the local labour market, thus addressing skill gaps and promoting local talent retention (OECD, 2023). Therefore, regional disparities, local labour market, community engagement, infrastructure and connectivity are essential regional factors.

Several professional articles are dedicated to measuring and evaluating education efficiency and research efficiency through DEA models, which are classic single-stage or multi-stage models, usually in the form of network DEA. An example is the article by Wegener and Soummakie (2020) who studied research efficiency of 50 Turkish higher institutions using output-oriented DEA under VRS. This was followed by a beta regression analysis to investigate the influence of external factors such as age, size and ownership of the university. The obtained results showed that the research efficiency of selected HEIs was in the range between 0.548 and 1, with an average efficiency score of 0.898 and 56% of effective HEIs. The main problem for the inefficient HEIs was the low number of published professional articles or registered patents. The estimation of the beta regression model established that large and older universities tended to be more research efficient, and the effect of ownership status efficiency score did not play a significant role.

MATERIALS AND METHODS

This section will first deal with the description of the data used for data envelopment analysis and panel regression analysis. In the next part, the DEA methods and panel regression model estimation methods are described. In the field of data envelopment analysis, it will be both basic methods and methods that deal with an undesirable variable. The regression analysis is then focused on panel data.

Data for public Higher Education Institutions in the Czech Republic

All 26 public HEIs in the Czech Republic were chosen as production units under investigation. The list of these educational units and their other characteristics is given in Appendix 2. The essential characteristics of HEIs include identifier U1 to U26, name of the institution, region of jurisdiction according to NUTS2, the total physical number of students in all forms and levels of study (*stud*), the total average calculated number of educational employees at the institution (*empl*). The source of this information is the annual activity reports for individual universities. Furthermore, the indicator *st_empl* was calculated as the ratio of *stud/empl,* i.e., the number of students per university employee. As mentioned earlier, these indicators will be used to evaluate the "size" of HEIs according to the number of students, the number of employees or the number of students per employee of HEI.

In his article, Rychlík (2018) presented the classification of 26 public universities in the Czech Republic into four groups according to the assessment of quality and performance (indicator K). Group S1 includes four arts colleges, and group S2 includes two non-university colleges. The most numerous group is S3 with 15 smaller universities (smaller universities), and the last group S4 includes five universities that are strong in research (Charles University, Masaryk University, Palacký University Olomouc, Czech Technical University in Prague and Brno University of Technology). The division of these universities into the mentioned groups is considered when distributing financial resources by the Czech Ministry of Education, Youth and Sports.

Descriptive statistics of the number of students (*stud*) in all forms of study in bachelor's, master's and doctoral studies are presented in Table 1 for the years 2020 and 2021.

	Year	2020	2021	2020	2021	2020	2021
Group	**Statis.**	***stud***	***stud***	***empl***	***empl***	***st_empl***	***st_empl***
S1	Mean	726.25	745.50	285.07	282.36	2.49	2.61
	Std. Dev.	499.46	515.04	166.98	168.44	0.36	0.48
S2	Mean	2,711.50	2,617.50	190.48	200.20	14.10	13.03
	Std. Dev.	779.94	685.19	36.18	46.61	1.42	0.39
S4	Mean	8,718.53	8,850.07	1,219.82	1,208.58	7.36	7.55
	Std. Dev.	4,549.81	4,702.17	476.57	480.41	3.20	3.36
S5	Mean	28,001.60	28,474.80	4,819.39	4,756.09	5.95	6.06
	Std. Dev.	13,338.87	13,952.28	2,492.72	2,305.57	1.18	1.20

Table 1: Descriptive statistics of HEIs data, 2020-2021 (source: own calculation, annual reports of universities)

Table 1 shows that group S4 has the most prominent university, with an average number of students of 28,002 in 2020, increasing to an average of 28,475 in 2021. Group S3 includes universities with an average number of students from 8,720 (in 2020) to 8,850 (in 2021), i.e., with slightly lower growth than the S4 group. It can, therefore, be expected that not only research activity but also education efficiency will be higher for group S4 compared to group S3, which also supports the average number of students per employee, which in the group of large universities (S4) is on average 5.95 or 6.06 in 2020 or 2021 and in the group of smaller universities (S3) shows an average of 7.36 or 7.55 in 2020 or 2021.

Data for Data Envelopment Analysis

In order to determine and analyse beta efficiency in educational activity, the input and output variables used in empirical studies were listed in the literature review section. Based on this analysis and given the data availability, the input and output variables of the educational (production) system at universities in the Czech Republic were determined. Two input variables were selected for entry: the number of first-time enrolled students in a bachelor's, master's or doctoral program (*NSTUD*) and the average full-time number of academic staff (*STAFFA*) for each university. At the output of the education system, there were two variables for each HEI: the desirable variable expressed the number of completed and employed graduates of bachelor's, master's or doctoral studies (*ABS*), and the undesirable output was the variable expressing the number of unemployed graduates (*UNABS*) who, as job seekers, are registered at the employment office and successfully graduated from school no more than two years ago. The number of two inputs and two outputs satisfies the rule in relation (4) for 26 universities.

The source of *NSTUD* and *STAFFA* data are annual reports on the activities of individual universities, which are obliged to publish these reports on their websites. The data source for *ABS* and *UNABS* is the database of the Educational Policy Center at the Faculty of Education, Charles University in Prague (Education Policy Center, 2022). The data selected from this database are only for public universities in the Czech Republic for bachelor's, master's and doctoral studies. The data used for DEA are characterised in Table 2, and the values of these indicators are given in Appendix 1.

Item	Variable	Title	Measurement
Inputs	*NSTUD*	Students enrolled in the course for the first time	number
	STAFFA	Average calculated number of academic staff	number
Desirable Output	*ABS*	Number of graduates	number
Undesirable Output	*UNABS*	Number of unemployed graduates	number

Table 2: Description of inputs and desirable and undesirable outputs (source: own processing)

Panel Data for Estimating The Effects of Factors on Education Efficiency

A panel regression analysis explains changes in education efficiency due to changes in economic, social, regional, and institutional factors. In the *economic area*, indicators of gross domestic product, unemployment rate, work intensity, the availability of broadband (i.e., the percentage of households that are connectable to the internet), poverty (i.e., the persons with an equivalised disposable income below the risk-of-poverty threshold, which is set at 60% of the national median equivalised disposable income), the share of university-educated people in the total number of people over 15 years of age. Demographic indicators such as age distribution, population growth, migration and population density were considered *social factors*. The *regional factor* was the NUTS2 variable, expressed by assignment to a region at the CZ01 to CZ08 level (with a value of 1, 2,…, 8): CZ01 (Prague), CZ02 (Central Bohemia), CZ03 (Southwest), CZ04 (Northwest), CZ05 (Northeast), CZ06 (Southeast), CZ07 (Central Moravia) and CZ08 (Moravian Silesia). The largest number of HEIs was in Prague (8), followed by the Southeast (6) (see Appendix 2). The last group is the *institutional factors* of the university. This is, for example, the total number of students (*stud*), the number of all physically calculated employees of the institution (*empl*), or their ratio *st_empl*, i.e., the number of students per employee of the monitored university. The first two institutional indicators represent the university's size, and *st_empl* is one of the indicators of the quality of the educational process). The values of these institutional indicators are presented in Appendix 2 and are based on the annual reports of individual universities.

For the panel regression analysis and explanation of changes in education efficiency, factors representing one of the areas mentioned above (economic, social, regional, institutional), were selected where, the data sets were publicly available, and the factors were not strongly dependent. Table 3 describes the list of these factors and their characteristics.

A group of factors	Variable	Title (data source, data code)	Measurement
economic	*poverty*	at-risk-of-poverty rate by NUTS 2 (Eurostat 2023b, TGS00103)	percentage of total population
	ur	unemployment rate by NUTS2 (Eurostat, 2023b, TGS00010)	percentage
social	*pop_den*	population density by NUTS2 (Eurostat (2023b, TGS00024)	thousand persons per square kilometre
regional	*NUTS2*	basic regions for the application of regional policies	CZ01 – CZ08
institutional	*st_empl*	the number of students per one university employee (Appendix 1)	number

Table 3: Description of the data source of factors for explaining beta education efficiency (source: own processing)

Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric data-driven methodology widely used to evaluate decision-making units' relative efficiency (DMUs). The literature review focuses on three primary DEA models: CCR, BCC and SBM. The CCR (Charnes-Cooper-Rhodes) model (Charnes et al., 1978) is an original DEA model that assumes a constant return to scale (CRS) for the production function. It measures the relative efficiency of decision-making units by comparing their input-output ratios.

The BCC (Banker-Charnes-Cooper) model (Banker et al., 1984) is an extension of the CCR model that relaxes the assumption of constant return to scale and allows for variable return to scale (VRS). The CCR and BCC models are models where the distance from the efficient boundary is measured radially with the possibility of reducing all inputs or maximizing all outputs. The SBM (Slack-Based Measure) model extends the CCR model by considering the potential for improving efficiency by eliminating input or output slacks. The SBM model was proposed by Tone (2001). The SBM model also incorporates both desirable and undesirable outputs.

Navas et al. (2020) used an extended classical DEA model of Charnes et al. (1978) to evaluate the efficiency of Colombian HEIs by including flexible measures that allow the status of input or output variables to be classified.

To evaluate the efficiency of public HEIs, the classic output-oriented DEA model was modified by introducing:

- non-radial distance measure (DDF - directional distance function),
- non-proportional DDF (i.e., individual desirable outputs can be increased with different intensities, and similarly undesirable outputs can be reduced non-proportionally),
- undesirable outputs.

This model was also used and modified in the publication of Toloo and Hanclova (2021). Let us assume that we have a system of *n DMU*s, i.e., HEIs, where DMU_j (*j* = 1, 2,…, *n*), which has m inputs $\boldsymbol{x}_j = (\boldsymbol{x}_{ij})$ (*i* = 1, 2,…, *m*), desirable outputs $\boldsymbol{y}_j = (\boldsymbol{y}_{rj})$ (*r* = 1, 2,…, *s*) and undesirable outputs $\boldsymbol{b}_l = (\boldsymbol{b}_{lj})$ (*l* = 1, 2,…, *k*).

To increase the desirable outputs and reduce the undesirable outputs under a given level of inputs, Chung et al. (1997) introduced a directional output distance function as the joint production of desirable output $\boldsymbol{y}$ and undesirable output $\boldsymbol{b}$:

$$\vec{D}_T\left(x, y, b, g^y, g^b\right) = \sup\left\{\beta \mid (y,b) + \beta\left(g^y, g^b\right) \in T(x)\right\}, \quad (1)$$

where the nonzero vector $g = \left(g^y, g^b\right)'$ is the *direction vector*, and the vector $\beta = \left(\beta^y, \beta^b\right)'$ expresses the *non-proportional intensity* of the increase in desired production *y* and, simultaneously, the decrease in undesired production $\boldsymbol{b}$. Our DEA model $\left(g^y, g^b\right) = \left(y_o, -b_o\right)$. $T(x)$ is the permissible production technology. To evaluate the education efficiency of each HEI_j, we will look for the joint production (*y*, *b*) using the DDF with the following optimisation model:

$$\begin{aligned}
& z_{max} = \left\{w^{y\prime} \cdot \beta^y + w^{b\prime} \cdot \beta^b\right\} = \beta^* \\
s.t. \quad & \sum_{i=1}^{n} \lambda_j x_{ij} \le x_{io} && i = 1,\dots,m \\
& \sum_{j=1}^{n} \lambda_j y_{rj} \ge \left(1+\beta_r^y\right) y_{ro} && r = 1,\dots,s \\
& \sum_{j=1}^{n} \lambda_j b_{lj} \le \left(1-\beta_l^b\right) b_{lo} && l = 1,\dots,k \quad (2) \\
& VRS: \sum_{j=1}^{n} \lambda_j = 1 \quad \lambda_j \ge 0 && j = 1,\dots,n \\
& \beta_r^y, \beta_l^b \ge 0 \quad \forall\, r,l
\end{aligned}$$

where the vector $w' = \left(w^y, w^b\right)$ is the normalized weight vector, and we assume we have one desirable output and one undesirable output $w' = (0.5, 0.5)'$ for our output-oriented extended DEA model. DMU_j is efficient if corresponding $\beta_j^* = 0$, i.e., $\beta^{*y}_j = 0$ and $\beta^{*b}_j = 0$, otherwise, the monitored unit is inefficient.

Furthermore, a *y-b performance index* (*YBPI*) is introduced for each HEI according to the article by Zhou et al. (2012):

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$$YBPI_j = \left(1-\beta_j^{b*}\right)/\left(1+\beta_j^{y*}\right) \quad (3)$$

This index $YBPI_j$ is a proportion where the numerator expresses the average proportion by which the undesirable output can be reduced. At the same time, the denominator measures the degree to which the desirable output can be increased.
To have a reliable result, Cooper et al. (2007, p. 116) claimed that the number of performance measures (inputs and outputs) should satisfy the rule:

$$n \geq \max\left[3(m+s+k), m\cdot(s+k)\right] \quad (4)$$

In conclusion, applying DEA with undesirable output in higher education can explore educational quality and efficiency.

Panel regression analysis

To explain the influence of economic, social, regional, and institutional factors on the education efficiency of HEIs, a panel regression model will be estimated in the second step for a low number of years and 26 cross-sectional units (HEIs). Two estimation methods can be applied to estimate the regression coefficients of such a panel model and other statistics. The first group represents panel estimators with fixed effects (*FE*) or random effects (*RE*), with the Hausman statistical test to help with the selection (Baltagi, 2008). The second group is represented by estimates of the panel regression model using the generalized least squares method (Generalized Least Squares, GLS), where problems in the error term are usually solved, especially for Feasible GLS (FGLS) panel models.
The panel regression model can be formulated as follows:

$$y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + u_{it} = x_{it}^{'} \cdot \beta + \mu_i + \varepsilon_{it} \qquad u_{it} = \mu_i + \varepsilon_{it} \quad (5)$$

where $\beta = (\beta_1, \beta_2, \cdots, \beta_k)'$ are the regression parameters, $x_{it} = (x_{it1}, x_{it2}, \cdots, x_{itk})$ are the regressors, μ_i is the fixed or random effect of the i-th unit (HEI) and ε_{it} is the error term with the assumption $\varepsilon_{it} \sim iid(0;\sigma_\varepsilon^2),\ i = 1,2,\cdots,N \rightarrow and\ t = 1,2,\cdots T$.
For one-way *FE models* μ_i represents a cross-section fixed effect and is the unknown intercept for each *i-th* unit (HEI). Furthermore, within the framework of the *FE model*, it is assumed that with a cross-section fixed effect is designed to study the cases of changes within an entity (HEI). This model assumes that the mean value of the error term is zero and that there is no problem with serial correlation and heteroscedasticity of the error term:

$$E(\varepsilon_{it}) = 0$$

$$E\left(\varepsilon_{it}\varepsilon_{js}\right) = \sigma_\varepsilon^2 > 0 \ for\ i = j, t = s \quad (6)$$

$$= 0 \ \text{otherwise.}$$

In the *RE model*, the error term u_{it} is decomposed into *between-unit error* (μ_i) and *within-unit error* (ε_{it}). The *RE model* assumes that the unit's error term is not correlated with the predictor's regressors:

$$corr\left(\mu_i, x_{itj}\right) = 0 \quad (7)$$

which allows for time-invariant variables to play a role as explanatory variables. The *RE model* is based on the following assumptions:

$$\mu_i \sim iid(0, \sigma_\mu^2 > 0) \quad and \quad \varepsilon_{it} \sim iid(0, \sigma_\varepsilon^2 > 0)$$

$$E\left(\mu_i \cdot \mu_j\right) = 0 \ for\ i \neq j \quad and \quad E\left(\varepsilon_{it}\cdot \mu_j\right) = 0$$

$$corr\left(u_{it}, u_{js}\right) = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\varepsilon^2} = rho \quad for\ i = j, t \neq s \quad (8)$$

$$= 1 \qquad for\ i = j, t = s$$

$$= 0 \qquad \text{otherwise.}$$

Furthermore, for all i and t are μ_i and ε_{it} independent random variables, and the regressors are uncorrelated with x_{itj}. For a RE model, the significance of random effects can be performed using the Breusch-Pagan Langrangian multiplier (LM) test (Breusch and Pagan, 1980), which relies on the null hypothesis $H_0: \sigma_\mu^2 = 0$ and the alternative hypothesis $H_A: \sigma_\mu^2 > 0$ assuming normality $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$.
To recommend whether to use the *FE* or *RE model*, we use the Hausman specification test, where the null hypothesis supports the *RE model* and the alternative does not support the *RE model*, i.e., the *FE model*.
To estimate the influence of economic, social, regional, and institutional factors on beta efficiency, the second group can also use the estimation through the Feasible Generalized Least Squares (FGLS) approach, which allows the presence of heteroskedasticity or serial and cross-sectional correlation (Bai et al., 2021).
The general panel regression model described in Equation (9) will be specified for further research purposes:

$$beta_{it} = \beta_1 poverty_{it} + \beta_2 ur_{it} + \beta_3 pop\_den_{it} + \beta_4 st\_empl_{it} + \beta_5 NUTS2_i + u_{it}. \quad (9)$$

In order to estimate the panel regression model, the fixed and random effects method will be applied first, then the Hausman test will be used to verify which of the two approaches is more appropriate, and then we will focus on diagnostics. In the second stage, we will make an estimate using the FGLS method. We will verify and analyze the obtained estimation results in the context of this article.

RESULTS

In this section, we will first pay attention to analysis of the beta efficiency of the education process at selected public universities in the Czech Republic for 2020 and 2021. In the second part, we will explain the changes in the beta efficiency of education using selected economic, social, regional, and institutional factors.

Results of Data Envelopment Analysis

The optimization using the DEA model in the system of equations (2) took place first for 2020 and then for 2021 in the GAMS Distribution 41.5.0 software. The results of the DEA analysis for all universities are presented in Table 4.

Regarding the 1st part of the analysis, efficient public universities in education were 54% (i.e., 14 out of 26) in 2020 and 39% (i.e., 10 out of 26) in 2021. Thus, there was a reduction in the number of efficient public universities between the analyzed periods. From the point of view of the average efficiency in education (*beta*) shown in Table 5, this deterioration meant an increase in the average beta value from 0.172 to 0.217 in 2021. By analyzing the efficiency for desirable and undesirable output (*beta_ABS*, *beta_UNABS*), a slight decrease in the average value can be seen in Table 5 from 0.154 to 0.135, including a reduction in standard deviation. This means that there has been an improvement in efficiency from the point of view of increasing the number of completed studies and the employment of these graduates of all levels of study (i.e., bachelor's, master's and doctoral degrees in total) and the differences between public universities have also decreased.

We must, therefore, look for the cause of the deterioration of the average efficiency beta in the deterioration (increase) of the average efficiency *beta_UNABS* from 0.189 to 0.299, i.e., insufficient reduction of unemployed public university graduates. On the other hand, the average *YBPI* index (see Table 5), which was calculated according to equation (3), shows an average decrease from 0.772 to 0.649 in 2021, which documents that the average proportion of reducing the number of unemployed graduates to the level of increasing the number successfully of graduated and employed graduates improved in 2021.

year	2020				2021			
ID_HEI	*beta*	*beta_ABS*	*betaUNABS*	*YBPI*	*beta*	*beta_ABS*	*betaUNABS*	*YBPI*
U1	0	0	0	1	0	0	0	1
U2	0	0	0	1	0	0	0	1
U3	0	0	0	1	0	0	0	1
U4	0	0	0	1	0	0	0	1
U5	0	0	0	1	0.505	0.528	0.482	0.339
U6	0	0	0	1	0.300	0.010	0.589	0.407
U7	0	0	0	1	0	0	0	1
U8	0.389	0.201	0.577	0.352	0.451	0.219	0.684	0.259
U9	0.248	0.050	0.445	0.529	0.291	0.045	0.536	0.444
U10	0.283	0.566	0.000	0.639	0.359	0.382	0.336	0.480
U11	0.144	0	0.289	0.711	0.412	0.414	0.409	0.418
U12	0	0	0	1	0.112	0	0.224	0.776
U13	0	0	0	1	0.215	0.431	0	0.699
U14	0	0	0	1	0	0	0	1
U15	0.153	0	0.307	0.693	0	0	0	1
U16	0.336	0.343	0.330	0.499	0.453	0.222	0.683	0.259
U17	0.245	0.073	0.417	0.543	0.441	0.193	0.689	0.261
U18	1.613	2.516	0.711	0.082	0.662	0.611	0.713	0.178
U19	0.282	0.075	0.489	0.475	0.323	0.051	0.595	0.385
U20	0	0	0	1	0	0	0	1
U21	0.230	0.057	0.403	0.565	0.277	0.093	0.462	0.492
U22	0	0	0	1	0.290	0.112	0.467	0.479
U23	0	0	0	1	0	0	0	1
U24	0	0	0	1	0	0	0	1
U25	0.271	0	0.543	0.457	0.254	0	0.508	0.492
U26	0.267	0.125	0.409	0.525	0.287	0.186	0.387	0.517

Table 4: The HEIs with beta education efficiency and YBPI (source: own calculation in GAMS)

Variable	2020		2021	
	Mean	Std. Deviation	Mean	Std. Deviation
beta	0.172	0.324	0.217	0.202
beta_ABS	0.154	0.499	0.135	0.188
beta_UNABS	0.189	0.239	0.299	0.282
YBPI	0.772	0.275	0.649	0.308

Table 5: Comparison of descriptive statistics of education efficiency according to the years 2020 and 2021 (source: own calculation in GAMS)

Furthermore, Table 6 presents the results of the education efficiency according to groups of universities. At the same time, we will focus mainly on large universities in group S4 and universities in group S3. By comparing the education efficiency (*beta*), it is interesting to observe the deterioration of that efficiency in education for the S3 group (increasing *beta* from 0.269 to 0.306 in 2021), while the S4 group of large universities shows an improvement in education efficiency (decrease in *beta* from 0.085 to 0.051) and also the average *beta* level is lower (i.e., HEIs are efficient or close to the efficient frontier). A more detailed analysis of individual universities in the group of large universities (S4) confirms that the Czech Technical University in Prague (U3), Masaryk University (U7), Charles University (U14) and only in 2021 the Palacký University Olomouc (UP, U15). The Brno University of Technology (BUT, U25) is close to the efficient boundary in both years, where there was also a slight improvement in education efficiency (*beta* decreased from 0.271 to 0.254 in 2021).

The reason for the inefficiency of the education system is the insufficient reduction in the number of graduates registered at the employment offices. At the same time, there was an improvement for the UP in Olomouc and BUT in Brno in 2021 compared to 2020. The *YBPI* index for the latter universities shows an increase for both universities' *YBPI*, which expresses an improvement in the ratio of the increase of employed graduates to the decrease of unemployed graduates. The analysis of the results in the group of 15 smaller universities (S3) shows that the leading cause of the deterioration of the average education efficiency (*beta*) in 2020 and 2021 is the deterioration of efficiency in the reduction of unemployed graduates (i.e., *beta_UNABS* increased from 0.271 to 0.421 in 2021). On the other hand, there was an improvement in education efficiency in increasing successful and employed graduates (i.e., *beta_ABS* decreased on average from 0.267 to 0.191 in 2021). Still, the verage *YBPI* index for the S3 group shows that the ratio of the increase in the efficiency of employed graduates relative to the decrease in the efficiency of unemployed graduates has slightly worsened (i.e., the *YBPI* has decreased from 0.661 to 0.505 in 2021).

Group	Variable	Year 2020 Mean	Year 2020 Std. Deviation	Year 2021 Mean	Year 2021 Std. Deviation
S3	*beta*	0.269	0.397	0.306	0.177
	beta_ABS	0.267	0.642	0.190	0.192
	beta_UNABS	0.271	0.249	0.420	0.260
	YBPI	0.661	0.284	0.505	0.257
S4	*beta*	0.085	0.123	0.051	0.114
	beta_ABS	0	0	0	0
	beta_UNABS	0.170	0.247	0.102	0.227
	YBPI	0.830	0.247	0.898	0.227

Table 6: Descriptive statistics of education efficiency by a group of HEIs, 2020-2021 (source: own calculation in GAMS)

After the DEA analysis, the analysis of education efficiency and its causes in terms of strengthening the employment of graduates and the reduction of unemployed graduates can be examined for individual educational institutions based on the results in Table 4.

Estimating The Effects of Factors on Education Efficiency

In the next part, the specific panel regression model (9) is estimated by using fixed effects, random effects, and feasible generalized least squares methods.

Given the possible heterogeneity in public educational institutions, we first choose the fixed effects method and then the random effects method to estimate the panel regression model. The presence of educational efficiency heterogeneity is documented in Figure 2, which presents the development of education efficiency (*beta*) for each university U1 to U26 in 2020, and 2021 and the average value of both years, whose values are connected by a line. A value of zero represents an efficient college in the education process. The biggest problem appears with U18, specific to the Veterinary and Pharmaceutical University of Brno.

It is clear from the table that the beta efficiency is statistically significantly and negatively affected by the population density indicator (-0.404) at the 1% level of significance and positively by the number of students per employee of the university (-0.233) at the 5% level. importance.

Due to the undesirable multicollinearity and the dependence of the factors (regressors) that will explain the *beta* changes, Table 7 shows the Pearson's paired correlation coefficients for measuring the strength of linear independence of two factors. Below, this value is recorded as the *p*-value to determine the statistical significance of the pairwise correlation. It is clear from the table that *beta* efficiency is statistically significantly and negatively affected by the population density indicator (-0.404) at 1% significance level, and positively by the number of students per one employee of the university (-0.233) at the 5% level of significance.

The results of estimating the panel regression model from equation (9) using the fixed effects method is statistically insignificant because the *p*-value of the F statistic is 0.899, i.e., greater than 0.05. Therefore, we do not reject the null hypothesis that all regression parameters are equal to zero.

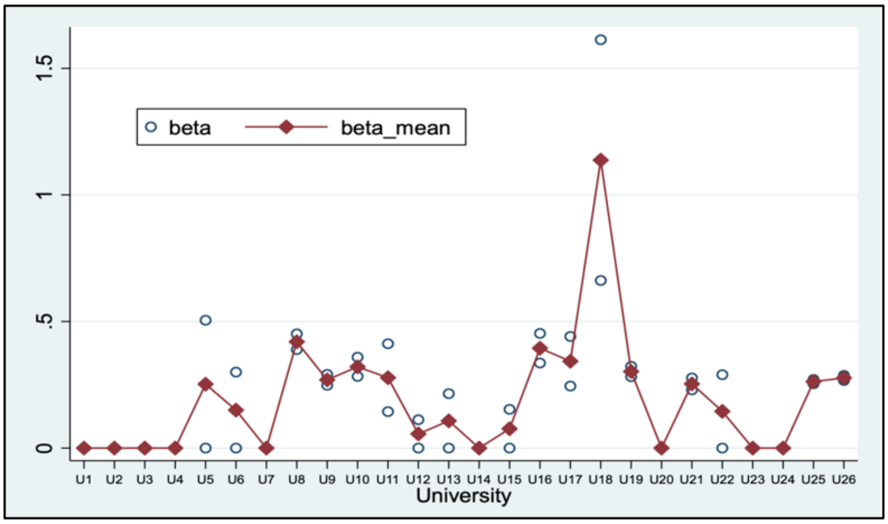

Figure 2: Beta efficiency of HEIs 2020-2021 (source: own calculation, in STATA)

	beta	*poverty*	*ur*	*pop_den*	*st_empl*
beta	1				
poverty	0.224	1			
	0.111				
ur	0.122	0.750	1		
	0.388	0.000			
pop_den	-0.404	-0.612	-0.259	1	
	0.003	0.000	0.064		
st_empl	-0.233	0.133	0.079	-0.152	1
	0.097	0.347	0.580	0.282	

Table 7: Pairwise correlation matrix of factors for beta panel regression, 2020-2021 (source: own calculation in STATA)

Also, *Rsquares(between)* = 0.186, which documents a low level of explanation of changes in *beta* education efficiency. The estimate of the model with random effect (RE) summarizes the following equations:

$$\hat{\beta}_{it} = 0.334 - 0.0027\, poverty_{it} + 0.039 ur_{it} - 0.050\, pop\_den_{it} - 0.021^{*}\, st\_empl_{it} + 0.043 NUTS2_{it}.$$

The results of the Wald test for *p*-value (chi^2) = 0.023 confirm that the estimate of the *RE model* is ok, i.e., we reject the null hypothesis that all the coefficients in the *RE model* are different from zero. Statistics $R^2_{between} = 0.371$ shows that only 37% of changes in education efficiency are explained by selected factors. Testing the statistical significance of individual regression coefficients confirms that only the estimated regression coefficient $\hat{\beta}_4 = -0.021$ for the *st_empl* factor is statistically significant at the 10% significance level. The estimate documents that, on average, beta education efficiency improves as the ratio of students per employee in a college increases. The preference of the *RE model* estimate over the *FE model* was also verified using a Hausman test (i.e., HEIs error (μ_i) is not correlated with any of the factors). Considering that the estimate of the regression *RE model* was not statistically significant and did not bring the expected explanation by the mentioned factors, we proceeded to estimate the panel regression model (9) using the feasible generalized feast square method, which allows for heteroskedasticity or serial and cross-sectional correlation. The results of the estimated model are summarized by the following equation (11):

$$\hat{\beta}_{it} = 0.335 - 0.039^{***}\, poverty_{it} + 0.060^{**}\, ur_{it} - 0.069^{***}\, pop\_den_{it} - 0.018^{***}\, st\_empl_{it} + 0.042^{***}\, NUTS2_{it}. \quad (11)$$

where the statistical significance of the regression coefficient is **5% and ***1%. The result of the Wald test confirm that for statistics Wald chi^2(5) = 135.42 and the *p*-value (chi^2) < 0.001 we reject the null hypothesis and support the conclusion that all regression coefficients in the model are different from zero. At the same time, all the estimated regression coefficients are statistically significant at the 5% significance level, and we can proceed to interpret the results. The estimate $\hat{\beta}_1 = -0.039$ means that for the economic factor of poverty with a higher risk of low disposable income (below the monitored threshold of 60% of the national median), there is a slight improvement in the average education efficiency at universities under ceteris paribus conditions. The regression coefficient $\hat{\beta}_2 = 0.060$, which as an economic factor expresses the needs of the labour market, documents that with an increase in the unemployment rate by 1%, there is an increase in the average beta by 0.060, i.e., a deterioration in education efficiency at universities. The demographic factor of population density was included in the group of social factors. The estimate $\hat{\beta}_3 = -0.069$ suggests a lower average beta can be expected in areas with higher population density, representing a better average education efficiency in public universities. The regression coefficient for the institutional factor *st_empl* was estimated $\hat{\beta}_4 = -0.018$, which confirms that with a higher number of students per employee of the university, there is an increase in the average education efficiency. The last estimated regression coefficient $\hat{\beta}_5 = 0.042$ testifies that if we move away from Prague to the peripheral regions and towards the east, the average beta increases and the inefficiency in education at universities increases.

The estimated panel regression model using the FGLS method documents the influence of selected economic, social, regional and institutional factors on education efficiency at public universities.

DISCUSSION

The conducted research pointed to three critical results for the assessment and analysis of the education efficiency of Czech public universities in 2020-2021. The following discussion will be divided into three parts:

- the level and development of education efficiency (*beta*) at public universities and the causes on the side of the number of employees or unemployed graduates of bachelor‘s, master and doctoral studies,
- the effect of the division of public universities into more homogeneous groups on education efficiency,
- Higher education institutions‘ efficiency changes based on economic, social, regional and institutional factors.

A comparison of the number of efficient public universities in 2020 and 2021 shows a decrease from 54% to 39%, confirming the level of average inefficiency by increasing the average beta from 0.171 to 0.217 in 2021. Let us look at the reasons for the deviations in the educational system outputs for the output-oriented DEA model from the efficient frontier. The main problem is the need for more unemployed graduates; while comparing the average *beta_UNABS* in 2020 (0.189) with 2021 (0.299), this problem has worsened. However, at some universities, the problem of fewer employed graduates than expected persisted. Comparing the average *beta_ABS* in 2020 (0.154) with 2021 (0.135) indicates a slight improvement in this situation due to the need to increase employed graduates to an efficient level.

These results can be compared with other professional literature that focuses on evaluating the efficiency of HEIs using output-oriented DEA models, considering that the analyses were performed in a different period. Abbott and Doucouliagos (2003) identified 66% of efficient universities regarding teaching and research efficiency under VRS conditions in Australian universities in 1995. This number is also influenced by the number of inputs and outputs and their content. Education efficiency was assessed in the Czech environment for the same set of 26 public schools in Mikušová (2017). The data from 2015 and the DEA model included three inputs and two outputs, as mentioned in the literature review section. The number of efficient HEIs was 50%, and the average education efficiency was 0.855 when using the classic DEA output-oriented model with VRS. However, this analysis did not include undesirable output, only all graduated students.

The division of the Czech HEIs into four groups S1-S4, proposed by Rychlík (2018), allowed us to examine the influence of education efficiency for large universities (S4) and smaller universities (S3), which leads to the classification of HEIs with higher homogeneity. The results support the research hypothesis that more prominent universities have a higher average education efficiency (*beta* is 0.085 and 0.05 in 2020 and 2021, respectively), which improved even more in 2021. It can be said that these universities in the S4 group are mostly efficient or have little problems with inefficiency that is improving, and the only problem is the insufficient reduction in the number of unemployed graduates (the average *beta_ABS* in the S4 group is 0.170 and 0.102 in 2020 and 2021 respectively).

On the other hand, in the group S3, which includes 15 smaller HEIs, the average education efficiency beta worsened in years (from 0.269 to 0.306). It is logical that both, *beta_ABS* (0.267 to 0.306 in 2021) and *beta_UNABS* (0.271 to 0.420 in 2021) have therefore deteriorated. However, for *beta_UNABS* this deterioration was greater than for *beta_ABS*.

In the S4 group with five large universities, the annual total number of students reached over 28,000, total full-time employees around 5,000 and the number of students per employee around 3.3. In the group of 15 smaller HEIs, the total number of students was around 8.8 thousand, the number of employees was 1200, and the number of students per employee was around 6. The share of the S4 group is enormous in the group of universities, and the share of the number of students per employee points to the better teaching efficiency of larger universities.

The conclusion that more prominent universities and a group of more homogeneous HEIs record higher education efficiency is also confirmed by the publication of Mikušová (2017), who divided the same set of HEIs into three groups according to the coefficient of economic difficulty with an average teaching efficiency for individual groups of 0.989, 0.982 and 0.996, while teaching efficiency for the whole set it was 0.885 with a more significant standard deviation. Similarly, Navas et al. (2020) also observed higher teaching efficiency of the group of large universities compared to the medium and small size HEIs, in a sample of 157 Colombian HEIs between 2010 and 2015.

Several factors affecting public higher education institutions' education efficiency (*beta*) in the Czech Republic in 2020-2021 were investigated by estimating a panel regression model using the FGLS method. The results for selected economic, social, regional and institutional confirm that strong and statistically significant factors include population density, unemployment rate and location of HEIs in the NUTS2 region. A weaker but statistically significant institutional factor is the number of students per employee of HEI. Higher regional population density increases education efficiency for HEIs from that region. The unemployment rate as an economic factor shows the influence of the situation on the regional labor market. With higher unemployment, the education efficiency of HEIs from this region also deteriorates. The numbering of regions according to NUTS 2, in turn, documents that HEIs located in regions further from Prague (peripheral) and towards the east of the Czech Republic have worse education efficiency.

Pedro et al. (2022) also investigated the efficiency of HEIs in Portugal in 2018-2019 in their study. They concluded that HEIs with better efficiency of social responsibility are in large urban centers, and teaching efficiency is positively related to regional gross domestic product. The main contribution of our article is the analysis of the unemployment problem. In the data envelopment model, the undesirable output of the educational process is the number of unemployed public university graduates. In a panel regression, one of the economic factors selected is the unemployment rate in the region where the college is located. This factor expresses the situation in the regional labor market and plays an essential role in the job search of university graduates. Unemployment among university graduates is critical in many countries, including the Czech Republic. The unemployment rate of graduates of all universities, which was at 11.8% in 2013, gradually decreased and, as of 2019, is in the range of 4.2 – 4.9% (see Figure 1). The reason for this unemployment of graduates can be skills mismatch and lack of work experience, which is based on insufficient cooperation of universities with practice.

The results of the panel regression estimation also confirmed that with a higher number of university students per employee, the education efficiency *beta* improves for the observed public universities. This conclusion supports the already mentioned that for more prominent universities in the S4 group, where the *st_empl* indicator is 5.95 and 6.06 in 2020 and 2021, respectively, the education efficiency *beta* is significantly better (0.085 and 0.05 in 2020 and 2021, respectively) compared to the group S3, where the number of students per employee *st_smpl* is 3.20 and 3.36 in 2020 and 2021 respectively, and education efficiency decreases by 0.269 and.306 in 2020 and 2021 respectively. This is consistent with Mikušová (2017) and Navas et al. (2020) findings.

Limitations of The Analysis

The research in this paper also has its limitations. The proposed modified DEA model was based on aggregate indicators of the number of enrolled students and the number of employed or unemployed students for all levels of study (bachelor's, master's and doctoral). The DEA model focused only on evaluating education (teaching) efficiency and part abstracted from research and other activities universities implement for sustainability. The findings of this study are associated with public colleges, and results may differ for private colleges. Attention needs to be paid not only to the quantity but also to the quality of all university activities and their inclusion in the models.

Therefore, future research can extend the proposed DEA model to a DEA network model for individual degrees of study. Similarly, other possibilities are to stop into the evaluation of the effectiveness of the assessment, research activities and international cooperation. To improve the quality of the investigation of the influence of economic, social, regional and institutional factors, it is more appropriate to expand the set of these factors, which will be significantly correlated with effective education, but on the other hand, these factors will not be correlated with each other. It is also appropriate to extend the time horizon of the investigation, given that the situation of HEIs is changing now, at least in terms of the number of students - more students from the Czech Republic and more students from abroad (war in Ukraine), greater possibilities of using private universities and also the specialization of tudents - the trend of humanitarian fields and the use of artificial intelligence.

CONCLUSION

The article was devoted to evaluating the educational process at public universities and explaining the effectiveness of education by other selected economic, social, regional, and institutional factors.

A modified DEA model was proposed for determining education efficiency, which was based on the inputs of the number of newly enrolled students and the recalculated number of academic staff and the desirable output of the number of employed graduates and the undesirable output of the number of unemployed graduates of bachelor's, master's and doctoral study programs. The proposed output-oriented DEA model used the DDF distance from the efficient frontier, the possibility of a disproportionate increase in the number of employed graduates or reducing the number of unemployed graduates. The conclusions of the analysis for the 26 public universities in the Czech Republic showed that the number of effective public universities is decreasing in 2020-2021. The average education efficiency *beta* worsened in the mentioned period, mainly due to an insufficient reduction in the number of unemployed graduates. Therefore, public universities cooperating with employers in the labor market should pay attention to this issue and improve this situation through cooperation. The division of public universities into groups showed that large universities were almost all efficient, and the number of unemployed graduates was only a minor problem. These universities generally determine the best practice in the educational process. In the group of secondary and minor universities, education efficiency deteriorated due to the insufficient increase in the number of employed graduates and mainly due to the reduction of unemployed graduates.

The conclusions of the analysis of the influence of factors on changes in the education efficiency of public high schools in the monitored period showed that a vital positive factor is the demographic indicator population density, and the institutional factor, the number of students per employee of HEI, i.e., the size of the university. On the other hand, unemployment hurts education efficiency, i.e., problems in the regional labor market and the university's location in peripheral regions or towards the east of the Czech Republic.

The summary of these results shows the necessary cooperation measures between universities and employers of graduates, namely in creating study programs with adequate skills and knowledge needed in the future, as well as internships in companies in the corresponding institutions. Also, cooperation with labor offices in solving problems in the labor market and additional retraining can contribute to solving this situation.

University managers, in turn, must consider the size and structure of the academic body and choose adequate limits and structure for students admitted to bachelor's, master's and doctoral study programs. The Czech Ministry of Education, Youth and Sport should also help the development of peripheral public universities through subsidy programs.

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APPENDIX 1 INPUT DATA FOR DEA

year	2020				2021			
ID_HEI	*NSTUD*	*STAFFA*	*ABS*	*UNABS*	*NSTUD*	*STAFFA*	*ABS*	*UNABS*
U1	167	259.35	152	2	146	256.58	258	3
U2	38	63.76	1	1	30	67.07	39	1
U3	5,138	743.36	1710	81	4686	772.34	3,367	72
U4	3,527	1,604.30	1729	61	3471	1,605.00	3,266	38
U5	120	161.17	91	2	116	165.55	151	7
U6	1,903	635.34	1198	39	1981	628.94	1,806	50
U7	5,587	1,806.80	2648	156	5863	1,874.00	5,415	135
U8	2,068	540.60	963	89	2133	556.80	1,582	68
U9	1,656	532.58	945	57	1894	561.31	1,662	42
U10	1,496	261.17	432	23	1390	255.74	825	21
U11	1,338	517.59	664	26	1366	526.40	923	25
U12	1,225	349.80	722	30	1256	342.59	1,172	17
U13	1,744	439.38	814	23	1795	445.39	1,074	17
U14	7,763	3,887.44	2521	100	7989	3,971.18	6,541	92
U15	4,007	1,395.56	1863	118	3734	1,368.93	3,544	101
U16	1,825	544.60	794	51	1627	545.00	1,243	54
U17	2,217	466.70	1039	61	2425	483.09	1,797	76
U18	449	235.16	82	31	317	208.210	257	22
U19	2,285	814.46	1215	85	2359	826.28	2,072	61
U20	2,427	487.95	1214	39	2576	492.34	2,267	25
U21	734	690.39	369	16	884	703.70	847	20
U22	784	84.53	335	14	684	85.56	322	12
U23	879	76.74	241	10	807	88.11	399	7
U24	51	80.50	1	1	60	74.20	182	4
U25	4,277	1,128.17	1744	165	3997	1,169.42	3,382	110
U26	2,586	752.27	1176	74	2584	759.19	1,974	43

APPENDIX 2 LIST OF UNIVERSITIES AND THEIR CHARACTERISTICS

HEI	HEI name	Group	Address	NUTS2	ID_NUTS2	*stud_20*	*epl_20*	*stud_21*	*epl_21*	*st_ empl_20*	*st_ empl_21*
U1	Akademie múzických umění v Praze	S1	Praha 1	Praha	CZ01	1,438	500.4	1,485	498.6	2.87	2.98
U2	Akademie výtvarných umění v Praze	S1	Praha 7	Praha	CZ01	306	129.9	314	132.7	2.36	2.37
U3	Česká zemědělská univerzita v Praze	S3	Praha 6	Praha	CZ01	21,164	1,596.7	21,591	1,607.6	13.25	13.43
U4	České vysoké učení technické v Praze	S4	Praha 6	Praha	CZ01	17,442	4,137.9	17,550	4,177.2	4.22	4.20
U5	Janáčkova akademie múzických umění v Brně	S1	Brno-město	Jihovýchod	CZ06	687	330.5	679	332.0	2.08	2.05
U6	Jihočeská univerzita v Českých Budějovicích	S3	České Budějovice	Jihozápad	CZ03	8,895	1,472.0	8,847	1,470.7	6.04	6.02
U7	Masarykova univerzita	S4	Brno-město	Jihovýchod	CZ06	32,190	4,703.3	32,786	4,882.3	6.84	6.72
U8	Mendelova univerzita v Brně	S3	Brno-město	Jihovýchod	CZ06	8,886	1,604.7	9,019	1,606.2	5.54	5.62
U9	Ostravská univerzita	S3	Ostrava-město	Moravskoslezsko	CZ08	8,526	1,072.8	8,779	1,081.9	7.95	8.11
U10	Slezská univerzita v Opavě	S3	Opava	Moravskoslezsko	CZ08	5,282	601.1	5,337	582.4	8.79	9.16
U11	Technická univerzita v Liberci	S3	Liberec	Severovýchod	CZ05	5,948	1,178.9	6,166	1,159.7	5.05	5.32
U12	Univerzita Hradec Králové	S3	Hradec Králové	Severovýchod	CZ05	6,390	726.4	6,334	713.2	8.80	8.88
U13	Univerzita J. E. Purkyně v Ústí nad Labem	S3	Ústí n/L	Severozápad	CZ04	7,966	943.5	7,887	914.7	8.44	8.62
U14	Univerzita Karlova	S4	Praha 1	Praha	CZ01	49,508	9,098.9	50,918	8,634.3	5.44	5.90
U15	Univerzita Palackého v Olomouci	S4	Olomouc	Střední Morava	CZ07	22,106	3,087.2	22,983	3,089.2	7.16	7.44
U16	Univerzita Pardubice	S3	Pardubice	Severovýchod	CZ05	7,062	1,136.6	6,869	1,117.7	6.21	6.15
U17	Univerzita Tomáše Bati ve Zlíně	S3	Zlín	Střední Morava	CZ07	9,138	934.8	9,565	955.0	9.78	10.02
U18	Veterinární a farmaceutická univerzita Brno	S3	Brno-město	Jihovýchod	CZ06	1,884	605.1	1,792	537.8	3.11	3.33
U19	VŠB-Technická univerzity Ostrava	S3	Ostrava-město	Moravskoslezsko	CZ08	11,087	2,213.7	11,390	2,191.4	5.01	5.20
U20	Vysoká škola ekonomická v Praze	S3	Praha 3	Praha	CZ01	13,700	996.7	14,306	973.0	13.75	14.70
U21	Vysoká škola chemicko-technologická v Praze	S3	Praha 6	Praha	CZ01	3,823	1,222.6	3,836	1,263.4	3.13	3.04
U22	Vysoká škola polytechnická Jihlava	S2	Jihlava	Jihovýchod	CZ06	2,160	164.9	2,133	167.2	13.10	12.75
U23	Vysoká škola technická a ekonomická v ČB	S2	České Budějovice	Jihozápad	CZ03	3,263	216.1	3,102	233.2	15.10	13.30
U24	Vysoká škola uměleckoprůmyslová v Praze	S1	Praha 1	Praha	CZ01	474	179.5	504	166.2	2.64	3.03
U25	Vysoké učení technické v Brně	S4	Brno-město	Jihovýchod	CZ06	18,762	3,069.6	18,137	2,997.5	6.11	6.05
U26	Západočeská univerzita v Plzni	S3	Plzeň-město	Jihozápad	CZ03	11,027	1,992.0	11,033	1,954.1	5.54	5.65