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FINANCING EDUCATIONAL INNOVATIONS AS A FACTOR IN INCREASING THE COMPETITIVENESS OF HIGHER EDUCATION INSTITUTIONS IN EU COUNTRIES IN THE CONTEXT OF THE KNOWLEDGE ECONOMY

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ABSTRACT

This article explores and empirically validates the use of educational innovation funding as a driver of higher education competitiveness in the knowledge economy. The study is relevant because increased financial resources alone do not guarantee an institution's strengthened international, research, and partnership position, as these outcomes depend on the funding structure and the efficiency with which resources are converted into projects, mobility, and the international recruitment and training of researchers. This article aims to develop a comprehensive approach to assessing the relationship between educational innovation funding and higher education competitiveness. The dataset is based on the 2018 European Tertiary Education Register for 82 universities in 8 European countries. The methodology combines winsorization and data normalization, the analytic hierarchy process, entropy-based weighting, integrated assessment, LED, a dynamic effect analysis (DEA) model with varying returns to scale, robust regression, clustering, and scenario modeling. An index of educational innovation funding is constructed based on the intensity of research expenditures, the share of external funding, capital expenditures, and resource provision per applicant. Competitiveness was assessed using participation in EU framework program projects, partnerships with enterprises, Erasmus incoming mobility, the share of international applicants, and the intensity of PhD training. A strong positive rank correlation was found between the funding and competitiveness indices. Robust regression explains 48.3% of the variance in the final index, with the most consistent positive effect coming from resource allocation per applicant. A scenario of balanced strengthening of research, external, and infrastructure funding increases the predicted average competitiveness value by 7.23%, exceeding the results of single-channel scenarios. The practical significance lies in the applicability of this approach to budgeting innovation portfolios, comparing institutions, and identifying potential for converting financial resources into competitive advantages.

Keywords: education financing, educational innovation, higher education, competitiveness, knowledge economy, research funding, financial sustainability, resource efficiency

JEL Classification: I23, H52, O31, C44

INTRODUCTION

The knowledge economy is changing the competitiveness of higher education institutions. A competitive position is shaped not only by the size of applicant pools or the stability of budget funding, but by an institution's ability to systematically create, disseminate, and apply new knowledge. Educational innovations in this context encompass the modernization of program content, research-oriented teaching, international mobility, partnership projects with enterprises, the development of research infrastructure, the training of PhD students, and the creation of interdisciplinary educational and scientific environments. Each of these areas requires not one-time expenditures but rather anticipated financial support capable of supporting the entire cycle from ideation to scaling up.

The problem of funding educational innovation is twofold. On the one hand, insufficient resources limit infrastructure upgrades, the recruitment of researchers, participation in international programs, and support for mobility. On the other hand, a large budget does not guarantee competitive results if resources are distributed fragmentedly, are not linked to a portfolio of innovative projects, or are not accompanied by performance evaluation mechanisms. The OECD (2025) links the financial sustainability of higher education not only to covering current expenditures but also to the ability to invest in physical, human, and intellectual capital. This position directly addresses the issue of funding structure and the effectiveness of its use.

The European University Strategy identifies strengthening transnational cooperation, research and innovation capacity, mobility, and interaction with external partners as interrelated development directions (European Commission, 2022). In this context, an institution's competitiveness is a multi-criteria characteristic. It includes the ability to attract international resources and applicants, coordinate research projects, maintain partnerships with enterprises, provide research training, and translate funding into results with high social and economic value.

The scientific problem lies in the lack of a unified quantitative approach that would simultaneously reflect the volume and structure of funding for educational innovation, the resulting competitiveness, and the efficiency of resource conversion into results. Funding studies often focus on the relationship between budgets and publication productivity, while studies on competitiveness use rankings or individual international indicators. A separate group of studies applies DEA to assess technical efficiency. However, the combination of multi-criteria assessment, DEA, regression testing, and scenario modeling remains underdeveloped.

An additional complication is the heterogeneity of higher education institutions. They differ in size, profile, national funding mechanisms, and access to international programs. A simple comparison of absolute budgets favors larger institutions, while using only relative indicators may conceal limitations in scale. Therefore, the methodology must combine relative financial indicators, multi-vector competitiveness results, and a separate assessment of technical efficiency.

The European Tertiary Education Register provides information capabilities for such analysis. The register contains harmonized data on financial resources, personnel, applicants, international mobility, and research activity of higher education institutions. Lepori et al. (2023) justify ETER as an institutional reference framework for European higher education, supporting the comparison of individual institutions and taking into account OECD-UNESCO-Eurostat standards. The use of ETER microdata allows for a transition from a declarative interpretation of innovation to a reproducible quantitative assessment.

The proposed study assumes that competitiveness is determined not by maximizing a single funding source, but by a balanced combination of research expenditures, external funding, capital improvements, and sufficient resources per applicant. It is also important to distinguish between resource availability and effectiveness. An institution may have a high funding index but be inferior in terms of resource conversion into international projects, partnerships, and research training. Therefore, the methodology includes a DEA model and profile clustering.

Thus, the relevance of this study is determined by the need to align funding for educational innovation with the results that shape the competitiveness of higher education institutions. Existing scholarly works reveal isolated links between funding levels, research productivity, international activity, partnerships, and resource efficiency. However, a comprehensive approach that simultaneously considers the structure of educational innovation funding, the multi-criteria nature of competitive outcomes, and the relative efficiency of converting resources into such outcomes remains underdeveloped. The unresolved question is how a balanced combination of research, external, infrastructure, and core resource funding relates to the competitive position of higher education and whether high levels of resource provision are accompanied by high technical efficiency. These aspects are addressed in the sections of this article.

LITERATURE REVIEW

The theoretical basis of this study is formed at the intersection of higher education economics, innovation financing, university management, international competitiveness, and resource efficiency assessment. In the context of the knowledge economy, higher education performs educational, research, innovative, entrepreneurial, and societal functions. Marginson (2006) substantiates the multi-layered nature of competition in higher education, whereby universities simultaneously compete for applicants, researchers, financial resources, reputation, and participation in international networks. Aghion et al. (2010) link university performance to a combination of autonomy, competition, and good governance. Audretsch (2014) expands on the concept of the entrepreneurial university, emphasizing its ability to generate knowledge, entrepreneurial capital, and the prerequisites for societal development. These positions confirm that the competitiveness

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of higher education cannot be reduced to a single ranking, financial, or publication indicator. Higher education funding influences institutions' ability to maintain educational quality, research, international mobility, infrastructure, and partnerships. Jongbloed and Vossensteyn (2001) show that results-based funding creates incentives for increased productivity, but the nature of the effects depends on the chosen indicators and resource allocation mechanisms. Pruvot et al. (2015) note the need to align core, targeted, and external funding, as grant and project funding often requires co-financing, coverage of indirect costs, and stable staffing. Auranen and Nieminen (2010) established a link between funding models and the publication performance of universities, but found significant differences across countries. Thus, the absolute volume of financial resources does not provide sufficient information without considering their structure and conditions of use.

Attracting external resources expands the capabilities of higher education, but at the same time increases the demands on project management, coordination, and long-term sustainability. Perkmann et al. (2013) demonstrate that university-industry collaboration encompasses joint research, contract work, consulting, knowledge sharing, and various informal forms of cooperation. These relationships provide access to funding, data, equipment, and applied problems that can be integrated into educational programs. Klincewicz and Zaei (2025), studying investments in research infrastructure at higher education institutions in Poland and the Czech Republic, found that positive outcomes depend on the combination of infrastructure, human resources, specialization, project activity, and external partnerships. Consequently, capital expenditures generate competitive advantages when the created capacity is sufficiently utilized.

Scholars in our country examine higher education funding through the interrelationships of public funding, autonomy, revenue diversification, and institutional performance. Degtyarova et al. (2018) analyzed the national and local aspects of higher education funding and substantiated the need to improve budget allocation based on institutional performance. Polianovskyi (2022) examined the transition from the legacy funding model to performance-based funding and noted the need to consider the institutional diversity of higher education institutions. Both studies support the feasibility of shifting from funding for maintenance to funding for the ability to achieve specific educational, research, and social outcomes. Petlenko et al. (2021) examined the potential of using endowment funds to enhance the financial autonomy of classical universities in our country. The authors demonstrate that revenue diversification expands an institution's financial capacity but does not replace proper resource management and stable core funding. Kapustian et al. (2021) used a university in our country as an example to conduct an econometric assessment of financial sustainability during the pandemic and demonstrated the importance of the institution's revenue structure and its ability to adapt financial flows to external changes. Shykhnenko and Sbruieva (2024) focus on developing universities' grant-making capacity, project preparation skills, and international collaboration. Taken together, these studies confirm that attracting funds must be accompanied by developing internal organizational capabilities for their effective use.

A separate line of research concerns the assessment of the technical efficiency of higher education institutions. Charnes et al. (1978) developed a basic model of operational envelopment analysis, allowing for the comparison of the relative efficiency of homogeneous units with multiple inputs and outputs. Johnes (2006) substantiated the suitability of operational envelopment analysis for the higher education sector, where financial, human, and infrastructural resources are transformed into heterogeneous educational and research outcomes. De Witte and López-Torres (2017) note that assessing educational efficiency requires a careful selection of inputs, outputs, assumptions about the production function, and external factors. Cross-country studies confirm significant heterogeneity in the efficiency of higher education institutions. Agasisti and Jones (2009) demonstrated the potential for comparing universities across countries using DEA, while also highlighting the influence of national conditions. Thanassoulis et al. (2011) used DEA to assess the costs and efficiency of English higher education institutions and demonstrated that similar resource positions can be associated with different levels of performance. Agasisti and Berbegal-Mirabent (2021) found that the strategic positioning of universities based on their educational, research, and public service missions is associated with differences in the efficiency of internal resource allocation. These results substantiate the need to separate the level of resource provision from the efficiency of resource conversion into outputs.

Multicriteria methods complement DEA, as technical efficiency and competitiveness characterize different aspects of an institution's performance. The analytic hierarchy process enables the formation of theoretically sound weights based on pairwise comparisons and verification of their consistency (Saaty, 1980). The TOPSIS method determines the relative proximity of an alternative to a positive ideal profile and its distance from a negative ideal profile (Hwang & Yoon, 1981). Combining AHP with the entropy method allows one to take into account the theoretical significance of indicators and their actual information differentiation in the sample.

A prerequisite for interinstitutional comparison is the availability of harmonized data. The European Tertiary Education Register contains information on finances, personnel, applicants, mobility, international projects, and research activities of

European higher education institutions. Lepori et al. (2023) characterize the ETER as a reference institutional dataset compiled in compliance with OECD-UNESCO-Eurostat standards. Wagner-Schuster et al. (2023) provided a complete dataset and metadata, enabling independent replication of calculations. This review highlights several unresolved issues. Most studies analyze funding by individual sources or absolute volumes, whereas the development of educational innovation depends on a combination of research, external, infrastructural, and basic resources. Competitiveness is often equated with rankings or publication positions without simultaneously considering international projects, partnerships, mobility, and PhD training. However, resource availability and the technical efficiency of converting resources into results are considered separately. Therefore, a methodological approach is needed that combines the assessment of the funding structure of educational innovations, multi-criteria competitive position, and the efficiency of resource use.

AIMS AND OBJECTIVES

The purpose of this article is to substantiate and test a comprehensive methodological approach to assessing the impact of educational innovation funding on the competitiveness of higher education in a knowledge economy. The research focuses on the development of the competitiveness of higher education institutions under the influence of financial support for innovative educational and scientific activities. The study focuses on the theoretical, methodological, and applied foundations for assessing the funding structure, competitive results, and the efficiency of resource conversion into results.

To achieve this goal, the following objectives were defined:

1. Develop a system of financial indicators.
2. Calculate hybrid weights based on the AHP method and entropy estimation.
3. Create an educational innovation funding index and a competitiveness index based on the MEDI.
4. Assess the resource conversion efficiency using the DEA method. Test the robustness of relationships using rank analysis and robust regression.
5. Create a typology of institutions and determine the scenario implications of changes in the funding structure.

In this article, we aim to test the validity of two interrelated research hypotheses:

- **H1**. A balanced increase in research, external, and infrastructural funding for educational innovation has a stronger positive relationship with higher education competitiveness than a single increase in a single source or area of funding.
- **H2**. A high level of financial and resource support is not necessarily accompanied by high technical efficiency, as a result of which higher education institutions with similar resource positions may differ significantly in their performance in participating in international projects, partnering, and producing PhDs.

Hypothesis H1 is tested by analyzing the rank relationship between the educational innovation funding index and the competitive ideal proximity coefficient, constructing a robust regression model, and comparing scenarios for changing financial parameters. Hypothesis H2 is tested by comparing the funding index with DEA estimates of technical efficiency and clustering institutions by their resource position, competitive performance, and resource conversion efficiency.

METHODS

The study's methodological framework combines a systems approach, comparative analysis, multicriteria evaluation, nonparametric performance assessment, and econometric testing. This approach avoids equating funding with outcomes. First, a resource index is created, then the competitive outcome is determined separately, after which the efficiency of converting inputs into outputs is assessed, and the statistical relationship is tested.

The dataset is based on the full ETER v2 dataset, published on April 27, 2023 (Wagner-Schuster et al., 2023). The study has a retrospective design. The baseline period was 2018, as a preliminary data completeness check revealed that it provided the largest number of simultaneously available observations for all four financial and five competitive indicators, including financial data, incoming Erasmus mobility, and participation in EU framework program projects. Using a single reference year eliminates temporal misalignment between financial resources and performance indicators. The initial dataset for 2018 contained 2,851 institutional records. After selecting institutions classified in the ETER standardized "university" category, removing observations with missing values, and testing the positivity of denominators, a cross-sectional sample of 82 higher education institutions from eight countries was formed.

The results should be interpreted as an assessment of structural relationships within a comparable institutional sample for 2018, rather than as a characterization of the current state of European higher education. The choice of this period ensures internal comparability of the indicators, but limits the possibility of directly transferring quantitative estimates to modern conditions.

Funding for educational innovation was operationalized using four indicators:

1. Research expenditure intensity reflects the portion of resources devoted to knowledge creation and research-oriented teaching.
2. The share of external funding characterizes the ability to attract grants, contracts, and other external resources.
3. Capital expenditure intensity measures the rate of renewal of physical and research infrastructure.
4. Current revenue at purchasing power parity per applicant reflects the overall resource capacity to support high-quality teaching and innovative practices.

Competitiveness was assessed using five performance indicators. The number of EU framework program projects per 100 academic staff characterizes international research engagement. Participation in projects with at least one enterprise partner per 100 academic staff reflects practical interaction. Erasmus incoming mobility per 1,000 applicants indicates the attractiveness of the educational environment. The share of international applicants characterizes the international position, and the intensity of PhD training reflects the reproduction of research potential (Table 1).

Table 1. Indicator system used in the study. Note: All indicators are benefit criteria. PPP denotes purchasing power parity, and FTE denotes full-time equivalent.

Code	Indicator	Calculation method	Economic interpretation
F1	Research funding intensity	R&D expenditure / current revenues	Financing knowledge creation and research-oriented education
F2	Third-party funding share	Third-party funding / current revenues	Income diversification and capacity to attract external projects
F3	Capital expenditure intensity	Capital expenditure / current revenues	Renewal of educational and research infrastructure
F4	Resources per student	Current revenues PPP / total students	Financial basis for education, staff support, and services
C1	EU project activity	EU-FP projects / academic FTE × 100	International research integration
C2	University–industry partnerships	EU-FP industry participations / academic FTE × 100	Applied collaboration and knowledge transfer
C3	Incoming Erasmus mobility	Incoming students / total students × 1 000	International educational attractiveness
C4	Share of international students	Foreign students / students ISCED 5–7	Sustained international position
C5	PhD training intensity	ETER PhD intensity	Reproduction of research capacity

The initial financing and competitiveness indicators were formalised using Equations (1) – (2):

$$F_{1i} = \frac{RD_i}{TR_i}, F_{2i} = \frac{TPF_i}{TR_i}, F_{3i} = \frac{CAPEX_i}{TR_i}, F_{4i} = \frac{TR_i}{ST_i}, \quad (1)$$

$$C_{1i} = 100\frac{EUP_i}{AP_i}, C_{2i} = 100\frac{IND_i}{AP_i}, C_{3i} = 1000\frac{ER_i}{ST_i}, C_{4i} = FS_i, C_{5i} = PHD_i,, \quad (2)$$

where RD – research expenditure; TPF – third-party funding; CAPEX – capital expenditure; TR – current revenues; ST – the total number of students at ISCED levels 5–8; EUP – Framework Programme projects; IND – participations involving an industry partner; AP – academic staff FTE; ER – incoming Erasmus mobility; FS – the share of international students; and PHD, PhD training intensity.

The sample structure demonstrates a substantial concentration of observations in several countries. Swedish institutions account for 35.4% of the sample, while Slovakia and Finland represent 20.7% and 15.9%, respectively. Together, these three countries comprise 72.0% of all observations. Lithuania and Denmark provide additional groups of 10 and 8 institutions, whereas Malta and Luxembourg are represented by one institution each. Such a distribution provides sufficient institutional variation for the overall analysis but limits the interpretation of national averages. Therefore, country-level results should be treated as descriptive characteristics, while the primary unit of analysis remains the individual higher education institution (Table 2).

Table 2. Construction of the research sample. *(Source. Calculated using ETER data)*

Country	Number of institutions	Sample share	Share, %
Sweden	29	0.354	35.4
Slovakia	17	0.207	20.7
Finland	13	0.159	15.9
Lithuania	10	0.122	12.2
Denmark	8	0.098	9.8
Cyprus	3	0.037	3.7
Malta	1	0.012	1.2
Luxembourg	1	0.012	1.2
Total	82	1.000	100.0

Preliminary data analysis revealed significant heterogeneity of institutions in terms of funding scale, number of students, project activity, and international mobility. Under such conditions, individual extremely high or low values can disproportionately affect the min–max normalization limits, entropy weights, TOPSIS distances and regression model coefficients. To limit such influence without removing institutions from the sample, two-way winsorization was applied.

For each indicator j, the lower $Q_{0.025,j}$ and upper $Q_{0.975,j}$ percentiles were determined. The lower percentile is the value below which 2.5% of the observations are located, and the upper percentile is the value above which 2.5% of the observations are located. Values below $Q_{0.025,j}$ were replaced by the lower threshold value, and values above $Q_{0.975}$ were replaced by the upper threshold value. Observations between these limits remained unchanged:

$$x_{ij}^{w} = \min\{\max(x_{ij}, Q_{0.025,j}), Q_{0.975,j}\}. \quad (3)$$

After winsorisation, all benefit indicators were transformed to the interval [0, 1] using min–max normalisation according to Equation (4). A value of 0 corresponds to the lowest result in the sample, whereas a value of 1 corresponds to the highest result after adjustment for extreme values.

$$z_{ij} = \frac{x_{ij}^{w} - \min_i x_{ij}^{w}}{\max_i x_{ij}^{w} - \min_i x_{ij}^{w}}. \quad (4)$$

The weights of the indicators were determined using a hybrid procedure that combines theoretical and information components. The method of hierarchy analysis was used to formalize the relative theoretical importance of the indicators of financing and competitiveness. Its use is due to the fact that the indicators reflect different aspects of the institution's activities in terms of economic content and cannot be automatically considered equivalent. The entropy method complements the AHP and takes into account the actual differentiation of the values of the indicators in the sample under study. The pairwise comparison matrices were formed by the authors based on a theoretical review, economic interpretation of the indicators, and a consistent comparison of the contribution of each criterion to the financing of educational innovations or the formation of competitive results. For each pair of criteria j and k, the element a_{jk} reflects how much the criterion j is more important than the criterion k. The matrix has the property of mutual inversion $a_{kj}=1/a_{jk}$, and on the main diagonal $a_{jj}=1$.

For pairwise comparisons, the fundamental Saaty scale from 1 to 9 was used. The value 1 means equal importance of the criteria, 3 - moderate preference of one criterion, 5 - strong preference, 7 - very strong preference, 9 - extreme preference. The values 2, 4, 6, and 8 are used as intermediate scores. The inverse values 1/2,1/3,…,1/9 are used when the preference belongs to the criterion located in the column of the matrix.

$$A\mathrm{w} = \lambda_{\max}\mathrm{w}, \sum_{j=1}^{m} w_j = 1, \quad (5)$$

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$$CI = \frac{\lambda_{\max} - m}{m-1}, CR = \frac{CI}{RI}, \tag{6}$$

The financing matrix assigns the highest priority to research funding intensity, with a weight of 0.418 (Table 3). This result reflects the role of research expenditure in generating new knowledge, supporting research-oriented teaching, preparing projects, and developing doctoral training. Third-party funding occupies the second position with a weight of 0.271, indicating the importance of income diversification and access to external partnerships. Resources per student receive a weight of 0.191, while capital expenditure has a weight of 0.120. The lower priority of capital expenditure does not indicate its limited practical value. It reflects the position that infrastructure produces competitive outcomes when it is combined with research teams, projects, services, and adequate operating resources. The consistency ratio of 0.026 confirms the coherence of the pairwise comparisons.

Table 3. Pairwise comparison matrix for financing criteria. Note: λmax = 4.071; CI = 0.024; CR = 0.026.

Criterion	F1	F2	F3	F4	AHP weight
F1	1.000	2.000	3.000	2.000	0.418
F2	0.500	1.000	2.000	2.000	0.271
F3	0.333	0.500	1.000	0.500	0.120
F4	0.500	0.500	2.000	1.000	0.191

The competitiveness matrix gives the highest priority to participation in European Union Framework Programme projects, with an AHP weight of 0.365 (Table 4). University–industry partnerships receive the second-largest weight of 0.239, confirming the importance of applied collaboration and knowledge transfer. The share of international students occupies the third position with a weight of 0.180. Erasmus incoming mobility and doctoral training each receive a weight of 0.108. This distribution emphasises sustainable institutional engagement in research networks and partnerships rather than short-term mobility outcomes alone. The consistency ratio of 0.016 remains substantially below the acceptable threshold of 0.10 and confirms that the priority structure is internally consistent.

Table 4. Pairwise comparison matrix for competitiveness criteria. Note: λmax = 5.072; CI = 0.018; CR = 0.016.

Criterion	C1	C2	C3	C4	C5	AHP weight
C1	1	2	3	2	3	0.365
C2	0.5	1	2	2	2	0.239
C3	0.333	0.5	1	0.5	1	0.108
C4	0.500	0.5	2	1	2	0.180
C5	0.333	0.5	1	0.5	1	0.108

The objective component of the weights is formed using the entropy method. For each indicator, the p-particles are determined using formula (7):

$$p_{ij} = \frac{z_{ij} + \varepsilon}{\sum_{i=1}^{n} z_{ij} + n\varepsilon}, \tag{7}$$

where ε is a small positive constant to avoid the logarithm of zero.

Entropy and the degree of information diversification are calculated using formula (8), and the entropy weights are calculated using formula (9). Indicators with greater differentiation between establishments receive a higher objective weight.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij}, \qquad d_j = 1 - e_j, \tag{8}$$

$$w_j^E = \frac{d_j}{\sum_{k=1}^{m} d_k}. \tag{9}$$

The final hybrid weights were determined by geometrically aggregating the AHP and entropy components according to Equation (10). The geometric form prevents one source of weights from fully compensating for a low value of the other and maintains a balance between theoretical relevance and empirical informativeness.

$$w_j^H = \frac{\sqrt{w_j^{AHP} w_j^E}}{\sum_{k=1}^{m} \sqrt{w_k^{AHP} w_k^E}}. \tag{10}$$

The hybrid weighting changes the initial AHP proportions by incorporating the actual differentiation of institutions (Table 5). Within the financing group, research funding retains the highest weight of 0.281, while resources per student increase to 0.268 because of their considerable informational variation. Third-party funding receives a comparable weight of 0.259, whereas capital expenditure remains the least influential financing criterion at 0.192. In the competitiveness group, European Union projects and industry partnerships jointly account for 55.4% of the final weight. The share of international students also has a substantial contribution of 0.214. Erasmus mobility and doctoral training receive lower weights, although they remain necessary for representing international educational attractiveness and the reproduction of research capacity. The resulting structure balances theoretical priorities with the empirical heterogeneity of the sample.

Table 5. Hybrid indicator weights.

Group	Code	Indicator	AHP	Entropy	Hybrid weight
Financing	F1	Research funding	0.418	0.169	0.281
	F2	Third-party funding	0.271	0.222	0.259
	F3	Capital expenditure	0.120	0.273	0.192
	F4	Resources per student	0.191	0.336	0.268
Competitiveness	C1	EU projects	0.365	0.241	0.300
	C2	Industry partnerships	0.239	0.264	0.254
	C3	Erasmus mobility	0.108	0.102	0.106
	C4	International students	0.180	0.249	0.214
	C5	Doctoral training	0.108	0.144	0.126

The Educational Innovation Financing Index (IFI) was calculated as the weighted sum of the normalised financing indicators according to Equation (11). The index ranges from 0 to 1 and characterises the institution's relative resource position within the sample.

$$IFI_i = \sum_{j=1}^{4} w_j^H z_{ij}. \tag{11}$$

The Competitiveness Composite Index was constructed using the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). First, a vector-normalised matrix and weighted values were obtained using Equation (12).

$$r_{ij} = \frac{x_{ij}^w}{\sqrt{\sum_{i=1}^{n} \left(x_{ij}^w\right)^2}}, v_{ij} = w_j^H r_{ij}. \tag{12}$$

The positive and negative ideal solutions were then determined using Equation (13); the Euclidean distances were calculated using Equation, and the closeness coefficient CCI was obtained using Equation (14). The closer CCI is to 1, the closer the institution's profile is to the best combination of outcomes in the sample.

$$A_j^P = \max(v_{1j}, \dots, v_{nj}), \quad A_j^N = \min(v_{1j}, \dots, v_{nj}), \tag{13}$$

$$CCI_i = \frac{D_i^N}{D_i^P + D_i^N}. \tag{14}$$

The CCI coefficient shows how close the competitive profile of a particular institution is to the best simultaneous combination of participation in European Union framework program projects, partnerships with enterprises, incoming Erasmus mobility, the share of foreign education applicants and the intensity of doctoral training. A value close to 1 means a high relative proximity to the positive ideal and a significant distance from the worst profile. A value close to 0 means the opposite situation. The economic essence of the CCI is to assess the ability of an institution to form a balanced portfolio of international, partnership, educational, and research results. The coefficient is used to rank institutions, compare the competitive result with the funding index, and identify cases where a significant resource position is not accompanied by

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a corresponding competitive result. The CCI is a relative indicator within the studied sample and should not be interpreted as an absolute assessment of the quality of education or technical efficiency.

The technical efficiency of resource conversion was estimated using an input-driven BCC DEA model with varying returns to scale. The inputs were PPP research expenditures, PPP capital expenditures, and FTE academic staff. The outputs were the number of framework program projects, participation in enterprise projects, and the number of ISCED 8 applicants. Problem (16)

$$\min_{\theta,\lambda_1,\dots,\lambda_n} \theta$$

$$\textstyle\sum_{j=1}^{n} \lambda_j x_{kj} \le \theta x_{ki}, \quad k = 1, \dots, K \tag{16}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ri}, \quad r = 1, \dots, R$$

$$\textstyle\sum_{j=1}^{n} \lambda_j = 1, \quad \lambda_j \ge 0$$

where θ is the efficiency estimate, and λ are the weights of the comparison institutions.

A value of θ = 1 indicates being at the efficient frontier.

Statistical testing was performed in two directions. The rank relationship between IFI, CCI, and DEA was estimated using Spearman's coefficient using formula (19) with 5,000 bootstrap replicates for the confidence interval. The impact of financial parameters on CCI was tested using a working OLS model with HC3 standard error adjustment using formula (17). Explanatory variables were standardized, so the coefficients reflect the change in CCI with an increase in the corresponding parameter by 1 standard deviation. Taking the logarithm of F4 reduces right-sided skewness. Multicolinearity was tested using VIF.

Statistical testing was carried out in 2 consecutive directions. At the 1st stage, the monotonic rank relationship between the IFI educational innovation financing index, the CCI competitive proximity coefficient, and the DEA technical efficiency score was assessed. For this purpose, the Spearman rank correlation coefficient was used. The choice of this coefficient is due to the fact that it does not require a normal distribution of variables, does not imply mandatory linearity of the relationship, and is suitable for indices with a limited range of values. Since the DEA scores have the same values, in particular a score of 1 for institutions on the efficient frontier, the coefficient was defined as the correlation of the average ranks:

$$CCI_i = \beta_0 + \beta_1 \tilde{F}_{1i} + \beta_2 \tilde{F}_{2i} + \beta_3 \tilde{F}_{3i} + \beta_4 \widetilde{\ln F_{4i}} + \varepsilon_i \tag{17}$$

where R_i and S_i are the average ranks of the 2 compared variables; R^- and S^- are the average values of the corresponding ranks; n=82 is the number of institutions. This form of calculation correctly takes into account the related ranks.

Confidence intervals for ρs were determined by the nonparametric bootstrap method. At each iteration, a new sample of 82 institutions was randomly formed from the initial sample, with replacement, after which the Spearman coefficient was recalculated. The procedure was repeated 5,000 times. The lower and upper limits of the 95% confidence interval were determined as the 2.5th and 97.5th percentiles of the resulting bootstrap distribution. The number of 5,000 replications was chosen as a compromise between the stability of the percentile limits and computational costs. To confirm the sufficiency of this number, it is necessary to additionally check that the interval limits at 2,500 and 5,000 replications do not change significantly.

In the 2nd stage, the partial relationship of financial parameters with CCI was estimated using the working ordinary least squares model:

$$\Delta_s = \frac{\overline{CCI}_s - \overline{CCI}_0}{\overline{CCI}_0} \times 100\% \tag{18}$$

$$\rho_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \tag{19}$$

Clustering was performed using the k-means method on standardized IFI, CCI, and DEA. The number of clusters was four, corresponding to the managerial typology of resource position and performance. To ensure algorithm robustness, 50 initializations and a fixed random seed were used. The calculations were performed in Python 3.13 using pandas, NumPy, SciPy, statsmodels, and scikit-learn. All intermediate calculations were double-checked for weight sums, index ranges, matrix consistency, and the identity of scenario increments.

Preliminary standardization eliminates the influence of different variations of indicators and ensures their comparable contribution to determining the Euclidean distance. The method minimizes the sum of squares of distances from institutions to the centroids of the corresponding clusters. The number of clusters K=4 was determined in accordance with the management goal of the study, which involves distinguishing 4 typical combinations of resource position, competitive results, and technical efficiency. To reduce dependence on the random initial location of the centroids, the algorithm was run 50 times with different initial centers, after which the distribution with the smallest intracluster sum of squares was selected. To ensure reproducibility, a fixed value of the random number generator was used.

RESULTS

Today, two important financial trends can be distinguished. First, spending on education remained relatively stable in the structure of GDP, although its level differed significantly between countries. Sweden, Denmark and Finland maintained their highest performances steadily, while Slovakia, Lithuania and Luxembourg operated with significantly lower relative government spending. Ukraine remained between these groups, which indicates that the share of GDP allocated to education alone cannot explain the difference in the financial capacity of higher education systems. Secondly, the absolute resource base, economic scale, purchasing power, financial structure and the ability to attract additional resources are also important elements influencing the amount of financing of the knowledge economy.

Before assessing the institutional sample, it is appropriate to characterise the financial environment in which higher education institutions operate. For this purpose, government expenditure on education and expenditure on research and development as a percentage of GDP were compared for selected countries represented in the institutional sample and for Ukraine. These indicators describe different aspects of financial support. Education expenditure reflects the general resource commitment to the education system, whereas R&D expenditure characterises the intensity of financing knowledge creation and innovation across the economy, including the higher education sector. Therefore, the latter is used as a contextual indicator of the financial environment of the knowledge economy rather than as a direct measure of university research funding (Table 6).

Table 6. Dynamics of education and R&D expenditure in selected countries, % of GDP.

Country	Indicator	2018	2019	2020	2021
Finland	Education expenditure	6.32	6.45	6.68	6.59
	R&D expenditure	2.78	2.82	2.93	3.01
Slovakia	Education expenditure	3.94	4.27	4.72	4.72
	R&D expenditure	0.83	0.82	0.89	0.90
Luxembourg	Education expenditure	3.66	3.74	3.85	3.69
	R&D expenditure	1.17	1.18	1.10	1.04
Ukraine	Education expenditure	5.32	5.44	5.38	5.14
	R&D expenditure	0.47	0.43	0.41	0.38

Descriptive statistics confirm significant heterogeneity among the institutions studied. The average share of research expenditures is 35.7% of operating revenue, with a median of 31.9%. The average share of external funding is 21.8%, with a median of 20.9%. Capital expenditures have a lower average share of 3.7%, but reach a maximum of 19.6%. Resource provision per applicant differs by more than a factor of 12 between the minimum and maximum observations. Significant variation is also observed in project activity, mobility, and the international composition of applicants (Table 7).

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Table 7. Descriptive statistics of the indicators. Note: Ratio indicators are reported as percentages. Descriptive statistics are presented before winsorisation.

Indicator	Mean	Q1	Median	Q3	Minimum–maximum
F1, R&D share	35.7	21.5	31.9	52.4	4.2–82.6
F2, third-party funding	21.8	10.6	20.9	31.7	1.5–70.9
F3, capital expenditure	3.7	1.9	2.8	4.3	0.1–19.6
F4, resources per student, PPP	12 459	6 258	10 379	14 463	3 860–47 698
C1, EU projects / 100 FTE	2.63	0.61	1.76	3.40	0.00–18.59
C2, partnerships / 100 FTE	1.77	0.26	1.16	2.40	0.00–10.05
C3, Erasmus / 1.000 students	20.64	11.10	17.44	27.14	0.00–120.09
C4, share of international students	9.5	3.9	6.1	10.4	1.6–69.2
C5, PhD intensity	4.0	1.3	3.1	5.4	0.0–19.5

Q1 denotes the first quartile and corresponds to the 25th percentile. Q2 denotes the second quartile, which is equal to the median and corresponds to the 50th percentile. Q3 denotes the third quartile and corresponds to the 75th percentile. The interval between Q1 and Q3 contains the central 50% of observations. Ratio indicators are reported as percentages. The descriptive statistics are calculated using the original values before winsorisation.

The hybrid weighting assigned the highest weight to the intensity of research funding and applicant resourcing in the financial group. Their resulting weights are 0.281 and 0.268. The share of external funding received a weight of 0.259, and capital expenditures a weight of 0.192. In the competitiveness group, the highest weights were given to framework program projects (0.300) and enterprise partnerships (0.254). The share of international applicants received a weight of 0.214, doctoral training intensity a weight of 0.126, and Erasmus mobility a weight of 0.106. The consistency ratio for both AHP matrices is below 0.10.

The TOPSIS ranking demonstrates significant differentiation in competitive profiles. KTH Royal Institute of Technology (Sweden) took first place with a CCI of 0.722. The following positions are held by Chalmers University of Technology (Sweden) with a CCI of 0.687 and the University of Cyprus (Cyprus) with a CCI of 0.668. The group of institutions with relatively high CCI values also includes Cyprus University of Technology (Cyprus), Karolinska Institutet (Sweden), Luleå University of Technology (Sweden), and the Technical University of Denmark (Denmark). The lower half of the ranking is represented by institutions with low levels of participation in international projects, partnerships with enterprises, or international mobility programs. Furthermore, a low CCI value is not always accompanied by a low IFI, confirming the need for a separate analysis of resource conversion efficiency. The selected ranking positions demonstrate that funding, competitiveness, and technical efficiency shape different institutional profiles. KTH Royal Institute of Technology (Sweden) and Chalmers University of Technology (Sweden) combine high funding indices, leading competitiveness values, and a DEA efficiency of 1. The University of Cyprus (Cyprus) ranks third with a moderate IFI of 0. This is in contrast to the strongest competitive positions in the rankings. Karolinska Institutet (Sweden) has the highest IFI value among the leaders, although its CCI is lower than the values of the top four institutions. The University of Luxembourg (Luxembourg) combines a relatively strong competitive position with a DEA efficiency of 0.569, indicating room for improvement in resource efficiency. Institutions at the bottom of the rankings have low CCI values but vary significantly in DEA. Therefore, a weak competitive position may be due to resource constraints, low resource efficiency, or a combination of both.

The selected ranking positions demonstrate that financing, competitiveness, and technical efficiency form different institutional profiles. KTH Royal Institute of Technology and Chalmers University of Technology combine high financing indices, leading competitiveness values, and DEA efficiency equal to 1. The University of Cyprus reaches third place with a moderate IFI of 0.438, indicating an effective conversion of a comparatively limited resource position into strong competitive outcomes. Karolinska Institutet has the highest IFI among the displayed leaders, although its CCI remains below the values recorded for the first four institutions. The University of Luxembourg combines a relatively strong competitiveness value with DEA efficiency of 0.569, revealing considerable potential for resource conversion improvement. The institutions at the bottom of the ranking have low CCI values, although their DEA scores differ substantially. Therefore, a weak competitive position can arise from resource constraints, conversion inefficiency, or a combination of both factors (Table 8).

Table 8. Selected positions in the institutional TOPSIS ranking. Note: The 8 highest and 5 lowest positions among the 82 institutions are shown.

Rank	Institution	Country	IFI	CCI	DEA
1	KTH Royal Institute of Technology	Sweden	0.628	0.722	1
2	Chalmers University of Technology	Sweden	0.719	0.687	1
3	University of Cyprus	Cyprus	0.438	0.668	1
4	Cyprus University of Technology	Cyprus	0.318	0.579	1
5	Karolinska Institutet	Sweden	0.867	0.550	0.997
6	Luleå University of Technology	Sweden	0.446	0.544	1
7	Technical University of Denmark	Denmark	0.801	0.535	1
8	University of Luxembourg	Luxembourg	0.590	0.526	0.569
78	Constantine the Philosopher University in Nitra	Slovakia	0.136	0.049	0.827
79	Siauliai University	Lithuania	0.414	0.047	0.314
80	University of Gävle	Sweden	0.154	0.033	0.169
81	Ersta Sköndal Bräcke University College	Sweden	0.249	0.033	0.625
82	Swedish School of Sport and Health Sciences, GIH	Sweden	0.216	0.030	0.469

Table 7 has 3 mutually exclusive indicators. IFI is an integrated index of financing of light innovations and characterizes the significant resource position of the mortgage within the sample. CCI is a coefficient of close proximity to a positive ideal competitive profile, developed using the TOPSIS method. DEA is an assessment of the technical efficiency of the transformation of resources and the resulting results, based on the input-oriented BCC model with varying output to scale.

The DEA value is in the interval $0<\theta \leq 1$. The value $\theta=1$ means that the distribution of distributions on the main effective boundary between the monitored selections and the corresponding inputs and outputs does not affect any other contribution or their linear combinations that would demonstrate the best results. The value of $\theta<1$ indicates the presence of a radial reserve of shortening inputs for saving the flow of results. For example, DEA 0.569 means that the assumption of the model implies a theoretical radial reserve for the shortening of short-term inputs by 43.1% due to the savings in the flow rate of outputs.

Figure 1 visualises four strategic positions based on the median values of IFI and CCI. Institutions in the upper-right quadrant combine above-median financing with above-median competitiveness and represent the strongest balanced profiles. The upper-left quadrant contains institutions that achieve comparatively strong outcomes despite a more limited financing position, indicating effective internal capabilities and potential for scaling. The lower-right quadrant includes resource-rich institutions whose competitiveness remains below the median, signalling reserves in project selection, partnership development, infrastructure utilisation, or internationalisation. Institutions in the lower-left quadrant face simultaneous resource and performance constraints. Differences in marker size additionally demonstrate that institutions with similar IFI and CCI values may have substantially different DEA efficiency.

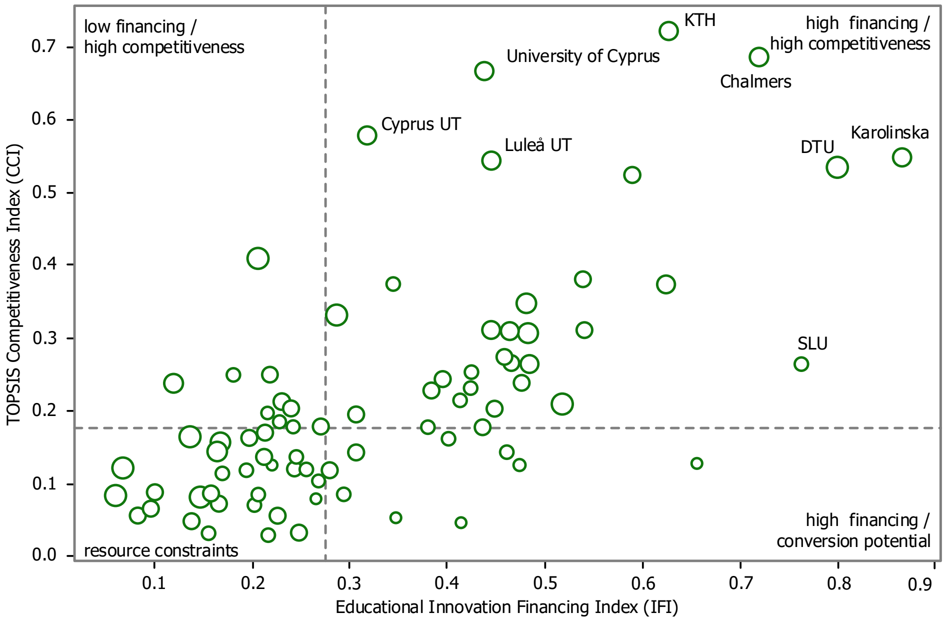

Figure 1. Relationship between educational innovation financing and competitiveness. Note: Marker size is proportional to DEA efficiency. The dashed lines represent the median IFI and CCI values.

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Country aggregation is used only as a descriptive characteristic, as the number of institutions is uneven. The highest average CCI is recorded for Cyprus (0.552), although the group contains three institutions. Luxembourg is represented by one university (0.526). Among countries with a larger number of observations, Denmark has the highest average CCI (0.313). Sweden and Finland have similar average IFIs, but Finland exhibits a higher average DEA efficiency. Slovakia has the lowest average IFI and CCI, while its average DEA efficiency is relatively high (Table 9).

Table 9. Mean results by country. Note: The values are unweighted institutional means. Country comparisons are descriptive.

Country	n	IFI	CCI	DEA
Cyprus	3	0.320	0.552	1.000
Luxembourg	1	0.590	0.526	0.569
Denmark	8	0.418	0.313	0.852
Malta	1	0.218	0.250	0.596
Sweden	29	0.371	0.224	0.579
Finland	13	0.389	0.214	0.882
Lithuania	10	0.350	0.162	0.511
Slovakia	17	0.165	0.114	0.792

The DEA model identified 21 institutions with a score of at least 0.999, and 29 institutions with an efficiency of at least 0.900. The mean DEA value is 0.705, and the median is 0.684. The minimum value is 0.169. The resulting distribution shows that some institutions approach the efficient frontier even with a low IFI, while some well-resourced institutions have significant reserves for converting financial and personnel inputs into project and doctoral outcomes (Table 10).

Table 10. Typology of institutions by financing, competitiveness, and efficiency. *(Source: k-means clustering based on standardised IFI, CCI, and DEA values)*

Cluster	n	IFI	CCI	DEA	F1, %	F2, %	F3, %
Innovation competitiveness leaders	8	0.601	0.601	0.946	56.4	32.5	6.1
Resource-rich institutions with conversion potential	20	0.471	0.280	0.843	51.3	33.0	2.4
Efficient resource converters	17	0.159	0.148	0.921	20.9	8.0	3.7
Resource-constrained institutions	37	0.278	0.131	0.479	29.6	19.7	3.9

The cluster of innovative competitiveness leaders includes eight establishments. It has the highest average IFI (0.601), CCI (0.601), and DEA (0.946). The group of resource-rich establishments with conversion reserves includes 20 establishments. Their average IFI is 0.471, but their CCI is 0.280. The group of efficient resource converters includes 17 establishments with a low IFI (0.159), moderately low CCI (0.148), and high DEA (0.921). The largest group of resource-constrained establishments includes 37 facilities and has the lowest average DEA efficiency (0.479). A rank analysis revealed a positive relationship between IFI and CCI. Spearman's rho is 0.640, $p < 0.001$, and the 95% bootstrap interval is [0.480; 0.759]. The relationship between CCI and DEA is moderate and positive, $\rho = 0.466$, $p < 0.001$. At the same time, IFI is almost unrelated to DEA, $\rho = 0.067$, $p = 0.547$. Therefore, resource endowment explains competitive outcomes but does not automatically determine relative technical efficiency (Table 11).

Table 11. Robust regression estimates of CCI determinants. Note: $n = 82$; $R^2 = 0.483$; adjusted $R^2 = 0.456$; $F = 11.50$; $p(F) < 0.001$. The explanatory variables are standardised.

Variable	Coefficient	HC3 SE	z	p	95% confidence interval	VIF
Constant	0.2170	0.0139	15.605	<0.001	[0.1897; 0.2442]	–
F1, research funding	0.0419	0.0218	1.923	0.054	[-0.0008; 0.0845]	2.43
F2, third-party funding	0.0114	0.0245	0.463	0.643	[-0.0367; 0.0595]	1.80
F3, capital expenditure	0.0374	0.0281	1.332	0.183	[-0.0176; 0.0923]	1.08
ln(F4), resources per student	0.0664	0.0196	3.377	<0.001	[0.0278; 0.1049]	1.67

The regression model explains 48.3% of the CCI variance. Resource provision per applicant has the largest and statistically robust positive coefficient of 0.0664, $p < 0.001$. Research funding intensity has a positive coefficient of 0.0419 and approaches the traditional significance level, $p = 0.054$. The coefficients for third-party funding and capital expenditures are positive but individually insignificant. All VIFs range from 1.08 to 2.43, so no significant multicollinearity was detected. The additional model for DEA has an R^2 of 0.146. In this model, the share of third-party funding has a negative coefficient of -0.0733, $p = 0.031$, indicating a difference between resource acquisition and the speed at which they are converted into selected outputs (Table 12).

Table 12. Scenario modelling results. *(Source: calculated using the robust regression model)*

Scenario	Parameter change	Predicted mean CCI	Change, %
Baseline	Actual values of the financing parameters	0.217	0.00
Balanced financing	F1 +10 %, F2 +15 %, F3 +10 %	0.233	7.23
Grant mobilisation	F2 +20 %	0.221	1.70
Infrastructure renewal	F3 +20 %	0.226	4.28
Resource support	F4 +10 %	0.228	5.14

A high increase in CCI yields a balanced funding scenario. Its predicted effect is 7.23%. A 10% increase in resource provision per applicant increases the predicted average CCI by 5.14%. A 20% increase in capital expenditure intensity yields a 4.28% increase. A single-channel increase in the share of third-party funding by 20% yields the smallest effect of 1.70%. The obtained values are consistent with the regression coefficients and show that external funding becomes more effective when combined with research and infrared capabilities (Table 13).

Table 13. Robustness checks. Note: The bootstrap interval was calculated using 5,000 replications.

Test	Statistic	Significance	Result
IFI–CCI	0.640	$p < 0.001$	95 % bootstrap CI [0.480; 0.759]
CCI–DEA	0.466	$p < 0.001$	Moderate positive association
IFI–DEA	0.067	$p = 0.547$	Statistically insignificant association
Kruskal–Wallis test for IFI	51.689	$p < 0.001$	Differences among the 4 clusters
Kruskal–Wallis test for CCI	47.958	$p < 0.001$	Differences among the 4 clusters
Kruskal–Wallis test for DEA	51.428	$p < 0.001$	Differences among the 4 clusters
Maximum VIF	2.43	< 5	No substantial multicollinearity

The robustness checks support the stability of the principal conclusions. The correlation between IFI and CCI is positive and statistically significant, confirming that stronger financing positions are generally associated with better competitive outcomes. The moderate relationship between CCI and DEA indicates that technical efficiency contributes to competitiveness but does not fully determine it. The absence of a statistically significant relationship between IFI and DEA confirms that resource endowment and resource-conversion efficiency constitute separate characteristics. The Kruskal–Wallis results identify statistically significant differences among the four institutional clusters for all three indices. The maximum VIF of 2.43 also confirms the absence of substantial multicollinearity. Consequently, the ranking, typology, and regression findings remain methodologically coherent.

The combined results form a consistent financial and economic interpretation of the relationship between funding for educational innovation and higher education competitiveness. IFI, CCI, and DEA characterize three different aspects of institutional performance. IFI reflects the relative availability of research, external, infrastructure, and basic resources. CCI characterizes the achieved competitive profile in terms of international projects, partnerships, mobility, internationalization, and PhD training. DEA determines how effectively available financial and human resources are converted into selected outcomes. Distinguishing these indicators prevents equating a significant budget with high competitiveness or high technical efficiency. The positive rank correlation between IFI and CCI, for which $\rho=0.640$ and $p<0.001$, means that institutions with stronger resource positions tend to have better competitive outcomes. However, this result does not prove direct causality. Funding creates the material and organizational prerequisites for participation in international projects, partnership development, mobility, and doctoral training, but the actual outcome depends on the quality of project portfolio management, staff capacity, international connections, and internal coordination. Consequently, increased financial resources provide the potential for competitive development, but realizing this potential requires appropriate management mechanisms.

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The regression model explains 48.3% of the CCI variance. The most robust positive correlation was found for resource provision per applicant. A 1 standard deviation increase in standardized ln(F4) is associated with a 0.0664 increase in the CCI. This result demonstrates the importance of sufficient basic resource provision for funding personnel, laboratories, information resources, international services, mobility, and project activities. Research funding intensity also has a positive coefficient of 0.0419, although its statistical significance is near the traditional threshold. The share of external funding and capital expenditures have positive, but individually statistically insignificant, coefficients, indicating that their results depend on their combination with other resource and organizational components. The near-zero correlation between IFI and DEA, for which p=0.067 and p=0.547, confirms that resource endowment does not automatically determine technical efficiency. An institution may have a significant budget and high research or capital expenditures, but fail to achieve proportional increases in international projects, partnerships, and doctoral training. At the same time, individual institutions with limited resources are located near the efficient frontier due to resource concentration, specialization, appropriate project selection, and the use of partner networks. From a financial and economic perspective, this means that the size of funds raised and the effectiveness of their use must be assessed. Scenario assessment separately further confirms the importance of the funding structure. A balanced, simultaneous increase in research funding by 10%, external funding by 15%, and capital expenditures by 10% yields a projected average CCI growth of 7.23%. This result exceeds the effect of a single-channel increase in resource provision per applicant, capital expenditures, or external funding. Therefore, financial policy for supporting educational innovation should be structured as an interconnected portfolio. Research funding supports knowledge creation and team development, external funding provides access to projects and partners, and capital resources create the infrastructure conditions for the implementation and scaling of relevant projects.

Clustering clarifies the management implications for different groups of institutions. Leaders in innovative competitiveness should maintain a balanced resource portfolio and avoid excessive reliance on short-term projects. Resource-rich institutions with potential for conversion should strengthen project selection, interdepartmental coordination, partnership development, and infrastructure utilization assessment. Effective resource converters should expand their funding base without losing their existing internal efficiency. Resource-constrained institutions should concentrate their resources on specific specializations, create consortia, develop equipment sharing, and join international partnership networks.

The overall financial and economic outcome is that the competitiveness of higher education is determined not by the maximum possible volume of a single funding source, but by the consistency of the resource structure and capacity.

The obtained results also provide an analytical basis for adapting the identified financing principles to higher education institutions in Ukraine. Such adaptation should focus on creating a balanced innovation-financing portfolio that combines stable core funding, research expenditure, competitive grants, partnerships with enterprises, and targeted infrastructure investment. Higher education institutions should establish internal co-financing reserves for international projects, link capital expenditure to measurable infrastructure utilization and project pipelines, and introduce annual monitoring of resource provision, competitive outcomes, and resource-conversion efficiency. Institutions with limited financial resources should prioritize specialization, inter-university consortia, shared research infrastructure, and participation in international project networks. At the same time, the recommendations should be treated as directions for adaptation rather than direct estimates for Ukraine because the empirical institutional sample of this study consists of universities from eight EU countries.

DISCUSSION

The results confirm that funding for educational innovation is an important factor in competitiveness, but its impact is determined not only by volume but also by the structure and ability of an institution to translate resources into results. The strong rank correlation between IFI and CCI is consistent with the findings of Auranen and Nieminen (2010) regarding the dependence of performance on the financial environment. However, the near-zero correlation between IFI and DEA demonstrates that resource advantage and technical efficiency are distinct characteristics. This result is consistent with the approaches of Jones (2006) and Wolszczak-Derlacz (2017), who note the need to consider multiple inputs, outputs, and institutional heterogeneity.

The positive coefficient for research funding intensity and a p-value close to 0.05 indicate the importance of the research component. In a knowledge economy, teaching and research are mutually reinforcing. Research funding creates new content for educational programs, attracts project applicants, supports doctoral schools, and increases the institution's attractiveness to international partners. This interpretation is consistent with the triple interaction model of Etzkowitz and Leydesdorff (2000) and the results of Guerrero et al. (2015) on the combined economic impact of education, research, and entrepreneurship.

A separate increase in external funding has a weak scenario effect, and in the additional DEA regression, its share is associated with a decrease in current technical efficiency. A direct interpretation of this result as a negative impact of grants would be erroneous. First, project-based funding initially increases inputs, while publications, doctoral results, and partnerships emerge with a time lag. Second, a high share of external funding can be associated with complex projects, administrative burdens, and the concentration of resources in narrow areas. Third, ETER does not reflect the quality of each project or its long-term impact. The conclusion by Muscio et al. (2013) on the complementarity of core and private funding supports a portfolio approach rather than a substitution approach.

A comparison with Klincewicz and Zaei (2025) reveals a general conclusion about the configurational nature of infrastructure investments. Capital expenditures alone were not a statistically significant regressor of the CCI, although an increase in capital expenditures had a positive effect. This difference is explained by the fact that infrastructure is a long-term resource, and its effectiveness depends on personnel, specialization, project load, and the external environment. Therefore, investment decisions should be accompanied by a capacity utilization plan, applicant access indicators, and a research partnership portfolio.

The methodological combination of AHP and entropy weights reduces reliance on a single source of priorities. AHP reflects the theoretical perspective that project and partnership activity have a greater impact on competitiveness. Entropy accounts for the actual differentiation of the sample. The high weights of EU projects and partnerships are consistent with Perkmann et al. (2013), who demonstrate a wide range of academic interactions with enterprises, as well as with the European Commission (2022), which identifies transnational cooperation as one of the main areas for strengthening universities.

The scientific novelty of the obtained results lies in the development of an integrated methodological approach to assessing the relationship between funding for educational innovation and the competitiveness of higher education. The proposed approach combines the determination of hybrid weights using the methods of hierarchy analysis and information entropy, the construction of an index of funding for educational innovation, an assessment of competitive position using the TOPSIS method, the determination of the technical efficiency of resource conversion using a DEA model with varying returns to scale, and a statistical verification of funding and relationships. Unlike approaches focused on comparing individual financial or performance indicators, the proposed methodology allows for the differentiation of resource endowment, achieved competitive position, and the effectiveness of converting financial, human, and infrastructural resources into project, partnership, international, and research results.

The study has limitations. The sample was selected for data completeness, so it is dominated by institutions in Northern Europe and certain countries of Central and Eastern Europe. The results are not representative of all European universities. The year 2018 was chosen to ensure the completeness of funding, Erasmus, and framework projects, so the assessment does not capture the impact of the pandemic and subsequent crises. The spatial design does not allow for causal inferences. ETER financial indicators are harmonized, but national accounting practices and institutional missions remain heterogeneous. The MEDI and DEA are sensitive to the choice of indicators, and the effects of external funding may manifest with a lag.

CONCLUSIONS

The study achieved its stated objectives, which were to substantiate and test a comprehensive methodological approach to assessing the relationship between funding for educational innovation and the competitiveness of higher education institutions. The developed approach ensures a consistent distinction between resource position, competitive performance, and the technical efficiency of resource use. The combination of hybrid AHP entropy weights, the Educational Innovation Funding Index, the TOPSIS method, BCC DEA, rank analysis, robust regression, clustering, and scenario assessment enables a comprehensive analysis of the various components of funding for educational innovation. The results confirmed a strong positive rank relationship between the IFI and CCI. A Spearman coefficient of 0.640 at $p < 0.001$ indicates that a stronger resource position is predominantly associated with a better combination of international projects, partnerships with enterprises, inbound mobility, internationalization, and doctoral training. However, the cross-sectional design of the study does not provide grounds for interpreting the established relationship as a direct causal effect of funding.

Hypothesis H1 received empirical support. A scenario of balanced growth in research funding by 10%, external funding by 15%, and capital expenditures by 10% resulted in a predicted increase in the average CCI of 7.23%. This effect exceeds the results of single-channel scenarios. Therefore, funding for educational innovation should include a balanced combination of basic resources, research expenditures, grant revenues, and infrastructure investments. A regression analysis revealed that resource provision per education applicant has the most robust positive relationship with competitive position.

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The fitted coefficient is 0.0664 at $p<0.001$. Research funding intensity also has a positive relationship with CCI, although its statistical significance is near the traditional threshold. External funding and capital expenditures generate positive potential, but their separate increases do not provide the same results as a balanced combination of several financial components.

Hypothesis H2 also received empirical support. The relationship between IFI and DEA is statistically insignificant and close to zero. Consequently, a high level of resource endowment does not guarantee the effective conversion of resources into international projects, partnerships, and doctoral training. The DEA assessment identified 21 institutions at the relatively efficient margin, while other well-resourced institutions have significant potential for efficiency improvement. Consequently, financial policy should consider the volume of resources, their distribution structure, and the effectiveness of their use.

Scenario modeling yields the most practical results. A balanced scenario outperforms single-channel options by simultaneously strengthening research activity, the ability to attract external resources, and infrastructure readiness. Funding for an innovation portfolio should synchronize at least three cycles. The first cycle is associated with knowledge creation and team training. The second encompasses attracting grants and partners. The third provides equipment, space, services, and scaling. A gap between cycles reduces the marginal effectiveness of each individual component.

The clustering results provide concrete management guidelines. Leaders need support for a balanced portfolio and protection against overreliance on short-term projects. Resource-rich institutions with the potential for conversion should focus on project selection mechanisms, interfaculty coordination, partnerships, and infrastructure utilization. Effective resource converters demonstrate strong internal capabilities but require scaling their funding base. Resource-constrained institutions should develop narrow specializations, consortia, and shared access to infrastructure, as directly replicating the model of large universities is financially unrealistic.

The emerging cluster typology confirmed the need for differentiated funding management. Leaders need to maintain a balanced portfolio and long-term financial sustainability. Well-resourced institutions with potential for conversion need to improve project management, partnerships, and infrastructure utilization. Effective resource converters should scale up their funding base, while resource-constrained institutions should develop specialization, consortia, and shared access to research facilities. The practical significance of the results lies in the potential application of the proposed approach to strategic budgeting for educational innovation, assessing grant and investment portfolios, comparing institutions, identifying infrastructure utilization reserves, and developing differentiated financial measures. In our opinion, the central management benchmark should not be the absolute volume of funds raised, but rather the improvement of competitive performance in terms of the financial, human, and infrastructural resources utilized.

The country-level financial analysis provides an important context for interpreting the institution-level results obtained for the 82 higher education institutions. The dynamics of education and R&D expenditure demonstrate that the general level of financing of education does not by itself determine the financial capacity of a knowledge economy. Finland combined consistently high education expenditure with R&D intensity close to 3% of GDP, whereas Slovakia maintained considerably lower R&D intensity despite an increase in education expenditure. Ukraine showed another configuration: education expenditure remained above 5% of GDP during 2018–2021, while R&D expenditure decreased from 0.47% to 0.38% of GDP. Consequently, the development of educational innovation requires not merely an increase in general education expenditure but a financial structure capable of supporting research, competitive projects, infrastructure renewal, and cooperation with external partners.

For Ukrainian higher education institutions, this finding substantiates the need to combine stable core financing with competitive research resources, international grants, enterprise partnerships and targeted infrastructure investment. Financial management should simultaneously assess the amount of resources attracted, their distribution among research, external and infrastructure components, and the effectiveness of their conversion into competitive outcomes. The recommendations derived from the EU institutional sample should therefore be adapted to the financial conditions of Ukraine rather than mechanically transferred to Ukrainian higher education institutions.

Future research should extend the analysis through a harmonized panel dataset covering several periods and, subject to data comparability, higher education institutions in Ukraine. Further methodological development should include lagged and panel regression models, bootstrap and metafrontier DEA, and additional outcomes related to employment, patents, open science, joint educational programs, international partnerships, and knowledge transfer. Such an extension would make it possible to distinguish more precisely between short-term resource effects and the longer-term consequences of educational innovation financing.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ФІНАНСУВАННЯ ОСВІТНІХ ІННОВАЦІЙ ЯК ФАКТОР ПІДВИЩЕННЯ КОНКУРЕНТОСПРОМОЖНОСТІ ЗАКЛАДІВ ВИЩОЇ ОСВІТИ КРАЇН ЄС У КОНТЕКСТІ ЕКОНОМІКИ ЗНАНЬ

Статтю присвячено обґрунтуванню та емпіричній перевірці фінансування освітніх інновацій як чинника конкурентоспроможності закладів вищої освіти в умовах економіки знань. Актуальність дослідження визначається тим, що збільшення фінансових ресурсів саме собою не гарантує посилення міжнародної, дослідницької та партнерської позиції закладу, оскільки результат залежить від структури фінансування й ефективності перетворення ресурсів на проєкти, мобільність, міжнародне залучення та підготовку дослідників. Метою дослідження є розробка комплексного підходу до оцінювання взаємозв'язку між фінансуванням освітніх інновацій і конкурентоспроможністю закладів вищої освіти. Інформаційну основу сформовано за даними European Tertiary Education Register за 2018 р. для 82 університетів 8 європейських країн. Методика поєднує вінзоризацію й нормалізацію даних, метод аналізу ієрархій, ентропійне визначення ваг, інтегральне оцінювання, MEP, DEA-модель зі змінним ефектом масштабу, робастну регресію, кластеризацію та сценарне моделювання. Сформовано індекс фінансування освітніх інновацій за інтенсивністю дослідницьких витрат, часткою стороннього фінансування, капітальними витратами та ресурсним забезпеченням у розрахунку на здобувача. Конкурентоспроможність оцінено за участю в проєктах рамкових програм Європейського Союзу, партнерствами з підприємствами, вхідною мобільністю Erasmus, часткою іноземних здобувачів та інтенсивністю підготовки докторів філософії. Установлено сильний позитивний ранговий зв'язок між індексами фінансування й конкурентоспроможності. Робастна регресія пояснює 48,3% варіації підсумкового індексу, а найбільш стійкий позитивний ефект має ресурсне забезпечення на одного здобувача. Сценарій дослідницького, зовнішнього й інфраструктурного фінансування підвищує прогнозне середнє значення конкурентоспроможності на 7,23%, що перевищує результат одноканальних сценаріїв. Практичне значення полягає в можливості застосування підходу для бюджетування інноваційних портфелів, порівняння закладів і визначення резервів конверсії фінансових ресурсів у конкурентні переваги.

Ключові слова: фінансування освіти, освітні інновації, вища освіта, конкурентоспроможність, економіка знань, фінансування досліджень, фінансова стійкість, ресурсоефективність

JEL Класифікація: I23, H52, O31, C44