DOI: 10.24193/tras.74E.5
Published First Online: 02/27/2025

HIGHER EDUCATION'S ROLE IN FOSTERING INNOVATION. IMPACT OF FINANCING ON PATENT DEVELOPMENT —CASE OF EUROPEAN UNION

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Abstract

Innovation is a key catalyst for economic development, providing a comprehensive framework to address those many challenges that humanity is facing. Nowadays, the phrase 'higher education' frequently accompanies discussions about innovation. In this context, higher education institutions are seen as a key driver of innovative development. However, on their way to excellence, higher education institutions are supported by government funding, which plays an important role in supporting and encouraging innovation. Thus, the main objective of this paper is to analyze the impact of education spending on innovation in EU countries using the latest available data. The methodology is O.L.S. on panel data using Driscoll and Kraay's covariance matrix estimator, whose standard error estimates are robust to disturbances for heteroscedasticity, autocorrelated with MA(q) and cross-section dependent.

The results certify the direct link between higher education funding and the increase in the number of innovations in the context of access to information using broadband technology, supported by the empirical evidence provided by the importance of universities as agents of economic and social development and suggesting the need to strengthen public financial allocations for R&D.

Keywords: university patents, innovation ecosystem, knowledge transfer, Triple Helix Model, landscape analysis, digital infrastructure, Ordinary Least Squares.

1. Introduction

Defined in simple terms as creating something new or improving, innovation in modern society illustrates that innovative ideas can be discovered and implemented in many sectors and become an integral part of everyday life. Innovation is also seen as a strategy for creating competitive advantage, which in turn brings numerous benefits to companies. Moreover, governments around the world are embracing this concept, often mentioning it in speeches about the current challenges facing society.

Innovation is the outcome resulting from the process of transforming the ideas, research, development, scientific and technical, socio-economic, political, and other decisions that contribute to improving the quality of life and national security by harmonizing the economic interests of business (profit-making firms), market interests of consumers (needs at the lowest cost) and the interests of society (reducing unemployment, increasing average household incomes, increasing the tax base) (Yakovleva *et al.*, 2015). In this context, for innovation to be successful, both products and their promoters are needed (McMullan and Melnyk, 1988), and, in this equation, due to its specific peculiarities (access to financial and technological resources, high degree of human capital—students and professors), the university occupies a fundamental position, which gives it a well-defined role in stimulating and facilitating innovation. According to Fisch *et al.* (2016), universities contribute to innovation through the provision of quality education, the generation of spin-offs, which are also considered embryos of the innovation process, or university patenting. This whole process is only completed when the innovative product is commercialized, producing wealth (Jacobides and Winter, 2003).

Perceived as the wellsprings of knowledge, universities have generated since ancient times the most important resources for society (intellectual geniuses and educated labor force), which in turn have produced state-of-the-art research and innovative products aimed at directly contributing to economic development. Thus, in a knowledge-based economy, universities have become the epicenter of innovation ecosystems and socio-economic development, moving from traditional centers of teaching and research to true knowledge hubs, thus moving away from Humboldt's principles. The result of these changes has been the 'entrepreneurial university', the 'corporate university', and the 'neoliberal university'.

In recent decades, scholars have redirected their attention to the role that universities play in local innovation ecosystems (Hințea *et al.*, 2022). Thus, endogenous growth theory, as well as the Triple Helix model, highlight the important role that universities play in the transfer of new ideas for commercial use. In addition, research on university-industry partnerships has proliferated in recent years, and this relationship has been considered by many researchers as a success factor for innovation (Iorga *et al.*, 2016; Perkmann and Walsh, 2007). However, within the European Union, governments remain the main providers of funding for higher education institutions (HEIs). While working together can be difficult because of different interests, perspectives, and priorities, both have a common goal—to increase the well-being of society through education, research and innovation.

This objective underlines that collaboration between the government and the academic world is essential for a successful economy. In this context, the main purpose of our paper is to examine the role of higher education in promoting innovation¸ in the context of public funding of innovation. Funding for this purpose is both an indispensable material support and a strong incentive for innovation, which should also be materialized in the number of patent applications, reflecting the ability of countries and firms to exploit knowledge and translate it into potential economic gains. Seen in this light, our study can provide the empirical evidence needed to (re)configure higher education funding policies in connection with the sectoral development policies involved, targeting more appropriately public policy goals such as climate neutrality.

The paper is further structured as follows: Section 2 reviews the role of higher education institutions and the government in the Triple Helix model, government funding of public higher education, including academic research and development to highlight the contribution of these factors to innovation. Section 3 presents the data and methodology used, followed by Section 4 which discusses the results; section 5 concludes.

2. Literature review

2.1. The role of university and government in the Triple Helix model

In recent decades, universities have enjoyed remarkable growth, which has led to improved educational standards and expanded access to education, thereby strengthening their essential role in promoting innovation, creativity, and economic growth (Klein and Pereira, 2021). In today's dynamic and challenging economy, there is a growing perception that education is treated as a 'commodity' (Hockley, 2007), where students are seen as customers and higher education institutions as service providers. In this context, universities are no longer limited to the generation of knowledge but are also active participants in its transfer to the market. The Triple Helix model, used to address problems at the micro, macro, and meso levels, is based on three main actors—academia, industry, and government. This model is based on the idea that innovation occurs in each of the three institutional spheres, but as the complex interactions between them intensify, each component evolves to accommodate specific features of the other institutions (Hailu, 2024). According to Callon (1998), innovation is perceived as a process that 'cuts across institutions, weaving intricate and unexpected relationships between different spheres of activity'.

In contrast to the etatist and laissez-faire models (Figure 1), in the Triple Helix model, the three institutional spheres partially overlap, thus generating new formats for the creation, transfer, and application of new knowledge. In this context, universities can contribute to regional and local innovation by training specialists in different fields and by reputable academics' contributions to regional innovation networks (Benneworth and Fitjar, 2019). The government, seen as an extra-university power, can promote innovation in universities through appropriate public policies and direct or indirect government support.

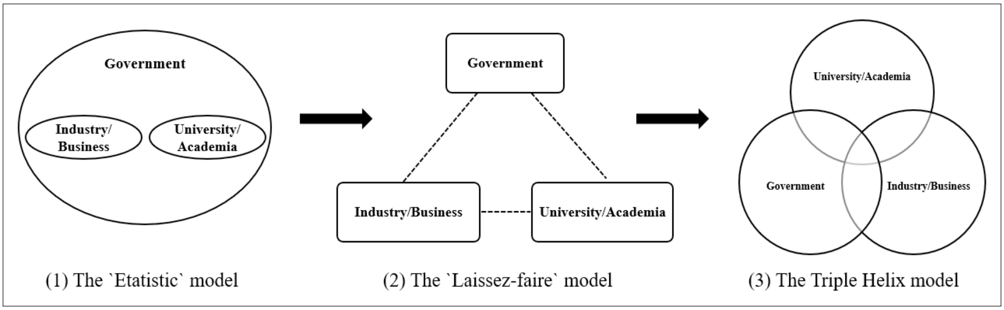

Figure 1: Configurations of university-industry-government collaboration

Source: Adapted from Etzkowitz and Leydesdorff (2000

At the national level, the environment in which higher education institutions operate is shaped by decisions made at the government level. Depending on their quality and appropriate alignment with realities and needs, these decisions can help universities to develop and be competitive, but they can also affect these aspects. They can also have a direct impact on academic performance, the relevance of educational and research programs, and employment opportunities for students.

2.2. Government funding of public higher education

Higher education institutions and governments have a symbiotic relationship (Shore, 2020), with the state responsible for funding universities to build an educated society and improve local, regional and national economies. In today's university environment, the need for financial resources is increasing, and governments are also facing difficulties in securing the funding that universities need to carry out their core activities.

According to Ziegele and Rischke (2013), an appropriate education funding model should be structured around three fundamental pillars: (1) core funding that incentivizes universities to perform core tasks, (2) performance-oriented funding, and (3) funding that supports innovation within universities. However, a sustainable approach to higher education funding has not yet been achieved, and, as a result, the financial resources directed to this sector remain insufficient.

Analyzing the literature to understand the variation in practices among public institutions receiving government support, we have observed that, globally, education competes with health (Figure A1 in the Appendix). According to Kane and Orszag (2003), during economic downturns, when the share of government budgets devoted to health spending increases significantly, countries decrease funding for higher education and increase tuition fees. After the economy recovers, the budget priorities set during the recession persist, and cuts in education funding are never restored.

Higher education institutions are financed from budget allocations and tuition fees paid by students (the amount of which depends on the funding policy of each faculty). Figure 2 shows the evolution of education expenditure in the period 2014–2020. Influenced by the economic, social, and political context, public spending on education has oscillated over the period under review, although the European Commission has regularly called on European states to implement structural reforms and invest in education policy development (Maj-Waśniowska, 2017). Such developments translate in practice into reduced predictability of funding for academic activities (implicitly, those in the sphere of academic innovation), which is ultimately reflected in a reduced ability of academic actors to create and transfer to the real economy sector innovative solutions capable of increasing the performance of the various agents involved.

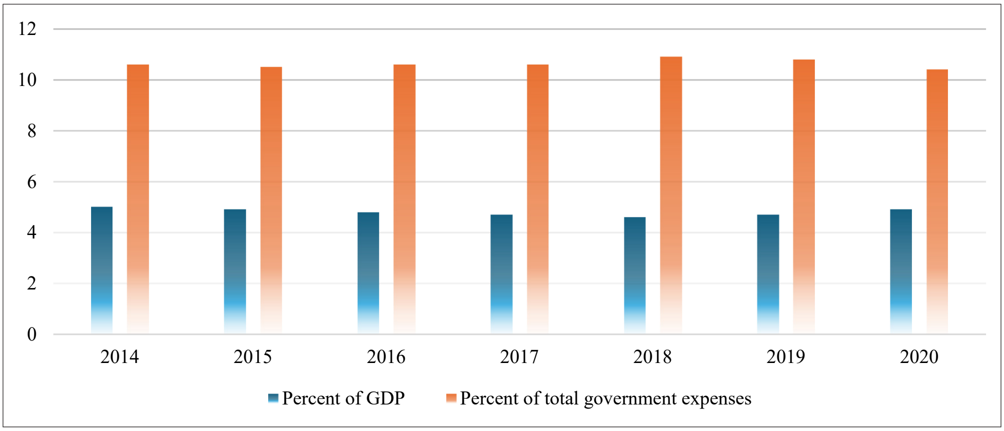

Figure 2: Public spending on education in the European Union

Source: Own representation based on collected data

Next, we analyze education spending by considering variations across nations. The differences between Member States can be explained both by different levels of funding per student/number of beneficiaries and by the proportions of GDP from which each country allocates certain percentages to tuition fees in line with their public policy priorities.

Public spending on education in 2014 ranged from 7.9% of GDP in Italy to 15.2% of GDP in Latvia. Italy's low share is due to macroeconomic imbalances, including structural weaknesses in the education system, which make tertiary education spending among the lowest in the European Union (European Commission, 2020). Ichino and Tabellini (2014) investigated the factors leading to low educational attainment in Italy and showed that the main reason why spending remains at such a low level is due to demographics, and consequently, Italian universities must learn to respond to the expectations and needs of their ecosystems, diversifying their strategies and missions in order to become pillars of innovation and sustainable development.

In Latvia, the development of human capital has been one of the development policy priorities. Although Latvia is among the countries with high spending on education (OECD, 2016), after gaining independence, the Latvian tertiary education system has expanded at a rapid pace, but the country is currently facing a system whose capacity is not

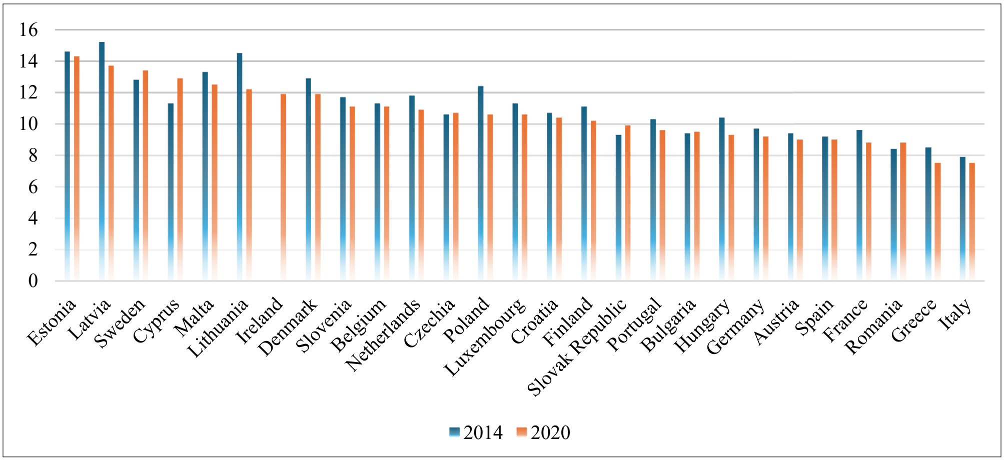

Figure 3: Spending on education in the EU, total (% of GDP)

Source: Own representation based on collected data

aligned with the demographic decline, fiscal reality, and labor market needs. A number of subsidized places in higher education are funded by the government, but this funding system does not serve wider national priorities. Academic salaries are, for example, very low and are based solely on teaching tasks, not including research.

University education has a multitude of purposes in line with the principles and objectives of the national education system—it contributes to the economic growth of a state, competes with other countries in the field of knowledge and technology, including research and development, and provides society with skilled labor force (Goksu and Goksu, 2015). The world's wealth will increasingly depend on knowledge capital (Lung *et al.*, 2012).

2.3. Academic research and development: international comparisons

In an advanced and knowledge-based society, research and development (R&D) plays a key role in propelling economic, social, and technological progress. The ability of nations to innovate and acquire knowledge is essential for global competitiveness, which has led to an increased emphasis on R&D (Dyba, 2012).

The level of R&D spending is a critical factor in determining the innovation potential and performance of a given region. R&D expenditure also illustrates the research productivity of an educational institution. Together with other indicators, such as patent commercialization, scientific publications listed and number of citations, they provide an assessment of the impact of a university's collective research. At the EU level, there are significant variations in the funding of innovation potential, as shown in Figure 4.

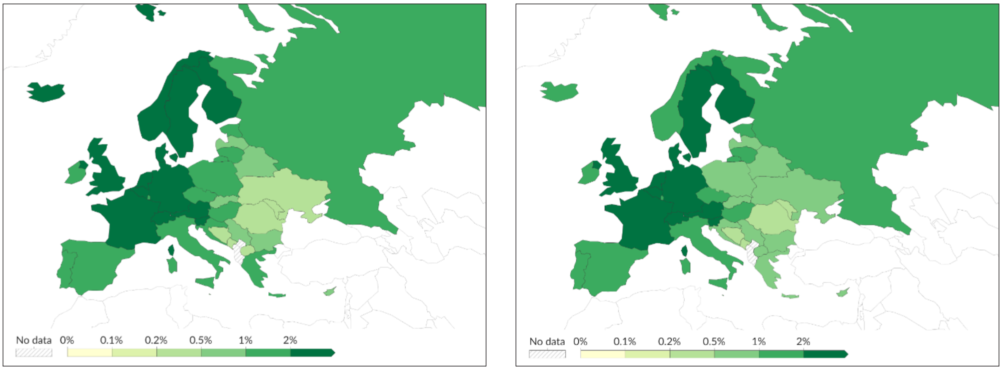

Figure 4: R&D spending (% GDP), 2014 vs. 2020

Source: UNESCO Institute for Statistics (2024)

In 2014, EU Member States spent a total of around €283 billion on R&D, with the highest R&D shares in Finland (3.15%), Sweden (3.10%), and Austria (3.08%), all with R&D spending above 3% of GDP (European Commission, 2015). The fact that Finland and Sweden's spending on R&D and innovation is above the EU average has not been news for a long time. Finland's innovation ecosystems, comprising highly innovative higher education institutions, research institutes, innovation-promoting organizations, and government agencies, have encouraged innovation since the 1990s (OECD, 2022), and all the massive investment in R&D has placed Finland among the most productive EU member states.

One way to assess the significance of educational research across different sectors and nations is to look at the personnel devoted to research and development. Higher education institutions are organizations that rely heavily on human resources to deliver their services. Therefore, the caliber of staff in higher education institutions is crucial for their effectiveness, as in all people-centric organizations (Fielden, 1998). In this context, the research capacity of the higher education sector in 2014 and 2020 was 12,381 and 13,257 employees, respectively (Figure A2 – Appendix). At the opposite pole, Romania had the lowest R&D expenditure intensity at 0.38% of GDP.

According to the Deloitte (2014) study, the main reasons why Romania has the lowest percentage in terms of R&D spending are the absence of government incentives, excessive bureaucracy, lack of confidence in economic policies, technological disparity with developed countries, and the lack of educational standards in universities. Also, Romania has a low capacity to absorb European funds (Sandu, 2010).

In 2020, European countries spent approximately €311 billion on R&D, according to Eurostat reports. The highest R&D shares were recorded in Sweden (3.49%), followed by Belgium (2.06%) and Austria (3.29%), while Romania was in the same position.

Patenting activity is often identified in the literature as a major outcome of R&D activities. In theory, more innovators should generate more ideas and, therefore, more patents. However, this correlation is not guaranteed, as not all inventions result in patent applications, and there are other alternatives to protect intellectual property (e.g., trade secrets, copyright) (WIPO, 2007). Although more people involved in R&D may increase creative capacity, there is no guarantee that this will lead to a commensurate increase in the number of patents.

The production and distribution of knowledge is essential for stimulating economic growth, and public higher education institutions and governments have an important role to play in this process (Sanyal and Varghese, 2007).

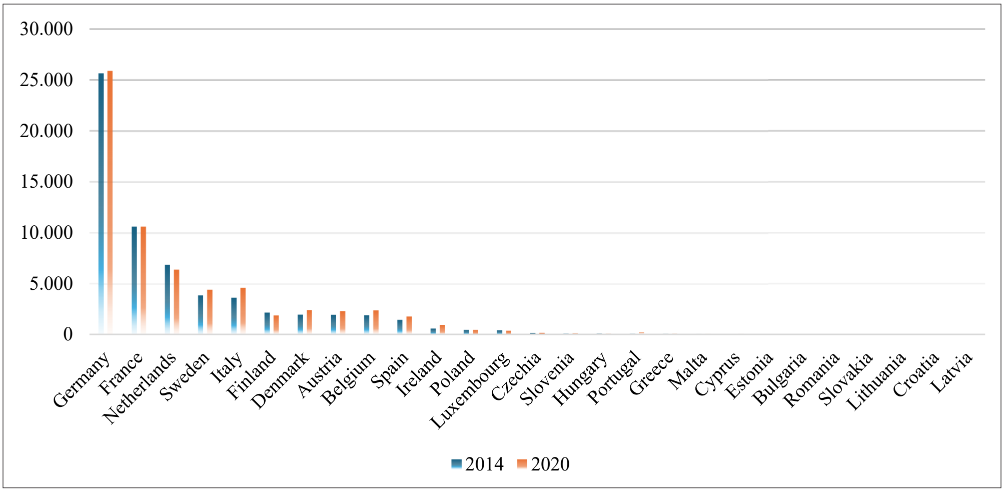

Figure 5: Number of patent applications filed at the European Patent Office (EPO)

Source: Own representation based on collected data

Differences between countries can be explained both by the structure and size of funding allocated to universities (e.g., the position of Germany compared to Greece and Croatia respectively—see Figure A3 and A4 in the Appendix) and by factors of legal (procedural steps regulated and length of process), institutional (degree of bureaucratization of registration systems), socio-cultural (e.g., concentration of intellectual peaks and top industries in certain countries) or other nature (e.g., migration for work as a very important factor). According to a survey conducted by the European University Association (EUA, 2022) financial resources, staff and space for co-creation are the most important elements in university innovation.

3. Data and methodology

In the current climate, higher education institutions are leaders in education, research, and innovation, making a key contribution to the development of economies (Blasco *et al.*, 2021). In these circumstances, the activity of universities, reflected in our interest in the number of patents (as an indicator of innovation), is conditioned by the size of available funding, the latter seen as a result of government financial policy decisions. Thus, the dependent variable in our models is patent applications filed at the EPO by the country of applicants and inventors, used as a proxy for innovation. We have opted to patent applications as a proxy for innovation because they provide a relevant, though not perfect, representation of innovation activity at the regional level. Even if this variable cannot be considered absolutely comprehensive in describing the process/results of innovation, it can be considered to best describe the phenomenon as it includes multiple plans and activities in the sphere of innovation (e.g., patents on environmental technologies, biotechnology, and nanotechnology or activities in the field of social innovation). In a narrower sense, innovations are the product of a scientific endeavor that generates intellectual property assets, namely patented inventions. This is also supported by other researchers in the literature (Acs *et al.*, 2002; Ponta *et al.*, 2021).

The explanatory variable is the total expenditure on education by education level, program orientation, and source type (tertiary education 5–8 and 6–8). The tertiary education level is presented in Figure 6.

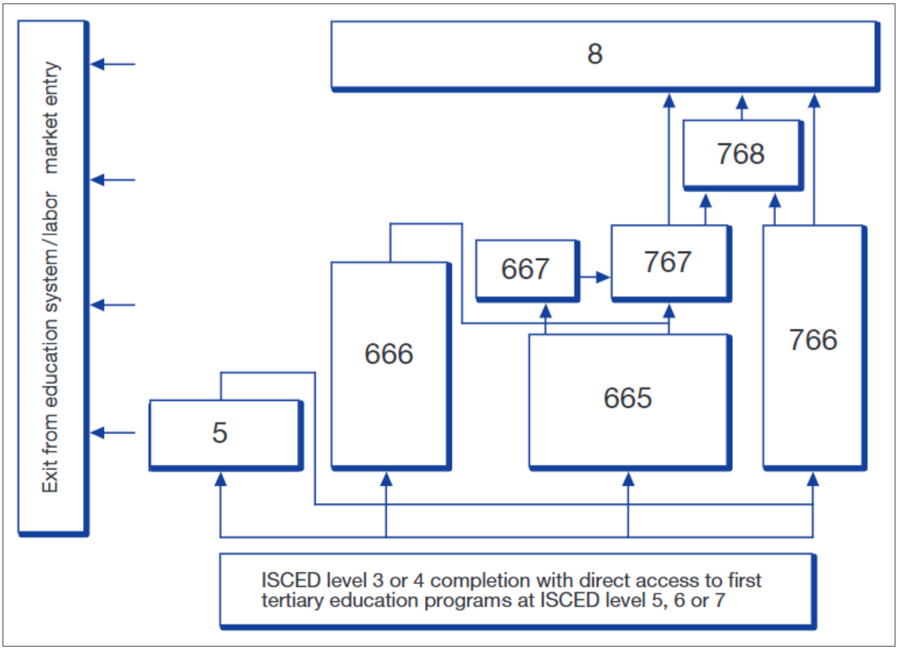

Figure 6: Tertiary education level

Source: Own processing after UNESCO Institute for Statistics (2012)

Finally, we use broadband internet coverage by technology and speed as a control variable. Broadband internet coverage as a function of technology and speed is a key indicator for assessing the infrastructural development of a region, representing an essential pillar for productivity growth and long-term economic development (Briglauer *et al.*, 2024) and connecting citizens, communities, and the public sector, thus shaping global innovation. By including this variable in our study, we aim to highlight the importance that digital infrastructure has on the development of innovative activities in the academic space.

Information on the variables analyzed comes from the Eurostat database, and their description is highlighted in Table 1.

Table 1: Description of variables.

Variable	Description	Source	References	Results
Patents	Patent applications to the EPO by country of applicants and inventors	Eurostat		
Educ	Total educational expenditure by education level, program orientation, and type of source	Eurostat	Liu *et al.* (2024a)	Public investment in education → Innovation↑
			Pegkas *et al.* (2019)	Education→ Innovation↑
Broad	Broadband internet coverage by technology and speed	Eurostat	Liu *et al.* (2024b)	Broad↑→ Innovation↑

Source: Authors' representation

The proposed methodology is panel data fixed effects, its selection being mainly related to the assumption of the existence of some entity—country' fixed effects/characteristics. In this approach, we consider that some variables may not change over time μ_i, but may vary across entities/countries, mainly differences in public financing, which can depend on the levels of population, GDP per capita, different levels of technology, and so on. A second argument is related to the possible existence of time fixed effects λ_t, meaning that some factors change over time but not across entities (i.e., national policies, local regulations, and international agreements). The component X_{it}, in general, can contain observable characteristics, that may be constant for an individual across all time—in our case, the different countries in the European Union, but also some non-observable characteristics, responsible for model heterogeneity (competencies and skills of the researchers, infrastructure in the community, or political unrest). If there is no dependence within individual groups, the panel data can be treated as one set, named pooled data, and the model parameters can be directly estimated using pooled ordinary least squares (Croissant and Millo, 2008). For our data, this is not the case, so we have chosen the fixed effects model as the appropriate one, based on economic logic—there might be a good reason to believe that financing may be affected by country characteristics. The statistical validation is checked by the (statistical) result(s) of the Hausman test. The initial tests and core methodologies are presented in the next section.

3.1. Independent Panel Unit Root Tests Framework

Panel unit roots are necessary to check if the series are stationary. To test it in panels data, as in our case, some specific tests are used (Breitung and Das, 2005; Choi, 2001; Harris and Tzavalis, 1999; Im *et al.*, 2003; Levin *et al.*, 2002). Panel unit root tests for panel data are specifically related to the restrictions on auto-regressive process (as in 1) across cross-sections or series.

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (1)$$

with y_{it} being the dependent variable vector, X_{it} the independent variables matrix, and ϵ_{it} is the idiosyncratic error. Based on these restrictions, one can state the assumptions $\rho_i = \rho$ for all i, and if $|\rho_i| = 1$, then y_i contains unit root.

The Levin, Lin and Chu (LLC), Breitung, and Hadri tests assume common unit root, that ρ_i is identical across cross-sections. LLC and Breitung consider basic ADF as in (2), with the null H_0 as in (3), and the alternative written as in (4).

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (2)$$

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (3)$$

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (4)$$

A second approach is developed in Im, Pesaran and Shin, and the Fisher-ADF and PP tests. All allow for individual unit root processes, so that the unit root may vary across cross-sections (5).

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (5)$$

with the null H_0 as in (6) and H_a in (7)

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \quad (6)$$

$$H_1 : \begin{cases} \alpha_i = 0 & \text{for } i = 1,2,\dots,N_1 \\ \alpha_i < 0 & \text{for } i = N+1, N+2, \dots, N \end{cases} \quad (7)$$

The empirical results for these tests are presented and explained in the next section.

3.2. The Driscoll-Kraay estimator methodology

The estimator was proposed by Driscoll and Kraay (1998) and refers to covariance matrix estimator for use with pooled OLS estimation and fixed effects regression, being statistically implemented by Hoechle (2007).

In panel data estimation, the error term μ_{it} can consider both individual and time effects as in equation no. 8, or time phenomenon can be used separately.

$$y_{it} = \alpha + \beta^\top x_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (8)$$

Model parameters β can be estimated as in (9), using feasible GLS methods, being calculated using Ordinary Least Squares (O.L.S.) method on partially demeaned data, the partial demeaning is defined as follows (10).

$$\hat{\beta} = \left(X^{\top}\hat{V}^{-1}X\right)^{-1}\left(X^{\top}\hat{V}^{-1}y\right) \tag{9}$$

$$y_{it} - \theta\bar{y}_i = (X_{it} - \theta\bar{X}_i)\beta + (u_{it} - \theta\bar{u}_i) \tag{10}$$

where:

$$\theta = 1 - \left[\frac{\sigma_u^2}{(\sigma_u^2 + T\sigma_e^2)}\right]^{\frac{1}{2}} \tag{11}$$

and the disturbance in (11) is homoscedastic and serially uncorrelated.

The condition in (11) is usually not valid, so to ensure valid statistical inference when some of the underlying regression model's assumptions are violated, relying on robust standard errors is common (Grozdić *et al.*, 2020).

We use the panel models with Driscoll and Kraay standard errors to address the later problems, so the coefficient estimates are obtained as the square roots of the diagonal elements of the asymptotic (robust) covariance matrix in (12) with $\hat{S}_T$ being defined as in (13), see (Newey and West, 1987).

The $\hat{\Omega}$ is defined as in (14) with $h_t(\hat{\theta})$ outlined in (15).

$$V(\hat{\theta}) = (X'X)^{-1}\hat{S}_T(X'X)^{-1} \tag{12}$$

$$\hat{S}_T = \hat{\Omega}_0 + \sum_{j=1}^{m(T)} w(j,m)\left[\hat{\Omega}_j + \hat{\Omega}_j'\right] \tag{13}$$

$$\hat{\Omega}_j = \sum_{t=j+1}^{T} h_t(\hat{\theta})h_{t-j}(\hat{\theta})' \tag{14}$$

$$h_t(\hat{\theta}) = \sum_{i=1}^{N(t)} h_{it}(\hat{\theta}) \tag{15}$$

The choice for the long-run effects methodology is related to the following important facts:

- variables are stationary in levels, so the classical coefficients of fixed and random effects can be used;
- if the unobservable common factors are uncorrelated with the explanatory variables, the coefficient estimates from standard panel estimators are consistent, but inefficient (Hoechle, 2007);
- standard errors or clustered standard errors may be biased;
- the proposed nonparametric covariance matrix estimator (Driscoll and Kraay, 1998) produces heteroskedasticity and autocorrelation-consistent standard errors that are robust to general forms of spatial and temporal dependence.

Data description is available in the next section.

4. Empirical results and discussions

Table 2 provides a comprehensive description of the particularities of the data analyzed. The collective number of observations registered in the 27 EU Member States amounts to 255.

Table 2: Summary statistics

	Mean	SD	Min	Max	N
patents	2507.8133	5171.2876	8.0000	26762.0000	225
educ58	5718.8889	8364.3654	152.3000	42720.0000	225
educ68	5486.0204	8107.5447	142.9000	42672.6992	225
broad	63.3902	25.3344	0.4000	100.0000	225
logpatents	6.0029	2.1102	2.0794	10.1947	225
logeduc58	7.6935	1.5129	5.0259	10.6624	225
logeduc68	7.6372	1.5059	4.9621	10.6613	225
logbroad	3.9623	0.8956	-0.9163	4.6052	225

Source: Authors' calculation

Our data is a Panel type, and we expect our series not to contain unit roots, the tests conforming our supposition. The initial sets of our data testing refer to the presence of unit-root, the results for Im-Pesaran-Shin and Fisher-type are available in Table 3.

Table 3: Unit Root Tests Results

Variables	r(zttildebar)	r(P)	r(L)	r(Z)	r(Pm)
logpatents	-5.6391***	207.9594***	-8.9783***	-7.6171***	13.1075***
d.logpatents	-14.7441***	1153.3111***	-57.2709***	-29.8308***	98.0026***
logeduc58	-1.9129**	94.4104***	-2.2463**	-2.0672**	2.9105***
d.logeduc58	-12.3856***	679.9097***	-33.7172***	-21.3108***	55.4899***
logeduc68	-10.9463***	508.4004***	-24.9569***	-17.4179***	40.0879***
d.logeduc68	-10.1516***	493.3399***	-24.2566***	-16.0167***	38.7355***
logbroad	-15.4396***	1276.0428***	-63.3785***	-32.0108***	109.0243***
d.logbroad	-11.4895***	275.0988***	-64.4950***	-12.0102***	124.0570***

Source: Authors' calculation

The results of unit-root tests suggest that all variables are stationary in levels, and in first-difference, being of type I(0).

Another test refers to variance inflation factor. There are no identified problems, for all the models the VIFs means are 1.00 (under 5.00, the threshold in literature – the results for the first model are presented in Appendix, Table A1, the other models being available on demand).

We have tested sixteen (16) models, using two proxies for tertiary education (educ58, educ68), and one proxy for access to the technological innovations—the broadband internet (*logbroad*). The results of *logeduc58* show that a raise with one unit in education, the patents elasticity increases by about 0.58 for fixed effect—model no. 1 (the model number is available on the first row of the table, near the type of the model, e.g., Fixed (1) means fixed—effects model no. 1), and with about 0.42 in model no. 2 (see Table 4).

The results are similar for random models—3 and 4, but with higher values. The Hausman test suggests that fixed effects models are appropriate (the results are available on demand).

The results for logeduc68 in models 5–8 are in line with previous coefficients but smaller, which is understandable, because the financing is lower in 6–8 levels related to 5–8 levels (see Table 4).

Table 4: FE and RE Results of Tertiary Education (58) Proxy

	Fixed (1)	Fixed (2)	Random (3)	Random (4)
logeduc58	0.588***	0.423**	0.853***	0.788***
	(0.143)	(0.161)	(0.0808)	(0.115)
logbroad		0.117***		0.0907**
		(0.0267)		(0.0381)
C	1.480	2.287*	-0.553	-0.411
	(1.079)	(1.162)	(0.496)	(0.719)
Obs.	225	225	225	225
Groups	29	29	29	29
Unit eff.	YES	YES	YES	YES
Time eff.	NO	NO	NO	NO
Robust	YES	YES	YES	YES

Source: Authors' calculation

The results show a positive association between education levels and broadband connection, as independent variables to patents development. Regarding the results for fixed effects, considering the model number (1), an increase with 10% in education financing—total education expenditure, ISCED levels 5 to 8, in logarithmic values, abbreviated in the model as logeduc58, it increases the patents by about 0.59 units (the calculation is 0.588 *log(1,1), due to fact that education series is expressed in logarithmic value) *ceteris paribus*. When taking into consideration the broadband independent variable, see model number (2), the increase with 10% in education expenditures, the increase in patents is about 0.42 units, on average, *ceteris paribus*. Digital infrastructure is now a fundamental element in promoting innovation and ensuring high quality education. It facilitates access to educational resources, the development of digital competencies and supports research and innovation. The link between digital infrastructure and spending on education is vital to creating a climate conducive to innovation, as it enables cooperation between universities, research institutions, and private companies, thus fostering knowledge transfer and the development of innovative solutions. Interdisciplinary cooperation is thus supported by digital platforms and tools, and in this context, it is the task of governments to allocate the necessary funds for the development of a high-performance digital infrastructure tailored to the needs of education. For the random effects models, the corresponding coefficients are 0.85 and 0.78 respectively, the economic explanation being the same as above. The random models suggest higher effects of tertiary education (level 5 to 8) financing on patents.

Table 5: FE and RE Results of Tertiary Education (68) Proxy

	Fixed (5)	Fixed (6)	Random (7)	Random (8)
logeduc68	0.542***	0.371*	0.833***	0.766***
	(0.143)	(0.182)	(0.0849)	(0.122)
logbroad		0.124***		0.0981**
		(0.0292)		(0.0396)
C	1.860	2.680*	-0.353	-0.225
	(1.073)	(1.307)	(0.584)	(0.785)
	(1.079)	(1.162)	(0.496)	(0.719)
Obs.	225	225	225	225
Groups	29	29	29	29
Unit eff.	YES	YES	YES	YES
Time eff.	NO	NO	NO	NO
Robust	YES	YES	YES	YES

Source: Authors' calculation

The results also show a positive association between education levels and broadband connection, as independent variables to patents development. Regarding the model number (5), an increase with 10% in tertiary education expenditure, this time considering tertiary education from levels 6 to 8, has a raising effect on patents number, the increase being by 0.54 units, on average, *ceteris paribus.* When considering the presence of broad connections, the calculated effect is 0.37 units, on average, *ceteris paribus* (see model number (6)). Comparing the coefficients between the level of financing, the coefficient is slowly higher for 5-8 levels, so the financing should be oriented mainly on this, but not disregarding the highest levels. The random effects models also show the highest coefficient (the positive effect is quantified as 0.83 and 0.76, see models 7 and 8).

4.1. Test for the robustness of the previous results

To test the robustness of the previous results, we have considered the presence of the time effects, the coefficients being available in Tables 6 and 7.

Table 6: FE and RE Results of Tertiary Education (58) Proxies (Considering Time Effects)

	(9) Fixed	(10) Fixed	(11) Random	(12) Random
logeduc58	0.272**	0.236**	0.789***	0.787***
	(0.175)	(0.188)	(0.113)	(0.118)
logbroad		0.0723***		0.0645*
		(0.0199)		(0.0428)
2014.year	-0.0121	-0.0239***	-0.0292**	-0.0408***
	(0.00735)	(0.00604)	(0.00917)	(0.00631)
2015.year	0.0802***	0.0646***	0.0353*	0.0189
	(0.0170)	(0.0154)	(0.0160)	(0.0129)
2016.year	0.0210**	-0.00353	0.00319	-0.0198
	(0.00802)	(0.00729)	(0.00585)	(0.0119)
2017.year	0.0918***	0.0635***	0.0650***	0.0381**
	(0.0105)	(0.00835)	(0.0109)	(0.0125)
2018.year	0.123***	0.0905***	0.0719***	0.0396**
	(0.0186)	(0.0154)	(0.0161)	(0.0157)
2019.year	0.139***	0.0874***	0.0630**	0.0121
	(0.0269)	(0.0221)	(0.0219)	(0.0200)
2020.year	0.218***	0.173***	0.133***	0.0879**
C	3.831**	3.844**	-0.0979	-0.312
	(1.329)	(1.387)	(0.846)	(0.800)
Obs.	225	225	225	225
Groups	29	29	29	29
Unit eff.	YES	YES	YES	YES
Time eff.	YES	YES	YES	YES
Robust	YES	YES	YES	YES

Source: Authors' calculation

Table 7: FE and RE Results of Tertiary Education (68) Proxies (Considering Time Effects)

	(13) Fixed	(14) Fixed	(15) Random	(16) Random
logeduc68	0.230**	0.192**	0.762***	0.761***
	(0.203)	(0.221)	(0.126)	(0.131)
2014.year	-0.0108	-0.0228**	-0.0287**	-0.0403***
	(0.00879)	(0.00727)	(0.00940)	(0.00737)
2015.year	0.0881***	0.0717***	0.0516***	0.0349**
	(0.0160)	(0.0142)	(0.0142)	(0.0134)
2016.year	0.0267***	0.000981	0.0177***	-0.00551
	(0.00691)	(0.00736)	(0.00448)	(0.0132)
2017.year	0.0987***	0.0691***	0.0818***	0.0546***
	(0.00845)	(0.00696)	(0.00900)	(0.0137)

	(13) Fixed	(14) Fixed	(15) Random	(16) Random
2018.year	0.132***	0.0980***	0.0894***	0.0568**
	(0.0180)	(0.0143)	(0.0148)	(0.0175)
2019.year	0.149***	0.0959***	0.0788***	0.0275
	(0.0284)	(0.0227)	(0.0207)	(0.0235)
2020.year	0.230***	0.183***	0.153***	0.107**
	(0.0306)	(0.0256)	(0.0260)	(0.0318)
logbroad		0.0737**		0.0649*
		(0.0211)		(0.0425)
Constant	4.162**	4.185**	0.134	-0.0853
	(1.537)	(1.624)	(0.938)	(0.913)
Obs.	225	225	225	225
Groups	29	29	29	29
Unit eff.	YES	YES	YES	YES
Time eff.	YES	YES	YES	YES
Robust	YES	YES	YES	YES

Source: Authors' calculation

To check the robustness of our models, the time effect is also considered (see models 9 to 16 in table 6 and 7), the results remaining in line with the previous findings. For the education expenditures (levels 5 to 8), the positive effect is quantified to 0.27. When considering the presence of broadband, the result is 0.23, so the difference in coefficients is lower compared to models 5 and 6 (0.59 to 0.42). For the random effects models, the results are higher, with a smaller space (gauge)—the coefficients are 0.789 and 0.877. For levels 6 to 8 of tertiary education financing, the corresponding results are 0.23 and 0.19 for fixed effects models, and 0.76, for the random models.

We can conclude that the presence of time effects stabilizes the results, demonstrating also the robustness of our findings—the positive effect of tertiary financing on innovation, where the patents number is used as proxy.

5. Conclusions and policy recommendations

This study presents a comprehensive analysis of the role of higher education institutions in promoting innovation on a sample of the 27 Member States of the European Union.

Applying the Ordinary Least Squares method, the results reveal that higher education institutions are true pillars of innovation, with notable implications for technological and scientific progress. More specifically, an increase by one unit in logeduc58 and logeduc68, respectively, leads to an increase by 0.58 units and 0.54 units, respectively, in the number of patents. Therefore, higher education institutions not only could generate in-depth knowledge in the fields concerned but also translate it into pragmatic solutions that have beneficial effects throughout the economy, while stimulating sustainable development and global competitiveness. At the same time, we note that the results closely align with the endogenous growth theory, according to which innovation and knowledge are the main drivers of economic growth.

Given the dynamic climate in which higher education institutions operate, ensuring adequate funding becomes a prerequisite for sustaining scientific and technological progress. While the results of this study demonstrate unequivocally that higher education institutions are central actors in the innovation process, it is imperative to recognize that these achievements cannot be sustained without constant and well-targeted financial funding. In these times of increasingly challenged financial resources, supporting higher education institutions through stable and sustainable funding policies is an investment in a nation's scientific, technological, and economic future.

With this in mind, it is essential that policymakers pay greater attention to the targeting of financial resources to higher education institutions, ensuring that they have the right infrastructure in place to enable them to pursue innovation. From our point of view, a budget allocation option that would simultaneously favor innovation and competitiveness in the university environment would be to separate as distinctive funds the budgetary resources to be distributed, which would then be allocated on the basis of project competition in order to further stimulate the natural instinct of universities towards the new, valuable and useful outcomes. In the same style of judgment, a system of conditioning the eligibility of applicants could also be used so that partnerships with a higher potential for success in principle (e.g. university-industry partnerships) are stimulated to the benefit of all parties involved.

Moreover, a well-informed budget allocation can be a strategic lever for economic and social development, encouraging both technological innovation and adaptability to change. In this context, the prioritization of financial resources across different tertiary education levels or disciplines with a view to optimizing innovation outcomes is a central element of education policy. For example, discussions on innovation are inevitably linked to investments in disciplines supporting STEM (science, technology, engineering, and mathematics) education. Moreover, advances in artificial intelligence, biotechnology or renewable energy have been made possible by sustained investment in STEM research and education. Thus, investment in STEM should be prioritized, especially as technology represents an opportunity for rapid growth and a priority for building a sustainable future. Looking structurally at the organization of the tertiary education system, resources should rather be directed towards higher levels and towards strands with higher innovative potential, while favoring multidisciplinary research so that added value can be maximized.

National governments could also support universities by, for example, setting up a dedicated university innovation fund, to be distributed on a competitional basis, in order to stimulate universities' competitiveness and also ensure high quality R&D activities. Of course, this would raise a number of questions about the conditions under which higher education institutions can benefit from such a fund. Here, academic excellence, involvement in international collaborations, actual impact of their R&D activities and results, reputation, transparency in the use of financial resources, as well as the existence of scientific research centers could be part of the selection criteria.

In addition to this, we should not forget that according to the resource-based view, a skilled workforce is a solid foundation in the innovation process (Patanakul and Pinto, 2014). Therefore, increased investment in R&D will enable higher education institutions to provide continuous training programs for academics and researchers. Stimulating creativity and intellect in the age of capitalism requires a generous allocation of funds both for equipment that is not affordable for conducting quality research and for incentivizing the personnel involved in the process.

Our research also has some limitations, stemming from the lack of availability of separate financial data on higher education and research, separated by education level and innovation activity, the limited possibility to directly compare the national patent regulations of all the countries concerned, and the institutional framework involved in each of them, and the ability of the variable selected as a proxy to fully describe innovation activity in all its complexity.

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Appendix

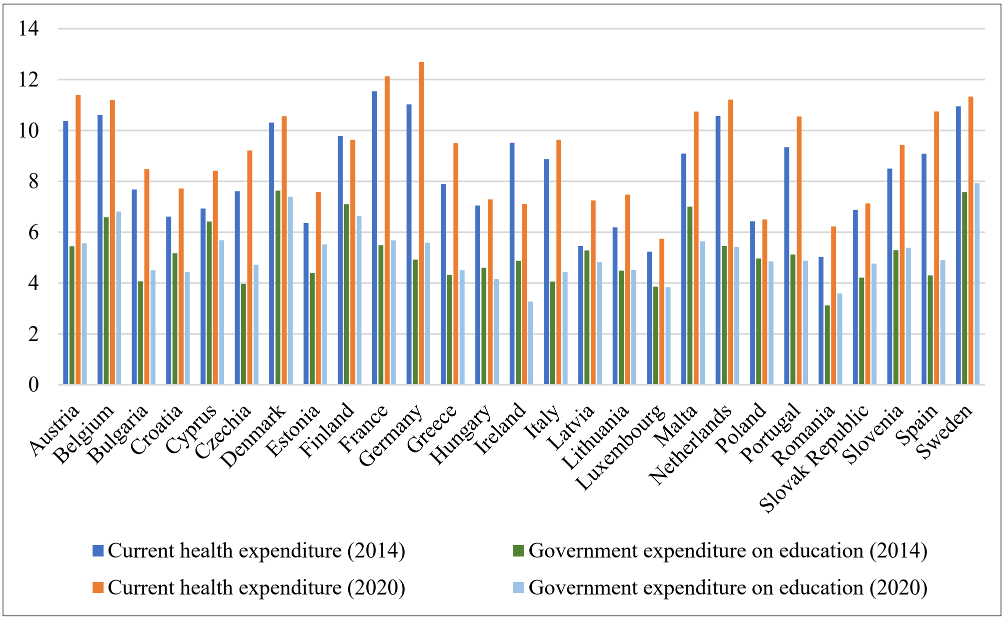

Figure A1: Spending on health vs. spending on education

Source: Representation of the authors based on the data collected

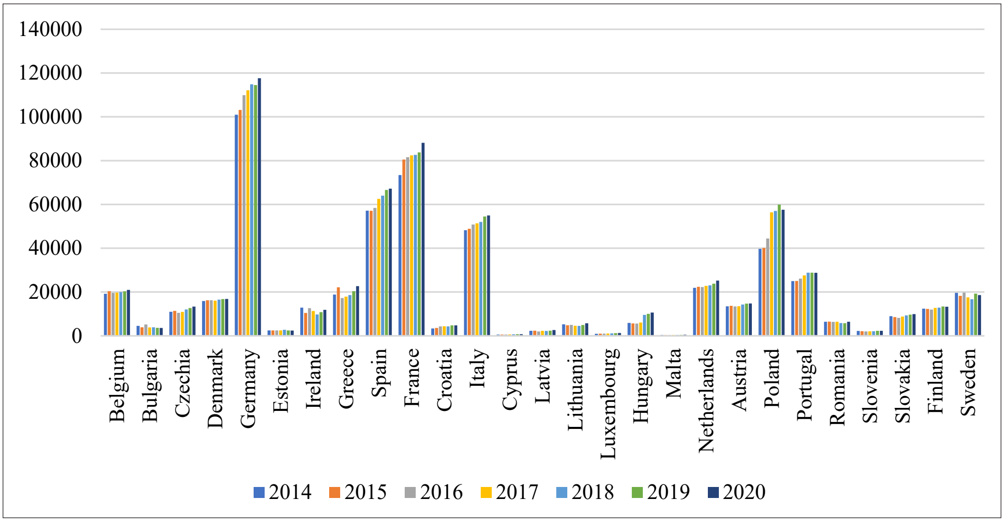

Figure A2: Research and development staff in higher education
(% share of the total number of researchers, based on full-time equivalents)

Source: Representation of the authors based on the data collected

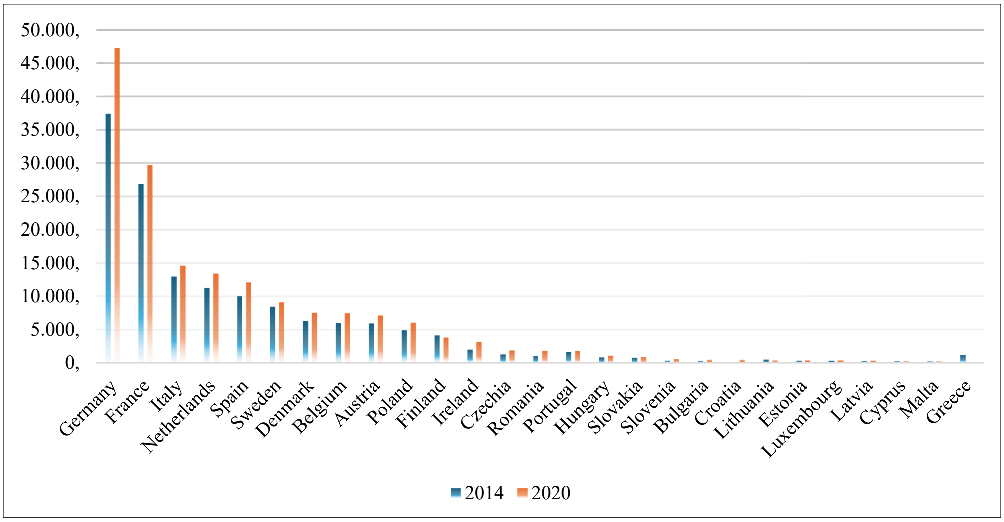

Figure A3: Total expenditure on education by level of education, program focus, and type of source (tertiary education 5–8)

Source: Representation of the authors based on the data collected

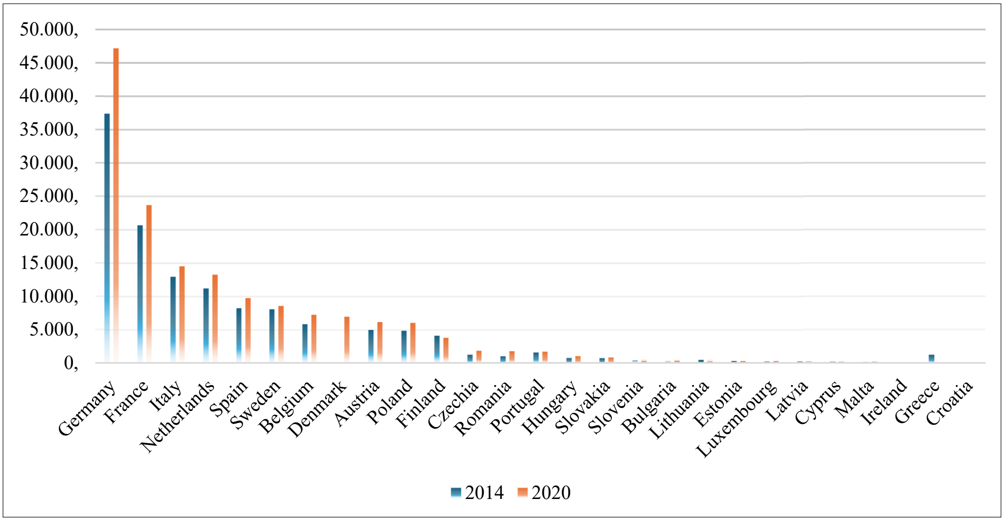

Figure A4: Total expenditure on education by level of education, program focus, and type of source (tertiary education 6–8)

Source: Representation of the authors based on the data collected

Table A1: VIF results

	VIF	1/VIF
logeduc	1.00	0.99
logbroad	1.00	0.99
Mean VIF	1.00	

Source: Authors' calculation

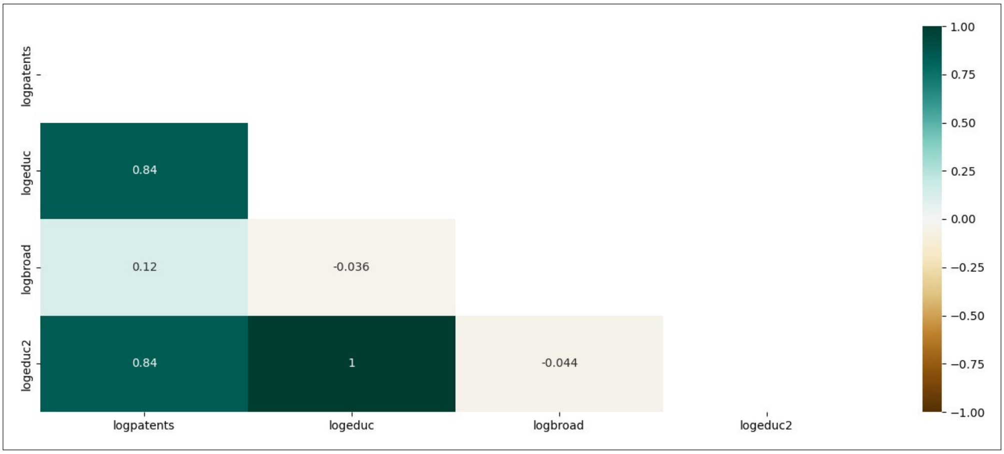

Figure A5: Correlation Matrix–Triangle heatmap

Source: Representation of the authors based on the data collected

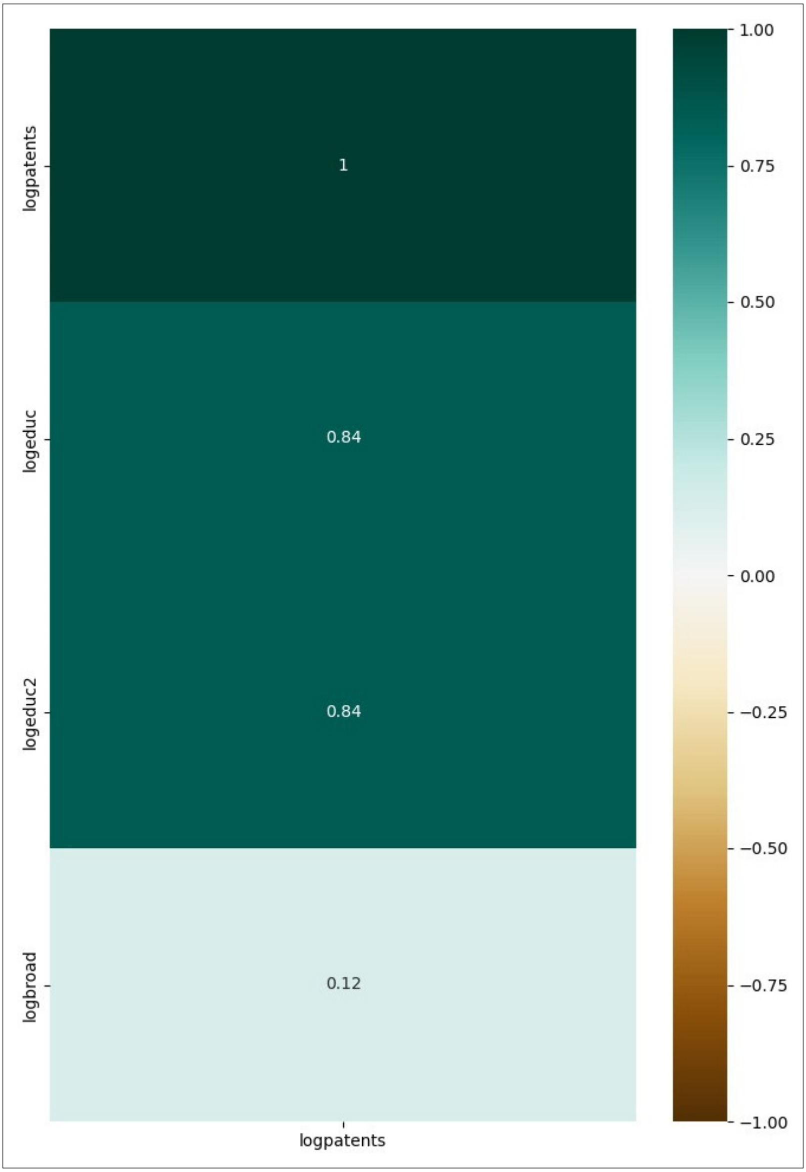

Figure A6: Dependent variable heatmap

Source: Representation of the authors based on the data collected