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Article

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The Impact of Selected R&D Indicators on Economic Activity in EU Countries

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Abstract

The R&D sector is one of the important economic phenomena in terms of competitiveness and innovation performance. The aim of the study is to examine the impact of selected R&D indicators on the economic activity of EU countries with emphasis on economic growth and employment in knowledge-intensive service sectors in 2011-2021. The research was carried out using panel data analysis (the fixed effects method) for three models of EU countries (EU27 countries as a whole and EU27 countries divided into two groups according to their innovation performance). The results in the evaluated years confirmed the different (positive/negative) impact of the examined R&D indicators on economic growth and employment in knowledge-intensive service sectors between the different groups of EU countries. In the "Innovation Leaders and Strong Innovators" countries, high-tech exports had the largest positive effect on GDP per capita, and general government expenditures had the largest negative effect. The largest negative effect of government expenditures on tertiary education was found in the case of Employment in knowledge-intensive service sectors. By contrast, in the case of GDP per capita and employment in knowledge-intensive service sectors, the largest negative effect of government expenditures on tertiary education and the positive effect of research and development expenditures were found in the "Moderate Innovators and Emerging Innovators countries". The findings may be useful for both makers of selected public policies and R&D practitioners in evaluating economic analysis.

Keywords

R&D indicators, Economic growth, Employment, Knowledge-intensive service sectors, Panel data analysis

JEL Classification

O11, C23

Introduction

The role of research and development (R&D) in economic growth has been intensively promoted by scholars and policy-makers of the last decades (Kucera and Fil'a, 2022; Arana-Barbier, 2023; Ciaffi et al., 2024). The R&D sector is considered a main driver in the fight against chronic underdevelopment, regional disparities, isolation and lack of socio-economic perspectives (Bayraktar et al., 2022; Badulescu et al., 2024). Emphasized is its impact on technological innovation, intensive and sustainable growth and economic revival. A fundamental step in order to build a unified system for studying the dynamics of innovation and competitiveness is determining how scientific achievements influence the subsequent process of knowledge creation (Patelli et al., 2017). Scientific and technical activities play a fundamental role in the creation of new knowledge necessary for the realisation of the goals of sustainable economic growth (Blecich, 2021; Ma, et al., 2022). The most important factor of innovation-based economic growth is considered to be the efficiency of the national innovation system. Some authors (Carracedo and Puertas, 2022; Ratner et al., 2022; Cetin & Erkiş, 2023; Manavgat and Demirci, 2023; Rossi et al., 2024; Darfo-Oduro et al., 2024) highlight the importance of technological progress focusing on the best use of available technology and on changes of scale in innovation activities.

According to Vegugelers and Baltensperger (2019, p.1) *"the EU offers global research capacities and larger opportunities for specialisation, but also increased competition for investment and the position as world-leader in critical technological fields"*. The EU also supports further integration of excellent research and is internationally

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connected with strong partners outside the EU.

In recent decades, governments in most countries, not just “*emerging markets*”, have invested heavily in scientific research. These investments are reflected in the volume of research, but also in the international cooperation activities of each country (Al-Jamimi et al., 2022). Therefore, not only European countries are striving to continuously upgrade their technological capabilities and to effectively use the resources allocated to R&D activities (Karabiyik, 2021; Afriana and Khoirunurrofik, 2023). The increasing pressure for efficiency is then caused by the decreasing amount of public funds directed to R&D. According to some authors (Fursov et al., 2016; Arana-Barbier, 2023; Ciaffi et al., 2024; Mao, 2024), current research themes are in particular (i) the relationship between R&D investment and economic growth, (ii) the growth of R&D investment and the increasing demand for optimal allocation of public funds to support researchers, or (iii) tax incentives and R&D investment of technology-based SMEs that affect employment absorption (Sein and Darfo-Oduro, 2024).

The demands associated with research support bring the need to assess research performance at multiple levels (countries, institutions or scientists). The quantification and evaluation of scientific production is closely linked in particular to bibliometric indicators (Garcia-Villar and Garcia-Santos, 2021; Rousseau and Rousseau, 2021; Al-Jamimi et al. 2022; Petrovich, 2022; Mikhailov, 2023). In the public but also in the private sector, R&D results are mainly associated with scientific outputs, research reports and publications (Némethova et al., 2022). The quality of publications is evidenced both by the ranking of journals and their classification according to quartiles, but also by the number of cited papers in worldwide databases (Khurana et al., 2023; Mikhailov, 2023). The results of research studies and publications in scientific journals are used to develop research directions, set research policies, and meet management needs (in universities). Bibliometric studies are increasingly required by R&D policy makers, funding agencies, and other relevant entities in countries (Al-Jamimi et al., 2022).

Research conducted so far has paid attention to the evaluation of R&D and innovation performance in terms of efficiency or quality using various statistical methods (Blecich, 2021; Ferro and Romero, 2021; Karabiyik, 2021; Carracedo and Puertas, 2022; Manavgat and Demirci, 2023; Prokop et al., 2023; Stefan et al., 2023). Other research has examined the role of R&D and the impact of selected R&D indicators and economic factors in relation to GDP per capita, employment or innovation performance and competitiveness (Bolívar-Ramos, 2017; Markovic, 2018; Pegkas et al., 2019; Bayraktar, et al., 2022; Uyar et al. 2022; Badulescu et al. 2024; Cifuentes-Faura et al., 2024). By contrast, little attention has been paid to the examination of selected areas of R&D in connection to employment in knowledge-oriented sectors and services.

Our motivation is to examine the impact of R&D indicators in connection to not only economic development but also the employment sector of knowledge-oriented services, thereby filling the research gap. We want to deepen the findings of the differential impact of different R&D indicators on the economic activity of EU countries and also, we seek to verify the finding that investment in R&D correlates with the size of the economy of countries through innovation (Arana-Barbier, 2023). The aim of the study is to assess the impact of selected R&D indicators on the economic activity of EU countries with a focus on economic growth and employment in knowledge-intensive service sectors in 2011-2021. In connection with the aim, the subject of the research are selected areas of R&D, innovation and economic activity in a narrow perspective. For the purpose of further investigation, selected indicators of R&D and economic activity (GDP per capita and Employment in knowledge-intensive service sectors) are used.

In comparison with other research (e.g. Kucera and Fil'a, 2022; Arana-Barbier, 2023; Ciaffi et al., 2024), we investigate the impact of selected R&D indicators on economic activity for groups of EU countries according to their innovation performance. By using panel data analysis in period 2011-2021 we first evaluate the effect of selected R&D indicators for all EU countries. For further investigation, EU countries are divided into groups according to innovation performance: 1) “Innovation Leaders and Strong Innovators”, and 2) “Moderate Innovators and Emerging Innovators”. This perspective allowed us to evaluate the effect of the R&D indicators under study not only for the EU countries as a whole, but also to analyse and compare between the two groups of EU countries according to their innovation performance.

In our research in relation to the aim we to verify 4 research questions (in more detail part Methodology). The findings confirm the different impact of the examined R&D indicators on economic growth and employment in knowledge-intensive service sectors and then develop the idea of the differential impact of R&D indicators on economic activity for groups of EU countries according to their innovation performance.

Literature Review

Efforts to support and develop scientific potential as well as to create principles for the implementation of scientific achievements in innovation activities are the main focus of a number of researches (Sachwald, 2015; Fursov et al., 2016; Patelli, et al., 2017; Ma et al., 2022; Ştefan et al., 2023; Badulescu et al., 2024; Ciaffi et al., 2024). A balanced approach needs to be maintained, but excellence and innovation performance are still a priority (Karabiyik, 2021; Ratner et al., 2022; Manavgat and Demirci, 2023; Rossi et al., 2024). A burning issue in recent years is the investigation of the relationship between R&D expenditure and R&D investment on innovation, economic growth, patents or technological development (Darfo-Oduro et al., 2024; Sein and Darfo-Oduro, 2024). According to

Bayraktar et al. (2022) R&D is one of the main determinants of technological development and has a critical role in determining the development differences between countries. Their results also show that there is a relationship between R&D expenditures and growth in BRICS-T countries. Focusing on the key drivers of high-tech R&D exports is crucial for technological maturity. According to Zapata et al. (2023, p. 1), as determinants of technology-intensive exports in individual countries can be identified in particular "*R&D expenditure in terms of GDP, the stock of inward foreign direct investment in terms of GDP, imports of high-tech manufactures as a share of GDP, gross fixed capital formation on total employment or the percentage of university graduates relative to the population group*". Other authors, Okoye et al. (2022, p. 11) conducted a comparative analysis about global government investment in relation to education, science, technology, and innovation and researchers/human capital development. "*Their results show that there were differences in the global government investments in the above constructs between the low-and middle-income vs high-income regions*". The authors also discuss the support for infrastructure investment policies by different governments. Derbentsev et al. (2021, p. 383) identified the impact of public spending on education and research and development (R&D) on the formation of gross domestic product (GDP) in nine Central European countries. Authors proved that "*impact of expenditures is different in individual countries and is determined by the public financial policy of national governments*". Ginevicius et al. (2022, p. 1001) argue that "*investments in R&D have a lower direct impact on a country's social development compared to the impact on economic development. This is because R&D affects economic development directly through technological innovations and social development indirectly through economic development*". Kucera and Fil'a (2022) identified the impact of R&D expenditure on innovation performance and impact of the innovation performance on economic development of the EU countries. The authors quantified a significant interdependence between R&D expenditure, innovation performance and level of economic development of the EU countries. Carracedo and Puertas (2022) found that there is no direct relationship between innovation performance and the resources allocated to it. Therefore, governments should promote scientific and technological research that will enable the creation and improvement of current technologies and have highly skilled human resources. Pegkas et al. (2019) investigated the relationship between innovation and research & development expenditure in European Union countries over the period 1995-2014. The results reveal the existence of a positive and significant effect of business, public and higher education R&D on innovation. Business R&D is then the sector with the highest positive effect on innovation. Prokop and Stejskal (2019, 384) claim that "*the provision of public subsidies, unlike cooperation, strongly influence firm's motivation to innovate. Supported innovation activities but do not always lead to an increase in firms' innovative performance*".

Ravselj and Hodzic (2020) focus on the interaction between the public and business sectors in a cross-national setting and they reveal that public governance practices have important implications for business R&D activity. Badulescu et al. (2024) emphasised the importance of economic growth in supporting public and private efforts for R&D, i.e. the regions that can allocate more resources to research, development and innovation (RD&I) will benefit from the more reliable and long-run-oriented economic growth. Other authors, Ciaffi et al. (2024, p. 363) have sought to assess the macroeconomic impacts of government investment in R&D and more generic fiscal policies by quantifying the Gross domestic product and business R&D investment multipliers. The authors' findings support the idea that "*expansionary fiscal policies can positively and persistently affect the GDP level and crowd in business R&D investment*". Arana-Barbier (2023) deepens the relationship between investment in R&D and economic growth, for developed and emerging countries. Their findings indicate that R&D investment strongly correlates to the economy's size of the countries and investment in R&D and its consequent scientific production then has the greatest impact over the size of their economies through innovation. Mao (2024) investigated the mechanisms of tax incentives and R&D investments on employment absorption. Results show that R&D investment, operating profit margin, and remuneration have more significant positive impacts on employment absorption. Another author, Naidoo (2023), found out a positive and significant relationship between innovation and export performance. Direct innovation positively impacts employment growth in manufacturing firms, however, R&D-induced exports have a negative impact on employment growth. Romero et al. (2023) examined the relationship between demand, innovation and research intensity in different industry groups. The authors found that research intensity is not affected by demand growth, but most likely depends on the quality of each country's national innovation system. Stejskal et al. (2018, 191) found that "*new knowledge and innovation outputs of creative industries subsequently affect products and processes of other businesses as well as innovation activities within different industries*". The findings of other research (e.g. Fursov et al., 2016, p. 44) then show that "*the quality of scientific capital, measured through diversity of research experience, has a stronger impact on research productivity, rather than the age or other socio-demographic characteristics*". Uyar et al. (2022, p.733) examined a causality relationship between macroeconomic factors and research productivity with used fixed-effects panel regression analysis. The results show "*a two-way relationship between R&D expenditure and economic development and research productivity*".

Methodology

The subject of the research are selected areas of R&D, innovation and economic activity in a narrow perspective. The aim of the study is to assess the impact of selected R&D indicators on the economic activity of EU countries with a focus on economic growth and employment in knowledge-intensive service sectors in 2011-2021. In the

context of the stated objective we verify 4 research questions (RQ) for two groups of EU countries according to their innovation performance.

RQ1a: R&D expenditure has a mostly positive impact on GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Innovation Leaders and Strong Innovators?

RQ1b: R&D expenditure has a mostly positive impact on GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Moderate Innovators and Emerging Innovators?

RQ2a: Spending on tertiary education has a mostly positive effect on GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Innovation Leaders and Strong Innovators?

RQ2b: Spending on tertiary education has a mostly positive effect on GDP per capita and employment in knowledge-intensive service sectors for the group of countries-Moderate Innovators and Emerging Innovators?

RQ3a: High-tech exports have a positive impact on GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries - Innovation Leaders and Strong Innovators?

RQ3b: High-tech exports have a positive impact on GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Moderate Innovator and Emerging Innovators?

RQ4a: Citable documents positively affect GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Innovation Leaders and Strong Innovators?

RQ4b: Citable documents positively affect GDP per capita and employment in knowledge-intensive service sectors for the group of EU countries-Moderate Innovators and Emerging Innovators?

The source of the research questions is i) the current state of knowledge of selected R&D indicators in relation to economic growth and employment in terms of innovation performance of countries in Europe, but also ii) the approaches and conclusions of selected empirical studies devoted to the topic.

Data

The analysis uses data from the Eurostat and Scimago Journal country rank databases. The Eurostat data include the thematic areas 1) Science, technology, digital society (Science and technology – research and development), 2) Digital economy and society and 3) Economy and Finance-Government statistic (Eurostat, 2024). Data from Scimago Journal country Rank (SJR) were used for the variable citable documents (SJR, 2024). The time period chosen for the analysis, 2011-2021, was linked to the availability of data from the relevant databases (Eurostat, Scimago Journal country Rank) for all variables analysed and all EU countries. Authors see the limitations of this research in the content of indicators as it was impossible to evaluate a larger scale of key R&D variables on account of the unavailability of data. In some variables, the timeseries was not sufficiently long for the purposes of panel data analysis. The original intention of the authors was to use a wider range of R&D indicators for the analysis. Due to the unavailability of some variables that were originally considered for all EU countries and the selected period, and also due to a high correlation-rate, some variables were excluded from the analysis (researchers (FTE) - RESFTE). A total of nine variables (seven independent variables and two dependent variables) were used for the analysis.

As dependent variables indicators are represented that express two areas of economic activity in the EU countries:

- Gross Domestic Product (GDP) per capita - is a core indicator of economic performance and commonly used as a broad measure of average living standards or economic wellbeing (Eurostat Statistics Explained, 2024).
- Employment in knowledge-intensive service sectors – Employment in knowledge-oriented sectors is defined as employment in high-technology manufacturing sectors and knowledge-intensive services. Economic activity sectors are defined as knowledge-intensive services, abbreviated as KIS. These are high-tech knowledge-intensive services, knowledge-intensive market services (excluding financial intermediation and high-tech services), knowledge-intensive financial services and other knowledge-intensive services (Eurostat Statistics Explained, 2023).

Independent variables include selected indicators from research, development and innovation (see Eurostat, 2019; Eurostat Statistics Explained, 2022; Eurostat, 2024; SJR, 2024):

- Research and development expenditures - Gross domestic expenditure on R&D (GERD) includes expenditure on research and development by business enterprises, higher education institutions, as well as government and private non-profit organizations (Eurostat Statistics Explained, 2022).
- General government expenditure - total expenditure comprises all transactions recorded under positive uses in the ESA framework, and subsidies payable, in the current accounts as well as transactions (gross capital formation, acquisition less disposals of non-financial non-produced assets plus capital transfers payable) in the capital account of the government (Eurostat, 2019).

- General government expenditure on tertiary education - government outlays on the highest level of education covering include provision of tertiary education at ISCED-97 level 5 and level 6; administration, inspection, operation or support of universities and other institutions providing tertiary education at ISCED-97 level 5 and level 6; scholarships, grants, loans and allowances to support students pursuing tertiary education at ISCED-97 level 5 and level 6 (Eurostat, 2019, p. 224).
- Human resources in science and technology – are those persons who have successfully completed a tertiary level education and are employed in a S&T occupation (Eurostat, 2024).
- Patent applications to the European Patent Office – is part of the indicator sets EU Sustainable Development Goals (SDG) indicator set. It is used to monitor progress towards SDG 9 on building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation which is embedded in the European Commission’s Priorities. Patents reflect a country’s inventing activity, show the capacity of countries and their businesses to exploit knowledge and research results, and translate it into potential economic gains. In this context, indicators based on patent statistics provide a valuable measure of the inventive performance of countries (Eurostat, 2024).
- High-technology exports - are products with high R&D Intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery (Eurostat, 2024).
- Citable documents are number of citable documents published by a journal in the three previous years (selected year documents are excluded). Exclusively articles, reviews and conference papers are considered (SJR, 2024).

The variables used are presented in Table 1.

Table 1. Used indicators.

	Indicators	Abbrev.	Unit	Source
Dependent indicators	GDP per capita	GDP	Euro per capita	Eurostat
	Employment in knowledge-intensive service sectors	EMKIS	percentage of total employment	Eurostat
Independent indicators	General government expenditure	GEXP	percentage of GDP	Eurostat
	Research and development expenditure	GERD	percentage of GDP	Eurostat
	General government expenditure on tertiary education	GEXPTE	percentage of GDP	Eurostat
	Human resources in science and technology	HRST	Thousands of persons	Eurostat
	Patent applications to the EPO	PATA	number	Eurostat
	High-tech exports	HTEXP	percentage	Eurostat
	Citable documents	CITDOC	number	Scimago

Source: Authors according to Eurostat (2024); SJR (2024).

The selected set consists of 27 EU countries. For the purpose of a more detailed analysis and for subsequent comparison, EU countries were divided into two groups according to innovation performance (in 2021). A comprehensive overview of innovation performance in European countries is provided by the Summary Innovation Index that is part of the European Innovation Scoreboard EIS). Based on the results EIS, countries are classified into “Innovation Leaders, Strong Innovators, Moderate Innovators and Emerging Innovators” (European Commission, 2023a, 2023b).

Table 2. Inter-correlations of used variables in 2021.

Correlation	GDP p.c.	EMKIS	GEXP	GERD	GEXPTE	RESFTE	HRST	HTEXP	PATA
EMKIS	0.6291	-							
GEXP	-0.1355	-0.3628	-						
GERD	0.3121	0.3223	0.5734	-					
GEXPTE	-0.09811	0.1645	0.2133	0.401	-				
RESFTE	0.09572	-0.09409	0.4151	0.4334	-0.1345	-			
HRST	0.0768	-0.1109	0.3785	0.3609	-0.1696	0.9904	-		
HTEXP	0.4133	0.5509	-0.4313	0.09271	-0.07213	0.09911	0.1068	-	
PATA	0.2116	0.05499	0.3114	0.4914	-0.05808	0.9216	0.9064	0.1599	-
CITDOC	0.09717	-0.1502	0.433	0.3772	-0.2199	0.9322	0.9211	0.04935	0.8321

Source: Authors’ calculations

The first group of countries – Innovation Leaders and Strong Innovators (IL+SI) includes Denmark (DK), Sweden (SE), Finland (FI), Belgium (BE), Netherlands (NL), Austria (AT), Germany (DE), Luxembourg (LU), France (FR), Cyprus (CY), Ireland (IE). The second group of countries – Moderate Innovators and Emerging Innovators (MI+EI) includes Estonia (EE), Slovenia (SI), Italy (IT), Malta (MT), Lithuania (LT), Czechia (CZ), Greece (EL), Spain (ES), Portugal (PT), Hungary (HU), Croatia (HR), Slovakia (SK), Poland (PL), Latvia (LV), Bulgaria (BG), Romania (RO).

The correlation relationships between the selected variables, represented by the Pearson correlation coefficients, are shown in Table 2.

Based on the high correlation between the data, the RESFTE variable was discarded for further analysis. The variables Patent applications to the EPO (PATA) and Human resources in science and technology (HRST) were retained in the analysis due to their substantive significance despite the high correlation with CITDOC.

Method used

Panel data analysis is used to examine the relationship between R&D indicators and selected areas of economic activity. Panel (data) analysis is a statistical method, widely used in social science, and econometrics to analyse two-dimensional (typically cross sectional and longitudinal) panel data (Baltagi, 2021). The data are usually collected over time and over the same individuals and then a regression is run over these two dimensions. Panel data analysis has three more-or-less independent approaches: i) independently pooled panels; ii) random effects models, and iii) fixed effects models or first differenced models. The selection between these methods depends upon the objective of the analysis, and the problems concerning the exogeneity of the explanatory variables. In our case we use fixed effects model.

The data have the characteristic of a balanced panel where the cross-sections are countries with $n = 27$ individuals and $T = 10$ time periods. We have $k = 7$ independent variables.

Let

- Y_{it} are the dependent variables,
- X_{jit} are the independent variables,
- α_i are the individual intercepts,
- β_j are the parametric coefficients,
- u_{it} are the error terms,

where $i = 1, 2, \dots, n$; and $t = 1, 2, \dots, T$ and $j = 1, 2, \dots, k$, the panel regression time fixed effect model has equation

$$Y_{it} = \alpha_i + \beta_1 X_{1it} + \dots + \beta_k X_{kit} + u_{it}. \quad (1)$$

Because each individual (EU countries) is not obtained arbitrarily or randomly, there should not be applied the random effect panel regression model. We performed the Hausman to test the consistency of the random effect model (Baltagi, 2021). The Durbin-Wu-Hausman test (also called Hausman specification test) is a statistical hypothesis test in econometrics named after James Durbin, De-Min Wu, and Jerry A. Hausman (Hausman, 1978). The test evaluates the consistency of an estimator when compared to an alternative, less efficient estimator which is already known to be consistent. It helps one evaluate if a statistical model corresponds to the data. Except for the models for GDP in both described narrower groups, all the models have the p -value of Hausman test lower than 0.05, thus the fixed effect panel regression models have been used universally (Croissant, 2008).

Fixed effect panel regression model is equivalent to an ordinary linear regression model with dummy variables D_1, \dots, D_n

$$Y_{it} = \beta_1 X_{1it} + \dots + \beta_k X_{kit} + \gamma_1 D_1 + \dots + \gamma_n D_n + u_{it}, \quad (2)$$

The model in equation (2) can be tackled using the least squares method (Greene, 2012). The least squares method is a mathematical and statistical method for approximating the solution of overdetermined systems of equations (i.e., systems where there are more equations than unknowns). "Least squares" means that the resulting solution should minimize the sum of the squares of the deviations with respect to each equation. The least squares method is widely used to make scatter plots easier to interpret and is associated with regression analysis. The method minimizes the sum of the offsets or residuals of points from the plotted curve. Least squares regression is used to predict the behavior of dependent variables. Least squares problems fall into two categories: linear or ordinary least squares and nonlinear least squares, depending on whether the model functions are linear in all unknowns. The linear least-squares problem occurs in statistical regression analysis; it has a closed-form solution. The nonlinear problem is usually solved by iterative refinement; at each iteration the system is approximated by a linear one, and thus the core calculation is similar in both cases. In our case was used linear least-squares method. The „least squares“ method has a great deal of applications in many scientific branches (Vinzi et al., 2010).

One of the primary advantages of panel data analysis is its capability to control for individual-specific effects. It accounts for individual heterogeneity and allows researchers to isolate the impact of time-varying factors while controlling individual characteristics that remain constant over time. It maximizes the data use by incorporating information from time and entities. This results in efficient estimators and increased accuracy in identifying relationships between variables. The disadvantages of panel data analysis are that the analysis demands extensive data on the same entities over time. Data quality, consistency, and completeness are crucial, as missing, or unbalanced data can affect the analysis. Moreover, data collection over time may be expensive and time-consuming. One of the significant disadvantages of panel data analysis is that it requires advanced statistical knowledge and specialized software. Interpreting the results is also more complex, which can sometimes be challenging to explain and interpret accurately (Hsiao, 2003).

For the analysis, two regression models in the period 2011-2021 were chosen (each for the 27 EU countries and separately for EU countries according to their innovation performance, i.e. for EU countries "Innovation Leaders and Strong Innovators" (IL+SI) and for EU countries "Moderate Innovators and Emerging Innovators" (MI+EI). Regression models for the three groups of countries examine the effects of selected R&D indicators:

- 1) on economic activity - represented by GDP per capita (GDP p.c. model 1 for all EU countries, GDP p.c. model 1.1- countries as "Innovation Leaders and Strong Innovators", GDP p.c. model 1.2 - countries as "Moderate Innovators and Emerging Innovators");
- 2) on economic activity - represented by Employment in knowledge-intensive service sectors (EMKIS model 2 for all EU countries, EMKIS model 2.1- countries as "Innovation Leaders and Strong Innovators", EMKIS model 2.2- countries as "Moderate Innovators and Emerging Innovators").

In the terms of our indicators, equation (1) can be overwritten in the form:

$$GDP_{it} = \alpha_i + \beta_1 GEXP_{it} + \beta_2 GERD_{it} + \beta_3 GEXPTE_{it} + \beta_4 HRST_{it} + \beta_5 HTEXP_{it} + \beta_6 PATA_{it} + \beta_7 CITDOC_{it}. \quad (3)$$

where i passes through selected countries and t passes through all monitored years.

All computation of the panel regression were carried on R-package plm (Croissant, 2008). In the results, the coefficients β_j of equation (3) are shown in tables (3-8) in the column *Estimate* β_j . Each of these coefficients are tested with a t-test for significance. The tables (3-8) show standard error of β_j in column *Std. Error*, achieved t-statistics in column *t-value* and the significance of t-test in the column *p-value*. The level of significance is marked with asterisks for clarity. The individual effects of each country α_i are shown in tables in Appendices. Each of them is tested for significance by t-test.

Results

Between 2011 and 2021, the effects of selected R&D Indicators on economic activity of EU countries are investigated. The results of the panel data analysis are presented for three groups of countries: all 27 EU countries, and for two groups of countries according to their innovation performance i.e. for a group of 11 countries (Innovation Leaders and Strong Innovators) and for a group of 16 countries (Moderate Innovators and Emerging Innovators).

The Effect of selected R&D Indicators on GDP per capita in EU Countries in the years 2011-2021

In the years 2011-2021 we first examine the effect of selected R&D indicators on the economic activity of EU countries, which is expressed in terms of GDP per capita. The results of effects of selected R&D Indicators are presented for regression models: for all EU countries i.e. 27 countries (GDP p.c. - Model 1), for a group of 11 countries (Innovation Leaders and Strong Innovators) with high innovation performance and above the EU average (GDP p.c.- Model 1.1) and for countries (Moderate Innovators and Emerging Innovators) with medium and low innovation performance (GDP p.c.- Model 1.2).

The Effect of selected R&D indicators on GDP per capita for 27 EU countries in 2011-2021 (GDP p.c.- model 1) is documented in Table 3.

The results in the evaluated years for 27 EU countries (model 1, Table 3) show that two categories of government expenditures - general government expenditures (GEXP) at the level of 0.1% and government expenditures on tertiary education (GEXPTE) at the level of 1% had a statistically significant negative effect on GDP p.c. On the other hand, High-tech exports (HTEXP) at the level of 0.1% and citable documents (CITDOC) at 1% had a statistically significant positive impact on GDP p.c. For the EU countries, this means that an increase in government expenditures (GEXP, GEXPTE) by 1% of GDP has an effect on a decrease in GDP p.c. (by 316.2 Eur in the case of GEXP and by 3871 Eur in the case of GEXPTE). An increase in High-tech exports by 1 percentage point affects GDP p.c. growth by 286.1 Eur and an increase in citable documents by 1 document affects GDP p.c. growth by 0.095 Eur. On the contrary, in the case of GDP p.c. no statistically significant effect was demonstrated for the three investigated indicators – research and development expenditures (GERD), human resources in science and

technology (HRST) and patent applications to the EPO (PATA) (in the model of 27 EU countries).

Table 3. The Effect of R&D indicators on GDP per capita in 2011-2021 (Model 1 - all EU countries).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	-316.2	41.27	-7.662	3.534e-13	***
GERD	-583	744.1	-0.7835	0.434	
GEXPTE	-3871	1205	-3.214	0.001474	**
HRST	-0.08813	1.358	-0.06492	0.9483	
HTEXP	286.1	45.07	6.348	9.506e-10	***
PATA	0.6071	0.4966	1.222	0.2226	
CITDOC	0.095	0.03417	2.78	0.005825	**

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

The effect of selected R&D Indicators on GDP per capita for the group of 11 EU countries “Innovation Leaders and Strong Innovators” in 2011-2021 is shown in Table 4.

Table 4. The Effect of R&D indicators on GDP per capita in 2011-2021 Model 1.1 - countries “Innovation Leaders and Strong Innovators”).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	-617.6	86.22	-7.162	1.219e-10	***
GERD	-1989	1282	-1.552	0.1238	
GEXPTE	-3955	3246	-1.218	0.2259	
HRST	-1.168	1.895	-0.6163	0.5391	
HTEXP	197.8	64.48	3.068	0.00275	**
PATA	0.3598	0.602	0.5977	0.5513	
CITDOC	0.2379	0.07072	3.365	0.001078	**

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

For the period 2011-2021 for 11 countries – the Innovation Leaders and Strong Innovators, the (Model 1.1, Table 4) results show that High-tech exports (HTEXP) and citable documents (CITDOC) had a statistically significant positive effect on GDP per capita at the 1% level. This means that a 1 percentage point increase in High-tech exports increases GDP per capita by 197.8 Euros and 1 citable document has the effect of increasing GDP per capita by 0.2379 Euros. On the other hand, general government expenditures (GEXP) had a statistically significant negative effect on GDP p.c. at the level of 0.01%. Then an increase in general government expenditures by 1% of GDP decreases GDP p.c. by 617.6 Eur.

In the group of countries - Innovation Leaders and Strong Innovators, the effect of the indicators (GEXP, CITDOC) on GDP p.c. is so strong that it is reflected in the model of all 27 EU countries (see Table 3). The results (Table 4) show that for the group countries – Innovation Leaders and Strong Innovators in the case the other examined R&D indicators (GERD, GEXPTE, HRST and PATA) no statistically significant effect was demonstrated on GDP per capita.

The results for the individual EU countries of the IL+SI group (Appendix A - Table 1a) show that in 2011-2021 in 10 countries there was a statistically significant positive individual impact of R&D indicators on GDP per capita at the level of 0.01%. The countries with the highest individual impact of R&D indicators on GDP per capita were Luxembourg Denmark, Finland and Sweden. On the other hand, the weakest statistically significant impact of R&D indicators was in France and Cyprus. In the case of Germany, there was no statistically significant individual effect of R&D indicators on GDP per capita proven.

In the years 2011-2021, the effect of R&D indicators on GDP per capita for the group of 16 EU countries “Moderate Innovators and Emerging Innovators” (MI+EI) is shown in table 5.

The results for 16 EU countries - Moderate Innovators and Emerging Innovators (Table 5, Model 1.2) show that there is a statistically significant positive effect of research and development expenditures (GERD) at the 5% level in the case of GDP per capita. This means that in these countries an increase in R&D expenditures by 1% of GDP has an effect of increasing GDP per capita by 1.502 Euros. On the other hand, general government expenditures (GEXP) and general government expenditures on tertiary education (GEXPTE) had a statistically significant

negative effect on GDP per capita (GEXP at the level of 5% and GEXPTE at the level of 0.1%). This means that an increase in government expenditures (GEXP, GEXPTE) by 1% of GDP decreases GDP p.c. (by -79.62 Euros in the case of GEXP and by -4439 Euros in the case of GEXPTE).

In the countries – Moderate Innovators and Emerging Innovators the effect of government expenditures on tertiary education is so high that it is reflected in the model of all 27 EU countries (see Table 3). For the other R&D indicators examined (HRST, HTEXP, PATA CITDOC), the Moderate Innovators and Emerging Innovators countries do not show a statistically significant effect in the case of GDP p.c. (see Table 5).

Table 5. The Effect of R&D indicators on GDP per capita in 2011-2021 (Model 1.2 -countries “Moderate Innovators and Emerging Innovators”).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	-79.62	31.11	-2.559	0.01147	*
GERD	1502	613.5	2.449	0.01547	*
GEXPTE	-4439	795.6	-5.579	1.069e-07	***
HRST	2.106	3.049	0.6906	0.4909	
HTEXP	-57.58	61.16	-0.9415	0.3479	
PATA	-0.2305	1.484	-0.1553	0.8768	
CITDOC	0.01851	0.0484	0.3824	0.7027	

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

The results for the individual EU countries of the MI+EI group show that in 2011-2021 there was manifested a statistically significant positive individual effect of R&D indicators on GDP per capita at the level of 0.01%. Italy and Malta showed the highest individual impact of R&D indicators. On the contrary, the lowest individual impact of R&D indicators on GDP per capita was observed in Romania and Bulgaria (see Appendix B - Table 2a.).

The Effect of selected R&D Indicators on Employment in knowledge intensive service sectors in EU Countries in the years 2011-2021

We also investigate the effect of selected R&D Indicators on economic activity of EU countries represented by Employment in knowledge intensive service sectors (EMKIS). The results in the years 2011-2021 are presented in three models: for all EU countries i.e. 27 countries (EMKIS - Model 2), for the group of EU countries Innovation Leaders and Strong Innovators (EMKIS - Model 2.1) and for countries Moderate Innovators and Emerging Innovators with medium and low innovation performance (EMKIS - Model 2.2).

The effects of selected R&D indicators on Employment in knowledge-intensive service sectors (EMKIS) for all 27 EU countries in 2011-2021 are shown in Table 6.

Table 6. The Effect of R&D indicators on Employment in knowledge intensive service sectors in 2011-2021 (Model 2 - all EU countries).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	0.01923	0.007768	2.476	0.01393	*
GERD	0.3614	0.1401	2.58	0.01041	*
GEXPTE	-1.32	0.2268	-5.82	1.71e-08	***
HRST	0.0003827	0.0002556	1.497	0.1355	
HTEXP	0.007887	0.008485	0.9295	0.3535	
PATA	6.253e-05	9.349e-05	0.6689	0.5041	
CITDOC	1.34e-05	6.432e-06	2.083	0.03823	*

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

For the period 2011-2021 for 27 EU countries (Model 2, Table 6), results show that a statistically significant positive effect on EMKIS had general government expenditures (GEXP), research and development expenditures (GERD) and cited documents (CITDOC) at the 5% level. However, the positive effect of general government expenditures on EMKIS was not reflected in the other models (i.e. in the country group Innovation Leaders and Strong Innovators or in the country group Moderate Innovators and Emerging Innovators. In contrast, general government expenditures on tertiary education (GEXPTE) had a statistically significant negative effect on EMKIS at the 0.1% level. For EU countries, this means that an increase in expenditures (GEXP, GERD) by 1% of GDP affects the growth of EMKIS (by 0.01923 percentage of total employment in the case of GEXP and by 0.3614 in the case of

GERD). At the same time, an increase in citable documents by 1 document affects the growth of EMKIS by 0.0000134 percentage of total employment. Based on the results (Table 6), we can state that for the three R&D indicators examined HRST, HTEXP and PATA (in model the 27 EU countries) no statistically significant effect was demonstrated in the case of EMKIS.

For the group of 11 EU countries Innovation Leaders and Strong Innovators the effect of R&D indicators on Employment in knowledge intensive service sectors (EMKIS) in 2011-2021 is shown in Table 7.

Table 7. The Effect of R&D indicators on Employment in knowledge intensive service sectors in 2011-2021 (Model 2.1 – countries “Innovation Leaders and Strong Innovators”).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	0.01175	0.01225	0.9588	0.3399	
GERD	0.1315	0.1822	0.7218	0.472	
GEXPTE	-0.9158	0.4612	-1.985	0.04976	*
HRST	0.0001867	0.0002694	0.6932	0.4898	
HTEXP	0.003286	0.009162	0.3586	0.7206	
PATA	9.871e-05	8.555e-05	1.154	0.2512	
CITDOC	3.154e-05	1.005e-05	3.138	0.002217	**

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

From the results for the Innovation Leaders and Strong Innovators countries (Table 7, Model 2.1) we can see that only two R&D indicators have a statistically significant effect on EMKIS, namely general government expenditures on tertiary education (GEXPTE) and citable documents (CITDOC). In the case of EMKIS, citable documents have a statistically significant positive effect at 1% level and general government expenditures on tertiary education has a statistically significant negative effect at 5% level. For the EU countries – Innovation Leaders and Strong Innovators, this means that an increase in general government expenditures on tertiary education (GEXPTE) by 1% of GDP has an effect of reducing EMKIS by 0.9158 percentage of total employment and an increase in citable documents by 1 document has an effect of increasing EMKIS by 0.00003154 percentage of total employment.

However, in the group of countries Innovation Leaders and Strong Innovators the effect of cited documents is so high that it is reflected in the model of all 27 EU countries. The results for the countries - Innovation Leaders and Strong Innovators also show (Table 7) that for the other R&D indicators examined no statistically significant effect was demonstrated on EMKIS.

Table 8. The Effect of R&D indicators on Employment in knowledge intensive service sectors in 2011-2021 (Model 2.2 – countries “Innovation Leaders and Strong Innovators”).

Variables	Estimate β_j	Std. Error	t-value	p-value	
GEXP	0.02096	0.01098	1.909	0.05811	
GERD	0.4818	0.2164	2.226	0.02747	*
GEXPTE	-1.361	0.2807	-4.85	3.008e-06	***
HRST	0.0001047	0.001076	0.09733	0.9226	
HTEXP	0.01747	0.02158	0.8097	0.4194	
PATA	-0.0003806	0.0005237	-0.7268	0.4685	
CITDOC	1.807e-05	1.708e-05	1.059	0.2915	

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

The results for the individual EU countries in the IL+SI group show that in the period 2011-2021, eight countries had a statistically significant positive individual impact of R&D indicators on EMKIS (highest impact in Ireland and Finland at the 0.1% level, lowest individual impact in Austria at the 5% level). Germany showed a negative individual impact of R&D indicators on EMKIS at the 5% level. And in the case of two countries (France and Netherlands), there was demonstrated no statistically significant individual impact of R&D indicators on EMKIS (see Appendix A - Table 1b).

For the group of 16 EU countries - Moderate Innovators and Emerging Innovators, the effect of R&D indicators on Employment in knowledge intensive service sectors (EMKIS) in 2011-2021 is shown in Table 8 (Model 2.2).

For the group of countries - Moderate Innovators and Emerging Innovators, the results show that only two R&D

indicators (categories of expenditures) had a statistically significant effect on EMKIS, namely general government expenditures on tertiary education (GEXPTTE) and research and development expenditures (GERD). However, on EMKIS, research and development expenditures have a statistically significant positive effect at the level of 5% and general government expenditures on tertiary education have a statistically significant negative effect at the level of 0.1%. For the countries - Moderate Innovators and Emerging Innovators, this means that an increase in GERD expenditures by 1% of GDP affects the growth of EMKIS by 0.4818 percent of total employment and an increase in GEXPTTE expenditures by 1% of GDP affects the reduction of EMKIS by 1.361 percent of total employment.

In the countries - Moderate Innovators and Emerging Innovators the impact of two categories of expenditure (GERD and GEXPTTE) on EMKIS is relatively high and is also reflected in the model for all 27 EU countries. The results (Table 8, Model 2.2) further show that for the other R&D indicators examined no statistically significant impact was demonstrated in the case of EMKIS.

The results for the individual EU countries of the MI+IE group (Appendix B - Table 2b) show that in the period 2011-2021, 14 countries showed a statistically significant positive individual impact of R&D indicators on EMKIS (the highest individual impact in Estonia and Malta at the 0.1% level, the lowest individual impact in Portugal and Greece at the 5% level). In the case of two countries Spain and Italy, no statistically significant individual effect of R&D indicators on EMKIS was demonstrated.

Discussion

Our research examined the impact of selected R&D indicators on the area of economic activity (expressed as GDP per capita and Employment in knowledge-intensive service sectors) and tested 4 research questions for two groups of EU countries according to their innovation performance. From the results obtained, it can be concluded that the impact of individual R&D indicators differs significantly when evaluating EU countries as a whole or when evaluating groups of EU countries according to innovation performance.

In the context of the evaluation of research question (RQ1): *“R&D expenditure has a predominantly positive impact on GDP per capita and employment in knowledge-intensive service sectors in EU countries: a) for the group of countries Innovation Leaders and Strong Innovators; b) for the group of countries Moderate Innovators and Emerging Innovators?”* For the group of countries Innovation Leaders and Strong Innovators, the results show that R&D expenditure did not have a statistically significant impact on GDP per capita or employment in knowledge-intensive service sectors in 2011-2021, therefore the answer to the research question (RQ1a) is negative (NO). On the other hand, for the Moderate Innovators and Emerging Innovators group of countries, the positive effect of R&D expenditure on GDP per capita and employment in knowledge intensive service sectors is confirmed. The answer to the research question (RQ1b) is affirmative (YES).

Also, based on the research of Tung and Hoang (2024), we can conclude that national R&D spending has a positive effect on economic growth, both from the direct and interaction dimensions in the case of emerging economies. Similar to our research, Ali et al. (2021) confirm that there is a strong positive association between R&D expenditure and economic growth (GDP) in the long run in developing and developed economies. Indeed, an increase in R&D expenditure (GERD) leads to an increase in GDP. However, the impact of R&D expenditure is lower in less developed and developing countries than in developed countries. In the short run, then, no impact of GERD on economic growth is observed.

As R&D spending is a prerequisite for the development of innovative activities, a link between innovation and job creation can be established (Moutinho et al., 2015; Shah et al., 2024). Employment growth is related to innovation, not only at the aggregate level, but also within groups of major industries. However, the positive impact of technological progress is more pronounced in the manufacturing sector. From the findings of Moutinho et al. (2015), we can then conclude that increasing government investment in R&D is not the only remedy for stagnant growth. University employment in R&D plays a relatively important role, especially in reducing youth unemployment, and it does not have a downside in terms of economic growth.

Similarly to our research, a number of authors (Veugelers and Baltensperger, 2019; Akcigit et al., 2024; Mor et al., 2024) agree that R&D expenditure and tertiary education expenditure can be identified as important indicators for economic growth, but also for the development of innovation activities and employment in knowledge-intensive service sectors. Indeed, R&D subsidies, can be strengthened in combination with higher education subsidies, by having education and R&D policies influence innovation at different time horizons. A country's innovation ranking is then crucial for its innovation, which is based on education, R&D and cooperation with industry in knowledge transfer. In this context, Akcigit et al. (2024) or Mor et al. (2024) found that the negative impact of primary and secondary education is significant only for upper middle-income countries, and in low middle-income countries, it is mainly tertiary education that affects innovation scores.

Our research also investigated the effect of education spending on GDP and employment in knowledge-intensive service sectors and tested the research question (RQ2): *“Does tertiary education spending have a predominantly*

positive effect on GDP per capita and employment in knowledge-intensive service sectors in EU countries: a) for the group of countries Innovation Leaders and Strong Innovators; b) for the group of countries Moderate Innovators and Emerging Innovators?” Based on our results, we can conclude that for the group of countries “Innovation Leaders and Strong Innovators” the impact of government spending on tertiary education was not significant for GDP per capita in 2011-2021. There was only a significant negative effect of government spending on tertiary education in the case of Employment knowledge-intensive service sectors, therefore the answer to the research question (RQ2a) is negative (NO) for the group of countries “Innovation Leaders and Strong Innovators”. For the group of countries “Moderate Innovators and Emerging Innovators” there was a significant but negative effect of government spending on tertiary education in the case of GDP per capita (table 5) and in the case of Employment in knowledge-intensive service sectors (table 8) in the years under evaluation. Based on these findings, the answer to the research question (RQ2b) for “Moderate Innovators and Emerging Innovators” countries is also negative (NO).

Similarly, from the findings of other research (Idrees and Siddiqi, 2013; Nuță et al., 2022; Okoye et al., 2022), we can confirm the effect of education spending in relation to economic growth or employment. Veugelers and Baltensperger (2019, p. 8) document that “investment in science, technology, innovation and education correlates strongly with the development of society and that individual countries commit substantial parts of their public expenditures to research and development and education, taking into account that knowledge is a global public good that can be used by others”. Okoye et al. (2022) note that equitable and effective investments in education and human capital development, including science, technology and innovation, have proven to be effective in ensuring an inclusive and development-oriented society. However, there are differences in government investment in education and in R&D and innovation among countries according to their income levels. As in our case, the findings of Nuță et al. (2022); Idrees and Siddiqi (2013) confirm that the long-run relationship between education spending and economic growth is mostly mixed. The impact of public spending on education in the case of economic growth is larger in less developed countries compared to developed countries. In comparison with our results from Intan Primandani and Purbadharmaja (2023), we can then conclude that government spending, investment and education levels have a primarily positive effect on job opportunities and employment growth. In a broader context, Hajebi et al. (2023) then point out that an improvement in the level of education of people is associated with an increase in human capital in a country, which has a positive effect on economic growth and on reducing inequality. Therefore, government spending on education can also be an effective factor to acquire knowledge and improve the level of education of people in the society.

Based on the validation of the research question (RQ3): “Do high-tech exports positively affect GDP per capita and employment in knowledge-intensive service sectors in EU countries a) for the group of countries Innovation Leaders and Strong Innovators; b) for the group of countries Moderate Innovators and Emerging Innovators?”, it can be concluded that: in the Innovation Leaders and Strong Innovators group, high-tech exports (HTEXP) had a positive effect on GDP per capita. In contrast, the effect of high-tech exports on employment in knowledge intensive service sectors was positive but insignificant. For the group of countries Innovation Leaders and Strong Innovators, the answer to research question (RQ3a) can only be partially confirmed in the case of the impact of high-tech exports on GDP per capita. For the Moderate Innovators and Emerging Innovators group of countries, the effect of high-tech exports on GDP per capita and on employment in knowledge intensive service sectors in the years evaluated was not significant. The answer to the research question (RQ3b) is therefore negative (NO) for the Moderate Innovators and Emerging Innovators group of countries.

Similarly to our research, Sojoodi and Baghbanpour (2024) confirm that exporting high-tech industries causes knowledge spillovers and can lead to rapid economic growth. At the country level, while there is positive causality from high-tech exports to GDP growth in some developing and developed countries, the number of such countries is limited. However, in selected developing and developed countries, there is no significant effect of high-tech exports on GDP growth and only a unidirectional causality from GDP growth to high-tech exports. Similarly, other authors Falk, 2009; Ekananda and Parlingoman (2017); Şahin and Şahin (2021); Domazet et al. (2022) find that the impact of high-tech product exports on economic growth varies across European countries. This is due to the fact that each country has its own composition of exports according to human capabilities and technology. According to Kabaklarli et al. (2018), it was found that there is a long-run relationship between high-tech exports and economic growth in selected OECD countries. While growth and investment rates play a negative role in boosting high-tech exports, an improvement in patent applications and foreign direct investment play a decisive role in upgrading selected OECD countries’ high-tech exports. In this context, Şahin and Şahin (2021) find that high-tech exports increase economic growth more than agricultural exports. Therefore, it is not only policy makers who should encourage investment in the mainstay industries (aerospace and automotive, but also nuclear and space). Older research (e.g. Falk, 2009) then suggests that the intensity of corporate R&D is more important than the share of high-tech exports in explaining GDP per working-age population.

From the evaluation of the research question (RQ4) “Do citable documents positively affect GDP per capita and employment in knowledge intensive service sectors in EU countries: a) for the group of countries Innovation Leaders and Strong Innovators; b) for the group of countries Moderate Innovators and Emerging Innovators?” The

answer to the research question (RQ4a) for the Innovation Leaders and Strong Innovators group of countries is affirmative (YES). Conversely, for the Moderate Innovators and Emerging Innovators country group, the significant impact of the citable documents on GDP per capita and employment in knowledge-intensive service sectors is not confirmed. The answer to the research question (RQ4b) is negative (NO) for this group of countries.

In the context of our results, we note that similar findings are confirmed by other authors (e.g. Meo et al., 2013; Yegros-Yegros et al., 2020; Al-Jamimi et al., 2022; Moyo and Phiri, 2024). Publication (document) citations reflect the impact of the research or its quality. However, as Aksnes et al. (2019) state, “*an increased use of citation indicators in research evaluation and funding may imply less attention to other research quality dimensions, such as robustness/credibility, originality, and societal value*”. According to Al-Jamimi et al. (2022: 5879) “*focusing on corresponding authors of publications might be more important than other indicators measuring the research productivity since they highlight the 'actual' contribution of national scientists*”. Also relevant are Collaboration indicators measuring national/international collaborative publications. Overall, then, it can be assumed that economically developed countries are more likely to produce high quality scientific publications, which is also reflected in the number of citations of these documents. Similar to our research, Meo et al. (2013) found that spending on R&D, number of universities and indexed journals have a positive correlation with number of published documents, citations per document and H-index in various science and social science subjects. However, according to Yegros-Yegros et al. (2020), citation rates are significantly lower in middle-income countries (e.g. in health care for the most prevalent diseases) than in low- and middle-income countries. The findings also show that researchers in middle-income countries receive more citations when they study diseases that are more common in high-income countries. Also, Moyo and Phiri (2024) show that knowledge generation through article publications is positively associated with economic growth. However, the impact of publications is greater for developed countries, which can be explained by the large number of publications compared to emerging and developing countries. However, publications in the fields of science and technology or engineering and mathematics have a greater impact on economic growth.

Similarly to our research, Agezew (2024) suggests that cited journal articles, technology exports and patents can be considered as essential factors for fostering economic growth (also outside Europe). There is a significant link between these indicators and growth of GDP per capita. In contrast, government expenditure on research and development has no discernible impact on economic growth, which can be explained by the fact that raising research spending by itself may not be sufficient to boost the economy.

Conclusion

The aim of the study was to evaluate the impact of selected R&D indicators on economic activity of EU countries with emphasis on economic growth and employment in knowledge-intensive service sectors in 2011-2021. The results of panel data analysis showed different impact of R&D indicators on economic activity (GDP per capita and on Employment in knowledge-intensive service sectors) for different groups of countries (all EU countries, Innovation Leaders and Strong Innovators, Moderate Innovators and Emerging Innovators). For the 27 EU countries, four R&D indicators had a significant impact on GDP per capita and on Employment in knowledge-intensive service sectors. In the group of countries “Innovation Leaders and Strong Innovators”, high-tech exports and cited documents had a significant positive effect on GDP per capita, and general government expenditures had a negative effect. In contrast, in the group of countries “Moderate Innovators and Emerging Innovators”, three categories of expenditures were found to have a significant impact on GDP per capita (positive impact of research and development expenditures and negative impact of total government expenditures and government expenditures on tertiary education). Also, in the case of Employment in knowledge intensive service sectors, the effect of different R&D indicators between the groups of countries studied according to their innovation performance was evident. In the case of Employment in knowledge-intensive service sectors, a positive effect of cited documents and a negative effect of general government expenditures on tertiary education were found to be significant in the countries “Innovation Leaders and Strong Innovators”. On the other hand, in the case of Employment in knowledge-intensive service sectors, a significant effect of two categories of expenditure (positive effect of research and development expenditures and negative effect of general government expenditures on tertiary education) was found in the “Moderate Innovators and Emerging Innovators” countries.

Our results partly confirm the findings of other research and then develop the idea of the differential impact of R&D indicators on economic activity for different groups of EU countries also according to their innovation performance. Results of the evaluated groups of EU countries point at key R&D areas for the development of economic activity and the potential for their improvement. The findings open topics for further examination. For future research, the authors foresee an extended analysis of the relationship of R&D indicators to areas of economic activity and an in-depth evaluation of the effects of R&D indicators in the individual EU countries. Another intention of the authors is to apply the extended analysis of R&D indicators to a larger number of European countries (including selected OECD countries). The findings of our research may be useful for both makers of selected public policies and practitioners in assessing sub-areas of R&D as well as to produce comparative analyses.

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Appendix A

Table 1a. The Effect of R&D indicators on GDP per capita for individual EU Countries (group IL+SI) in 2011-2021.

	Estimate	Std. Error	t-value	p-value	
AT	68804	5022	13.7	6.01e-25	***
BE	67510	5134	13.15	9.041e-24	***
CY	50966	3876	13.15	9.065e-24	***
DE	24682	16817	1.468	0.1452	
DK	83321	5800	14.37	2.415e-26	***
FI	76990	6102	12.62	1.272e-22	***
FR	42809	8930	4.794	5.522e-06	***
IE	66436	4044	16.43	1.549e-30	***
LU	109978	3830	28.72	5.789e-51	***
NL	58534	6959	8.412	2.441e-13	***
SE	72362	5713	12.67	9.939e-23	***

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

Table 1b. The Effect of R&D indicators on Employment in knowledge intensive service sectors for individual EU Countries (group IL+SI) in 2011 - 2021.

	Estimate	Std. Error	t-value	p-value	
AT	1.474	0.7136	2.065	0.04142	*
BE	2.068	0.7296	2.835	0.005519	**
CY	2.697	0.5508	4.896	3.634e-06	***
DE	-5.842	2.39	-2.445	0.0162	*
DK	3.21	0.8242	3.894	0.0001751	***
FI	4.576	0.8672	5.276	7.332e-07	***
FR	-2.295	1.269	-1.808	0.07348	
IE	4.779	0.5747	8.316	3.963e-13	***
LU	3.569	0.5442	6.557	2.231e-09	***
NL	1.212	0.9888	1.225	0.2232	
SE	2.839	0.8119	3.497	0.0006951	***

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

Appendix B

Table 2a. The Effect of R&D indicators on GDP per capita for individual EU Countries (group MI+EI) in 2011-2021.

	Estimate	Std. Error	t-value	p-value	
BG	10917	1316	8.295	5.232e-14	***
CZ	20805	1604	12.97	1.989e-26	***
EE	20697	1601	12.93	2.639e-26	***
EL	23347	1640	14.24	7.92e-30	***
ES	24051	1975	12.18	2.815e-24	***
HR	18471	1540	12	8.6e-24	***
HU	17977	1793	10.03	1.673e-18	***
IT	27045	4217	6.413	1.684e-09	***
LT	17891	1272	14.06	2.32e-29	***
LV	18073	1431	12.63	1.635e-25	***
MT	28006	2006	13.96	4.378e-29	***
PL	16923	2175	7.782	9.891e-13	***
PT	21111	1445	14.61	8.161e-31	***
RO	13010	1307	9.953	2.644e-18	***
SI	24524	1703	14.4	2.844e-30	***
SK	19675	1371	14.35	3.937e-30	***

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors

Table 2b. The Effect of R&D indicators on Employment in knowledge intensive service sectors for individual EU Countries (group MI+EI) in 2011 - 2021.

	Estimate	Std. Error	t-value	p-value	
BG	2.519	0.4643	5.425	2.224e-07	***
CZ	1.742	0.5658	3.079	0.002462	**
EE	3.545	0.5649	6.275	3.415e-09	***
EL	1.271	0.5785	2.198	0.02946	*
ES	1.148	0.6968	1.648	0.1015	
HR	2.414	0.5432	4.444	1.687e-05	***
HU	1.932	0.6325	3.054	0.00266	**
IT	0.7308	1.488	0.4912	0.624	
LT	2.193	0.4488	4.887	2.563e-06	***
LV	2.926	0.5047	5.797	3.738e-08	***
MT	3.351	0.7077	4.734	4.974e-06	***
PL	1.84	0.7672	2.399	0.01764	*
PT	1.179	0.5098	2.312	0.02213	*
RO	1.492	0.4612	3.236	0.001487	**
SI	2.87	0.6006	4.778	4.115e-06	***
SK	2.188	0.4836	4.524	1.21e-05	***

Note: asterisks describe statistical significance $p \leq 0.001$ ***, $0.001 < p \leq 0.01$ **, $0.01 < p \leq 0.05$ *. **Source:** Authors