▪ Journal of Competitiveness

Effect of public and private sector R&D indicators on innovation performance and competitiveness: Case of the western European NUTS 2 regions

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Abstract

Innovation performance is considered a crucial indicator of the competitiveness of countries and regions. Studies on innovation performance also need to assess it, distinguishing between public and private sector R&D indicators at the regional level. The objectives of this article are to explore the groups of innovation performance and their spatial distribution in NUTS 2 Western European regions and to evaluate the effect of selected public and private sector R&D indicators on innovation performance in 2014-2021. The fixed effects model on the panel data was used to analyse the impact of selected public and private sector R&D indicators on innovation performance. Research shows that innovation performance increases with time; however, performance suffers from regional disparities, which are affected by selected structural determinants from the public and private sector perspectives. The results of the panel data analysis suggest that the population aged 25-34 who have completed their tertiary education, the most cited scientific publications, and public-private co-publications are statistically significant R&D public sector indicators for the innovation performance of Western European NUTS 2 regions. Furthermore, the results indicate that SMEs that introduce product innovations, employment in knowledge-intensive activities, patent applications, and innovative SMEs that collaborate with others are statistically significant private sector R&D indicators. However, the results reveal various effects of these indicators on individual groups of innovation performance in both the public and private sectors. These findings can benefit policymakers in developing research and innovation systems when finding tools to increase innovation performance and, thereby, the competitiveness of left-behind NUTS 2 regions.

Keywords: *innovation performance, NUTS 2 regions, private sector, public sector, regional competitiveness, research and development*

JEL Classification: O11, M23, L13

Article history: Received: April 2023; Accepted: September 2023; Published: October 2023

1 INTRODUCTION

The past decade has seen an increased emphasis on innovation to strengthen the European Union's competitiveness. Innovation can play an important role in economic growth and a solution to urgent social and global challenges, including demographic shifts and scarce resources (Xu et al., 2023). Science and technology policy is regarded as an essential factor for future growth in the European Union and the global competitiveness of the union (Moagar-Poladian et al., 2017; Fragkiadakis et al., 2020). The European Union (including individual countries and regions) invests in research and innovation to address emerging challenges, reach economies of scale, strengthen the union's scientific excellence, create cross-border, multidisciplinary networks, and reinforce human capital and the structure of national and regional research and innovation systems (Mas-Verdu et al., 2020; Filippopoulos & Fotopoulos, 2022; Wahyudi et al., 2023). However, research and innovation must be able to deliver concrete

https://doi.org/10.7441/joc.2023.03.06

technical solutions across the whole value chain to ensure the transformation of the European Union into a more sustainable and competitive economy (Ganau & Grandinetti, 2021).

Research into innovation performance in European countries or regions already carried out predominantly focuses on the evaluation of innovation capacity and innovation potential aggregately, without distinguishing the sectors of performance, or it examined selected areas (instruments) of innovation performance (Zhylinska et al., 2020; Khyareh & Rostami, 2021; Cerulli et al., 2022). Regional innovation performance has been examined using the example of various selected groups of regions (developing, developed, coastal, lagging, in OECD, Visegrad groups) or using the model of regions in a single country or selected countries (Mudronja et al., 2019; Pires et al., 2020; Klímová et al., 2022). However, the neglected area is the evaluation of innovation performance according to the individual sectors of performance of research and development (R&D) (distinguishing the public and the private sectors) at the national or regional levels. This paper specifies R&D factors affecting public and private innovation performance compared to other research. The article seeks to fill the research gap. It attempts to evaluate innovation performance using the example of NUTS 2 regions in Western Europe and to identify the determinants of R&D that impact changes in regional innovation performance according to their respective groups using panel data analysis. The division into groups of regions by innovation performance assumes that there are disparities in innovation performance between the NUTS 2 regions of Western Europe (see European Commission, 2022; According to Eurostat, "the NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU and the UK"). We also assume a varying impact of different public and private R&D indicators on innovation performance by dividing NUTS 2 regions according to their innovation performance into four groups (Kijek & Matras-Bolibok, 2018; Lopes et al., 2021a, 2021b).

The objectives of this article are to explore the groups of innovation performance and their spatial distribution in NUTS 2 Western European regions and to evaluate the effect of selected public and private sector R&D indicators on the innovation performance of NUTS 2 Western European regions in 2014-2021. The article is structured into five sections. The first section is the introduction, which defines the focus of the research topic and the article's structure. The second section comprises the theoretical background and resources related to the given issue. The third section provides methodology, consisting of the research objective, aim, research questions, data used, description of the applied methods, and the methodological process. The fourth section provides results and discussion. In this part, innovation performance, the influence of R&D indicators on innovation performance according to four categories of innovators in the public and the private sectors in Western European Regions are evaluated, the acquired results discussed against other international research, and the research questions validated. The last section of the article is the conclusion, which summarises the results and provides the study's limitations and topics for further research.

2 THEORETICAL BACKGROUND

Innovation activity is an important source of competitiveness, economic growth, as well as the image of each country and region (Fragkiadakis et al., 2020; Ganau & Grandinetti, 2021; Klimova et al., 2022). Innovative economies are more productive, resilient, and adaptable to changes and can support higher living standards (Kijek & Matras-Bolibok, 2018; Filippopoulos & Fotopoulos, 2022; Xu et al., 2023). European Union innovation policies have for long remained mostly research-driven. Regarding the competitiveness of countries and regions, the areas in focus are funding research, development, and innovation. As some authors have shown (Moagar-Poladian et al., 2017; Kijek et al., 2022), investment in research and development

https://doi.org/10.7441/joc.2023.03.06

(R&D) creates preconditions for implementing more advanced and better technologies and introducing new products and production processes. This fact can result in the potential for higher economic growth (Mudronja et al., 2019; Pegkas et al., 2019; Prokop et al., 2021; Uhlbach et al., 2022). According to Hervas-Oliver et al. (2021, p. 1), "innovation policies based on the increase of R&D investment may not deliver the best outcomes in regions." Regardless of the context, we can say that "greater investment in public R&D does not always lead to improvements in regional SME innovation."

A fundamental precondition for the growth of innovation performance and competitiveness of countries or regions is total R&D expenditures (Bednář & Halásková, 2018; Pegkas et al., 2019; Blanco et al., 2020; Celli et al., 2021). The mutual relationship between innovation and expenditures on research and development in the EU has been addressed in multiple pieces of research. Pegkas et al. (2019) confirm the statistically significant positive impact of business, public and university R&D on innovation. Another study discusses the role of convergence and divergence concerning R&D expenditures and innovation performance in European regions (Bednář & Halásková, 2018; Barios et al., 2019; Blanco et al., 2020; Kijek et al., 2022). The authors agree that there exist differences between regions, with the most important factor being initial regional expenditures on R&D, which drive the division of regions into innovation convergence clubs. Celli et al. (2021) emphasise differences in allocated R&D resources in European regions. These authors state that regions are investing a higher share of resources in R&D, but these have the same convergence rate as regions investing more resources in other priorities. Mudronja et al. (2019) argue that investment in research and development affects the innovation performance of coastal regions. As a result, regions with high innovation capacity grow more quickly and manifest larger economic benefits than other regions. Tudor & Sova (2022) found that the number of researchers and export of cutting-edge technology can be considered the most important driving factors that affect R&D intensity (the share of R&D expenditures in GDP) or innovation performance and competitiveness of a country or region. Zhylinska et al. (2020) point out the impact of innovation factors on economic performance in E.U. candidate countries and their regions. The factors they consider statistically significant are ICT service exports and the number of researchers in R&D while considering the export of cutting-edge technology and patent applications statistically insignificant.

The interest in regional innovation systems has risen significantly along with the increasing interest in innovation as a source of competitive advantage and the need for new policies to tackle regional inequalities and differences (Gavurova et al., 2016, 2017; Han et al., 2018; Hauser et al., 2018; López-Rubio et al., 2022). According to López-Rubio et al. (2020), the regional innovation system explains a region's development and competitiveness and shows trends in regional innovation performance. Garcia-Alvarez-Coque et al. (2021) have identified drivers of innovation activities in European regions, namely public and private R&D expenditures, universities, and small- and medium-sized enterprises (SMEs). Competitiveness at the regional level is mainly affected, particularly in rural areas, by the level of university education combined with public and private research. Ganau & Grandinetti (2021) tested the possibilities associated with increased innovation performance, considering institutional quality a factor in increasing innovation productivity. Klímová et al. (2022) evaluated public investment in innovation, leading to the growth of the turnover of SMEs in Czech regions. The results show that a higher share of public resources should be allocated mainly to knowledge-demanding areas and SMEs.

As further authors show (Bristow & Healy, 2018; Blazek & Kadlec, 2019; Constantin et al., 2021; Spallone & Cerulli, 2022) dynamics of R&D affect the shaping of innovativeness and can provide a new view of economic development and regional growth. The position of each region from the viewpoint of innovation performance can be said to be unique concerning their

https://doi.org/10.7441/joc.2023.03.06

specific conditions (economic, demographic, social, or natural) (Soltes & Gavurova, 2014; Han et al., 2018; Celli et al., 2021; Calignano, 2022). Nevertheless, some research stresses the complexity of regional innovation capacities by stating that innovation performance in individual regions may be affected differently by identical factors (Revoltella et al., 2019; Caviggioli et al., 2023; Tudor & Sova, 2022). According to some authors (Hervas-Oliver et al., 2021; Kijek et al., 2022), increasing disparities between European regions constitute a great challenge for sustainable development and require the identification of the factors responsible for this process.

By reviewing less recent as well as more recent literature, it is possible to characterise key factors and determinants with an impact on innovation performance in European regions (Mudronja et al., 2019; Garcia-Alvarez-Coque et al., 2021; Xu et al., 2023). It is mainly the intensity of expenditures on research, development, and innovation (public or private), technological changes, economic development, investment in human capital, the share of the population with tertiary education, the presence of excellent universities, qualified human capital, the percentage of university-educated employees in science and technology, institutional quality, the support of entrepreneurship or regional openness. Other researchers, such as Barzotto et al. (2019) or Lopes et al. (2021a, 2021b;) regard the implementation of the research and innovation strategy for smart specialization (RIS3) as a statistically significant factor accounting for the performance of regional innovation. Regions with a high innovation performance (Leader and Strong) benefit from implementing innovation policy. By contrast, lagging regions need more technological possibilities and fully use innovation capacity. Blažek & Kadlec (2019) argue that the innovation performance of European advanced regions is often indicated by the smallest share of synthetic knowledge base, by either dominant private R&D or a relatively balanced structure of private and public R&D. The opposite is observed in the backward regions.

3 RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The subject of this study is innovation performance, as one of the indicators of territorial competitiveness, with its relation to the indicators of R&D in the public and private sectors being examined in developed countries, here specifically in NUTS 2 Western European regions treated as the object of study. The objectives of the article are 1) to explore the groups of innovation performance and their spatial distribution; 2) to evaluate the effect of selected public and private sector R&D indicators on the innovation performance in 2014-2021, using a division into four groups according to their innovation performance relative to the E.U. average in 2021. Two research questions develop the two objectives of the article as follows. RQ1: Do the strong and moderate innovation performance groups in NUTS 2 Western European regions relative to the E.U. average in 2021 prevail? RQ2): Do R&D indicators in public and private sectors have a varying effect on the innovation performance of NUTS2 Western European regions by innovation performance groups?

The paper commenced the study with 176 NUTS 2 regions. Considering the economic structure of the overseas areas of Western European countries that are predominantly dependent on tourism and the mining industry, all the overseas NUTS 2 regions of France, Portugal, and Spain were omitted from the analysis. Furthermore, Äland – a Finnish NUTS 2 region – was excluded from further examination due to missing data. The final dataset consisted of 170 NUTS 2 regions in fourteen Western European E.U. countries (Ireland, Sweden, Finland, Denmark, Germany, Netherlands, Belgium, Luxemburg, Austria, France, Portugal, Spain, Italy, and Greece) along with the United Kingdom, Norway, and Switzerland, covering data from 2014 to 2021. The investigated dataset of the NUTS 2 regions was selected to avoid countries of more than 10,000 km^2 that consist of one NUTS 2 region (Estonia, Latvia, Lithuania and

https://doi.org/10.7441/joc.2023.03.06

Iceland), where core-periphery issue plays a role in their development, where regional diversification can occur due to problems with the centre-periphery model. Our effort was to prevent the Western and Eastern divide made by the economic and innovation performance of the E.U. countries because of the former division of Europe between the Western Bloc and the Eastern Bloc, as noted by Amable (2009).

3.1 Data

The Regional Innovation Scoreboard 2021 database was used to analyse determinants of innovation performance in the public and private sectors in Western Europe between 2014-2021 (European Commission, 2022). The database offers the relative performance of normalised scores of indicators based on panel data, where the average E.U. performance in 2014 is set at 100. The Regional Innovation Scoreboard is available from several databases, including Eurostat, Scopus, and the OECD. The used regional dimension of the approach reflects a regional variety of data, as the Summary Innovation Index for countries is calculated as a mean of regional indexes of NUTS 2 regions. The Regional Innovation Scoreboard database was also used in other research and studies on the innovation performance of NUTS 2 European regions (Hervas-Oliver et al., 2021; Lopes et al., 2021a, 2021b; Xu et al., 2023). The database provided the most recent statistics from Eurostat and other internationally recognised sources in April 2021. The Summary Innovation Index (SII) was used as a proxy variable for the innovation performance of NUTS 2 Western European regions. The regions were divided by their innovation performance defined by the Regional Innovation Scoreboard 2021 into four groups (innovation leader, strong innovator, moderate innovator, emerging innovator). However, the groups defined by SII are relative to the European Union's last year of SII calculation – 2021. We selected the 2021 Regional Innovation Scoreboard indicators as independent variables to determine SII; see Tab. 1.

Tab. 1 – Used R&D indicators for determining innovation performance. Source: Authors, based on European Commission (2022) and Bristow & Healy (2018).

Innovation dimension	R&D indicator	Used sector	Abbreviation
Enablers of Innovation	Percentage Population aged 25-34 having completed tertiary education	Public	PTE
	Employment in knowledge-intensive activities as a percentage of total employment	Private	EIKA
	R&D expenditure in the public sector as a percentage of GDP	Public	RDEP
Innovation activity	R&D expenditure in the business sector as a percentage of GDP	Private	RDEB
	Public-private co-publications per million population	Public	PPCP
	EPO patent applications per billion GDP in PPS	Private	PCT
	Innovative SMEs collaborating with others as a percentage of SMEs	Private	ISME
	Scientific publications among the top 10% of most cited publications worldwide as a percentage of total scientific journals in the country.	Public	SPC

https://doi.org/10.7441/joc.2023.03.06

Innovation outputs	SMEs introducing product innovations as a percentage of SMEs	Private	SMEPI

The resulting balanced panel data comprised 6.824 observations for public sector indicators and the indicator of innovation performance represented by SII, and 8.184 observations for private sector indicators and the indicator of innovation performance represented by SII in the investigated NUTS 2 regions. Selected public and private sector R&D indicators covering three innovation dimensions developed by Bristow & Healy (2018) were treated as determinants of innovation performance. Specifically, PPCP, PTE, RDEP and SPC were used for the public sector R&D indicators, and the variables EIKA, ISME, PCT, RDEB and SMEPI were used for the private sector R&D indicators (see Table 1). At the same time, SII was treated as a common dependent variable for both sectors.

3.2 Methods

The fixed effect model was used to estimate the effect of selected public and private sector R&D indicators on SII. The estimation method used is a statistical regression model in which the intercept of the regression model is allowed to vary freely between individuals or groups (Allison, 2009; Baltagi, 2021). Fixed effect regression analysis models for balanced panel datasets (for regional public and private sector indicators) that vary over time on SII were developed. The selected approach is the most effective for finding time-invariant regional-specific unobserved heterogeneity. The Dickey-Fuller test was used to check the dependent variable - SII - for stochastic trends (Baltagi, 2021). The test showed the non-stationarity of the data, and a unit root was present. The first difference logarithm data (ln) was used to ensure the stationarity of the panel data as follows.

$$\Delta y_{it} = y_{it} - y_{it-1} \quad (1)$$

Due to the violation of the fixed effects models' assumptions in several panels – serial correlation and heteroskedasticity, robust alternatives of covariance matrix were used to estimate coefficients. However, the predominant number of estimated models shows a violation of cross-sectional dependency using the Pesaran λ_{CD} statistic, as the cross-sectional dimension of the panel (NUTS 2 regions – N) is not randomly selected. Moreover, panel datasets are a common problem in international economics, where the number of objects (N) is vast compared to the number of panels and time dimension (T). Therefore, consistent standard errors of spatial correlation without restricting the lag window proposed by Driscoll and Kraay (1998) were used by applying the Schreiber and Breitung (2020) CSDpanel function package for Gretl, an open-source statistical package to obtain robust coefficient estimations.

We opted for this method by extension of regression models utilising cross-sectional data; see Hervas-Oliver (2021) or cross-sectional spatial data; see Hauser et al. (2018) to model exploiting panel datasets on regional innovation issues. In our case, two specific models were used to reveal the determinants of innovation performance in the public and private sectors in the NUTS 2 regions of Western Europe from 2014 to 2021 as follows:

a) Model for public sector R&D indicators

$$SII = \beta 1PTE + \alpha_{PTE} + \beta 2SPC + \alpha_{SPC} + \beta 3PPCP + \alpha_{PPCP} + \beta 4RDEP + \alpha_{RDEP} + u \quad (2)$$

b) Model for private sector R&D indicators

$$SII = \beta 1RDEB + \alpha_{RDEB} + \beta 2PCT + \alpha_{PCT} + \beta 3EKIA + \alpha_{EKIA} + \beta 4SMEPI + \alpha_{SMEPI} + \beta 5\ ISME + \alpha_{ISME} + u \quad (3)$$

where:

SII = the dependent variable,

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β = the coefficient estimates for independent variables,

α = the intercept,

u = the error term.

Subsequently, each specific model was applied separately to the innovation performance groups relative to the E.U. average in 2021. The authors used an *α* level of 0.05 for all statistical tests in the paper as an *a priori* criterion for the probability of falsely rejecting the null hypothesis.

4 RESULTS AND DISCUSSION

This section presents the results of the distribution of innovation performance and the spatial distribution of the selected NUTS 2 regions according to the membership of the innovation performance groups (innovation leader, strong innovator, moderate innovator, and emerging innovator). Subsequently, the determinants of R&D in the public and private sectors that statistically significantly impact changes in the innovation performance in each innovation performance group are identified.

4.1 Evaluation of innovation performance in Western European NUTS 2 regions

The spatial distribution of the innovation performance in Western European NUTS 2 regions is presented by the chorochromatic map (see Fig. 1). The map (Fig. 1) shows the spatial distribution of innovation performance of the selected NUTS 2 regions in 2021 by the membership of innovation performance groups (innovation leaders, strong innovators, moderate innovators, and emerging innovators).

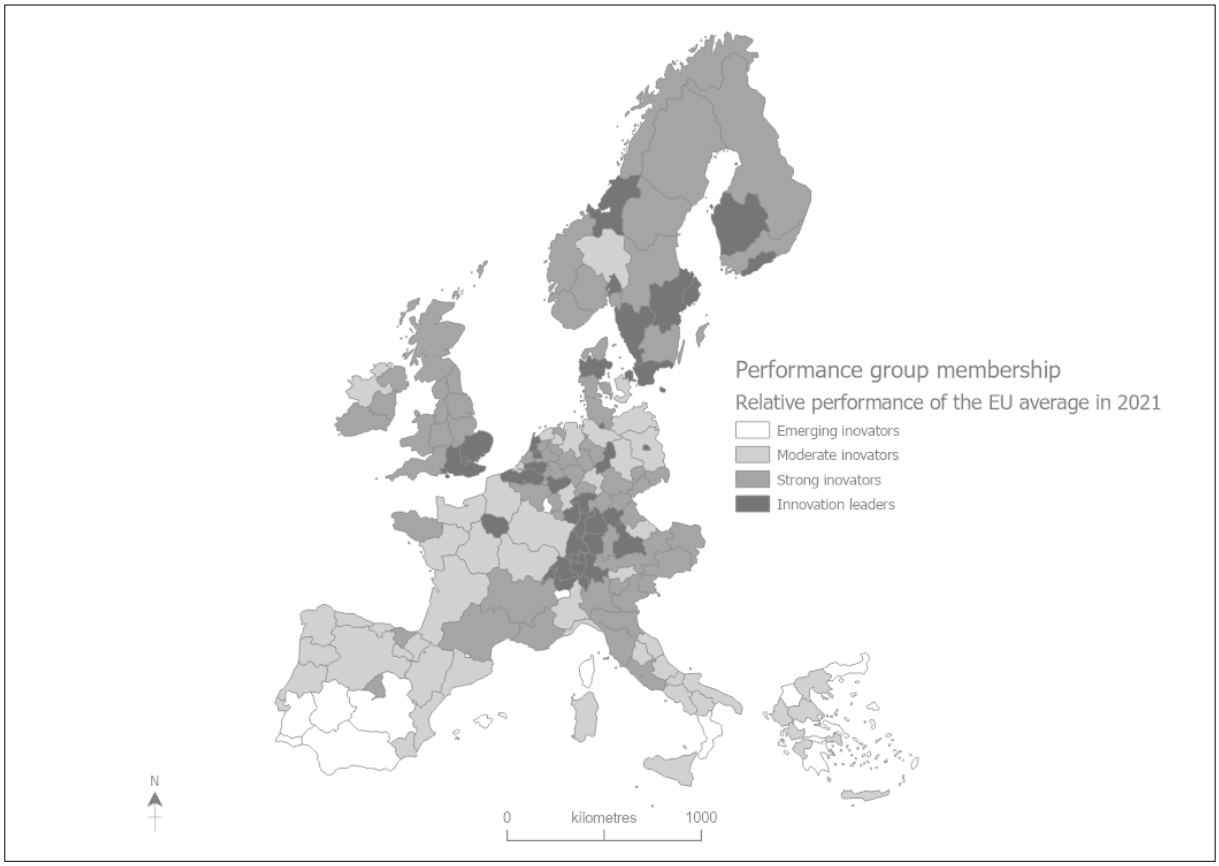

Fig. 1 – Innovation performance group membership of Western European NUTS 2 regions relative to the EU average in 2021. Source: own visualisation based on European Commission (2022) and EuroGeographics (2022)

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Of the 170 investigated regions, innovation leaders comprise 38 regions (22.4%), strong innovators in 64 regions (37.6%), moderate innovators in 52 regions (30.6%), and emerging innovators in 16 NUTS 2 regions (9.4%). The results of the innovation performance show that strong and moderate innovators are predominant in 116 regions (68.2%) out of the 170 investigated NUTS 2 regions.

Moreover, the results indicate a dominance of regional innovators that perform in the upper two quartiles (innovation leader and strong innovators) by innovation performance in 102 regions (60.0%) out of the 170 investigated NUTS 2 regions. The spatial distribution of the innovation performance group relative to the E.U. average in 2021 shows the primary concentration of innovation leaders and strong innovators regions in the United Kingdom, the Netherlands, the Île de France (Paris) region in France, Belgium, former 'Western' Germany, Switzerland, Austria, and northern Italy. The second cluster of innovation leaders and strong innovators can be found in the Nordic countries – Denmark, Norway, Sweden and Finland.

In contrast, the map (Fig.1) illustrates that the moderate and emerging innovator regions are mainly in Portugal, Spain, southern Italy, and Greece. Other clusters of moderate innovators and emerging innovators regions are shown in France, represented by Île de France neighbouring NUTS 2 regions and two NUTS 2 regions of NUTS 1 region, the Nouvelle-Aquitaine – Aquitaine and Limousin; and NUTS 2 regions surround Berlin in Germany. The only emerging innovators outside the Mediterranean part of Western Europe are Luxemburg and the Aosta Valley in the Alps area of northwestern Italy.

4.2 Evaluation of the influence of R&D indicators on innovation performance in the public and private sector in the Western European regions

The following presents a varying effect of public and private R&D indicators on the innovation performance of NUTS 2 Western European regions in different innovation performance groups relative to the E.U. average in 2021, considering the assumptions of the fixed effects model. The Dickey-Fuller test was used to check the dependent variable (SII) for stochastic trends.

The result was supported by the visualisation of the data in Fig. 2, which reveals that the average SII values, including 95% confidence intervals, continuously increased yearly from 2014 to 2021. The first difference was calculated for the summary innovation index (SII), and stationarised data (logarithmic form) were used to model fixed-effects models for public and private R&D indicators.

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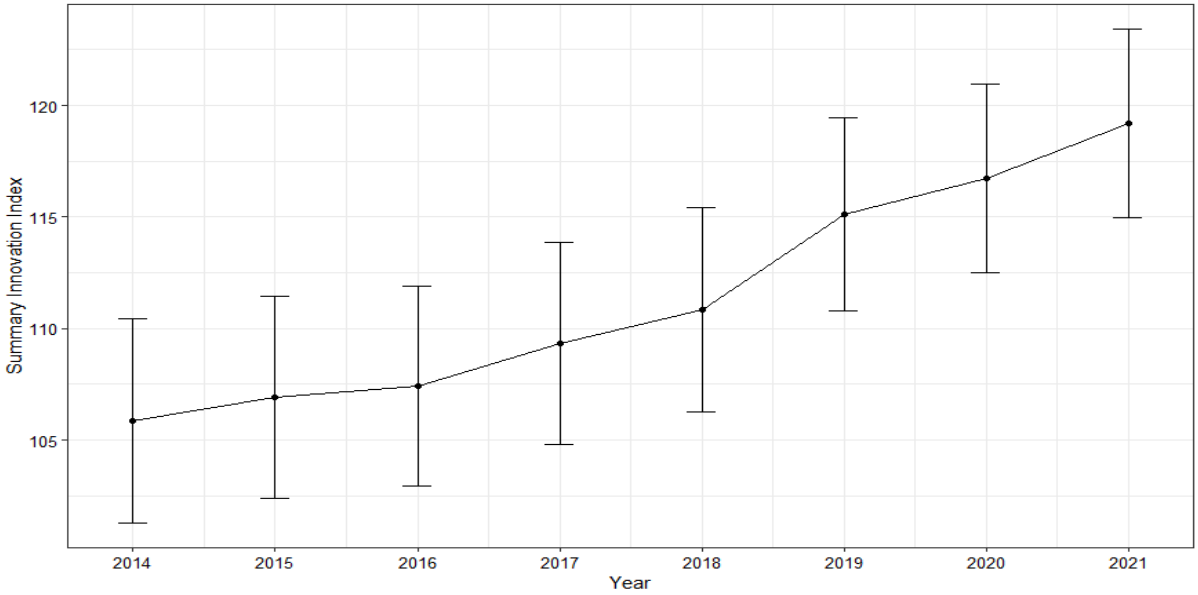

Fig. 2 – Group means and confidence intervals for Summary Innovation Index (SII) in the NUTS 2 regions in the Western European countries 2014-2021, 95% CI. Source: own calculation based on European Commission (2022).

4.2.1 The effect of public sector R&D indicators on innovation performance

The effect of public R&D indicators on the innovation performance of NUTS 2 regions in Western Europe over 2014-2021 is documented in Tab. 2. In the top 10% most cited scientific publications worldwide (SPC) as a percentage of total scientific publications of the country, a positive statistically significant effect on SII was proved for all groups of innovators. The strongest statistically significant effect on SII in the public sector was found for the population (25-34) with completed tertiary education (PTE) and public-private co-publications per million inhabitants (PPCP) in the group of emerging innovators. The results show that the statistically significant regression coefficients achieve the highest values in the case of the innovation performance group-emerging innovators. Here, this fact appears for the independent variables PTE and PPCP. Thus, the model estimated that these two R&D indicators exhibit the most substantial effect on the values of the percentage change in SII in the public sector. More specifically, if PTE increases by 1% each year for the innovation performance group of emerging innovators, the results suggest that SII increases by 0.13% on average in the following year. In the case of PPCP, the model offers an estimated average increase in SII of 0.14% in the next year, keeping other coefficients constant. Such results support elasticity in the model since all variables take logarithmic form.

Tab. 2 – Robust estimation of coefficients for public sector R&D indicators in the Western European NUTS 2 regions 2014-2021. Source: own research based on European Commission (2022)

	Innovation performance			
	Innovation leader	Strong innovator	Moderate innovator	Emerging innovator
PTE	0.039	0.037***	0.029***	0.130***
PPCP	0.090	0.051***	0.026	0.139***
RDEP	0.060***	0.043***	-0.020	-0.033
SPC	0.042***	0.050***	0.031*	0.068***

https://doi.org/10.7441/joc.2023.03.06

R^2	.065	.058	.027	.433
AIC	-1173.637	-1726.15	-1148.182	-324.316
BIC	-1023.130	-1447.032	-929.942	-257.838
HQC	-1113.173	-1616.124	-1061.442	-297.302

Note: * indicates significance at the 0.1 level, *** indicates significance at the 0.001 level

Regarding R&D expenditures in the public sector as a percentage of GDP (RDEP), the greatest positive influence given by the regression coefficient value is evident in the group of innovation leaders. Tab. 2 show a statistically non-significant result, which is the negative effect of RDEP on the SII for the performance levels of moderate and emerging innovators. The results imply that public R&D spending does not positively affect the level of the SII for this level of innovation performance.

In summary, the model shows that the predictors of public sector R&D indicators statistically significantly affect SII the most in the case of the emerging innovators' group, followed by the strong innovators' group, where all predictors are statistically significant, and then the innovation leader and moderate innovators. The strong innovation performance group is distinguished as the best-fit model for the data by three methods – Akaike' Information Criterion (AIC), Bayesian Information Criterion (BIC), and the Hannan–Quinn Calculation (HQC), (see Cottrell & Lucchetti, 2023), because its lowest value. Contrarily, the emerging innovation performance group is the worst fit model for data, although it reaches the highest value of the 'within' R^2, which was selected as the measurement of R^2 for the used fixed effects model, applying the perspective that the dependent variable is really $y_{it} - \bar{y}_i$ (Cottrell & Lucchetti, 2023). The low values of R^2 for innovation leaders and strong and moderate innovation groups suggest there should be other public sector R&D indicators having an effect on SII; however, many indicators are available at the national level only.

4.2.2 Effect of Private Sector R&D Indicators on Innovation Performance

The effect of R&D indicators on the innovation performance of NUTS 2 Western European regions in the private sector over 2014-2021 is presented in Tab. 3. The greatest influence on SII in the private sector was found for SMEs introducing product innovations (SMEPI) as a percentage of SMEs. SMEPI shows the highest statistically significant values of regression coefficients for all groups of innovation performance (especially strong, moderate, and emerging innovators), therefore, the most considerable impact on SII. Specifically, suppose that SMEPI increases by 1% in a given year. In that case, an average increase in SII of more than 0.11% can be expected in the following year for all innovation performance groups except the innovation leader group. However, the SMEPI regression coefficient value for the innovation leader group represents the fourth-highest effect of the R&D indicator on SII in the private sector.

Tab. 3 – Robust estimation of coefficients for private sector R&D indicators in the Western European NUTS 2 regions 2014-2021. Source: own research, based on European Commission (2022).

	Innovation performance			
	Innovation leader	Strong innovator	Moderate innovator	Emerging innovator
EIKA	0.041***	0.057***	0.062***	0.025***
ISME	0.032***	0.033***	0.035***	0.058*
PCT	0.051***	0.069***	0.039***	0.015

https://doi.org/10.7441/joc.2023.03.06

RDEB	0.028***	0.010	0.030***	0.004
SMEPI	0.071***	0.130***	0.114***	0.123***
R^2	.430	.564	.422	.369
AIC	-1303.461	-2069.337	-1336.066	-307.982
BIC	-1149.371	-1786.107	-1113.928	-238.614
HQC	-1241.557	-1957.685	-1247.776	-279.793

Note: * indicate significance at the 0.1 level, *** displays significance at the 0.001 level

As shown in Tab.3, the impact of patent applications per billion GDP in PPS (PCT) on innovation performance (SII) was the highest among strong innovators and innovation leaders. The effect of employment in knowledge-intensive activities (EIKA) as a percentage of total employment was seen remarkably in moderate and strong innovators. By contrast, for the indicator R&D – innovative SMEs collaborating with others as a percentage of SMEs (ISME), the strongest influence was found for the group of emerging innovators. In the EIKA case, the data indicate the lowest statistically significant value of EIKA's estimated effect (0.0251) in the emerging innovators' innovation performance group. This result reflects the location of NUTS 2 regions in this innovation performance group in peripheral areas of Western Europe (see Blažek & Kadlec, 2019). It also appears that this result is related to the statistically significant high regression coefficient value of the PTE R&D predictor in the public sector. In contrast, ISME shows the highest estimation coefficient for the emerging innovators' group (0.0579). Combining these findings with the highest value of the coefficient of PPCP (0.1389) in the public sector in the same innovation performance group, these results indicate the importance of collaboration within and between the public and private sectors in the emerging innovator's group.

Results in Tab. 3 also reveal that RDEB is not a statistically significant independent variable for estimating the change in SII values for all innovation performance groups. However, in contrast to the public sector, R&D expenditure in the private sector (RDEB) does not negatively affect any group of innovation performance. However, the regressor EPO patent applications per billion GDP in PPS (PCT) has no statistically significant effect on SII for the emerging innovators' group, which supports the results in Filippopoulos & Fotopoulos (2022).

In summary, the presented model suggests that the private sector predictors contributing to the most considerable statistically significant effect on SII can be ranked as follows, starting with the strong innovators' innovation performance group, together with the moderate innovators' group, and then the innovation leader group, together with the emerging innovators' group. The strong innovation performance group is also distinguished as the best-fit model for data, and the model reaches the highest value of 'within' R^2 in the private sector R&D indicators data, and the emerging innovation performance group is the opposite; however, all the models in the sector show within' R^2 over the value of .300.

4.3. Discussion

Following previous studies (Han et al., 2018; Hauser et al., 2018; Lopes et al., 2021b; Calignano, 2022), we can argue that there are several ways to measure and evaluate the innovation performance of regions. Like other authors (Bielinska-Dusza & Hamerska, 2021; Filippopoulos & Fotopoulos, 2022), our research evaluated innovation performance using the SII index, a complex and summarised indicator of innovation performance. According to Hauser et al. (2018, p. 43), the limitation of the research was that using a composite index (here, SII) to predict territorial innovation performance could be problematic. Based on the specificity of individual NUTS 2 regions, we assumed a different impact of R&D indicators on innovation performance according to four groups of innovators in the regions of Western Europe. To fulfil

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the objective, two research questions were verified: (RQ1): Do the strong and moderate innovation performance groups in NUTS 2 Western European regions relative to the E.U. average in 2021 prevail? Our research shows relatively large differences in innovation performance (according to SII) in the regions of Western Europe. This fact is also evident from the division of regions according to individual innovation performance groups in 2021 (see Figure 1). From the results, it can be stated that out of the total number of 170 NUTS 2 regions, emerging innovators have the smallest representation (9.0%), followed by the level of innovation Leaders (22.4%). The remaining 116 NUTS 2 regions represent strong and moderate innovators. Together, these regions comprise 69% of the total observed regions. From the results of our research, it was confirmed that strong and moderate innovators prevail in the NUTS 2 regions of Western Europe. Therefore, we can answer the research question (RQ1) in the affirmative.

Similarly, as was confirmed in our research (see Fig.1), we can also conclude from a comparison of other research (see European Commission, 2022; Filippopoulos & Fotopoulos, 2022) that in E.U. countries or NUTS 2 regions, there are large differences in innovation capacities according to individual groups of innovation performance. According to the findings of the European Commission (2022), performance groups are mainly spatially concentrated in certain regions. Groups of innovation performance – innovation leaders and most strong innovators are in Northern and Western Europe. In contrast, most moderate and emerging innovators are in Southern and Eastern Europe. This result also corresponds to the findings of Xu et al. (2023), who showed that seven E.U. countries out of 28 could be characterised as innovation leaders for 2004-2017. Similarly, their results show that Western Europe's northern and southern parts have relatively higher innovation performance than other regions.

To fulfil the objective, also research question was verified (RQ2): Do R&D indicators in public and private have a varying effect on the innovation performance of NUTS 2 Western European regions (by innovation performance groups)? From our achieved results (see Tab. 2 and Tab. 3), it can be stated that the influence of most of the monitored R&D indicators in the public and private sectors on the innovation performance of the regions of Western Europe has been proven. Our research has confirmed, by means of the fixed effect model, that innovation performance (according to four groups of innovators) in the NUTS 2 regions of Western Europe is significantly affected in the public sector by the top 10% of most cited publications worldwide (in all four categories of innovators), population (25-34) with completed tertiary education (in three groups of innovators) and public-private co-publications (in two groups of innovators). In the case of R&D expenditures in the public sector as a percentage of GDP, the greatest influence is evident in the group of innovation leaders. A statistically significant effect of research and development expenditures on innovation performance among the group of innovation leaders is related to the assumption that research and development expenditures are a starting factor for the innovation performance and competitiveness of countries or regions. It can therefore be concluded that the higher the expenditures on R&D, the better the innovation performance and competitiveness of a region and vice versa. Other research confirms this fact; see Blanco et al., 2020; Celli et al., 2021. Our analysis applies to R&D expenditures in the public sector in the groups of leaders and strong innovators and to R&D expenditures in the business sector in leader and moderate innovators groups.

The greatest influence on the SII in the private sector was found for R&D indicators: SMEs introducing product innovations (as a percentage of SMEs), employment in knowledge-intensive activities, EPO patent applications, innovative SMEs cooperating with others), see Tab. 3. From our results it can be argued that the influence of the monitored R&D indicators in the public and private sectors on the innovation performance varies according to individual groups of innovators. A strong influence on innovation performance in the private sector was

https://doi.org/10.7441/joc.2023.03.06

confirmed, especially for innovative SMEs collaborating with others as a percentage of SMEs in the emerging innovators' group. In addition, it was found that public-private co-publications per million inhabitants have the most statistically significant influence on innovation performance in the public sector in the group of emerging innovators. Therefore, we can answer the research question (RQ2) in the affirmative, i.e., that the innovation performance of the NUTS 2 regions of Western Europe in the public and private sectors is influenced by different indicators, which also affect individual groups of innovators in different ways. As has been confirmed by other authors (Filippopoulos & Fotopoulos, 2022, p. 1), "in European regions in the case of moderate innovators, the absence of skilled human capital is to the lack of technological skills in some regions. Lagging regions focus on softer' innovation aspects are then primarily driven by public R&D than of technological innovation." Barzotto et al. (2019, p. 213); Lilles et al. (2020, p.174) claim that "the lagging regions of the EU lack the technological capabilities and knowledge networks and lack technological possibilities and do not fully utilise innovation capacity to fully participate in and benefit from the European Union's innovation policy." According to the European Commission (2022), some regions in Southern Europe do not have sufficient prerequisites and support to profit from the benefits of the E.U. innovation policy. Similar to our study, Lopes et al. (2021) and Calignano (2022) argue that the leader and strong regions benefit from implementing innovation policy and may play a key role in transnational innovation networks. On the contrary, these authors confirm that lagging regions fail to utilise innovation capacity fully and lack technological possibilities. Barzotto et al. (2019) then found that to increase competitiveness and innovation performance at the regional level, the motivation of governance and the support of interactions between universities and industry should be developed and supported.

From the already performed research (Lilles et al., 2020; Garcia-Alvarez-Coque et al., 2021; Caviggioli et al., 2023), we can then summarise the influence of some R&D indicators and their impact on individual groups of innovators. The authors found certain conditions necessary to achieve a competitive European region. It is also required to develop the higher education sector with at least one top-ranked university and to motivate universities from competitive regions to cooperate with universities from lagging regions. According to Mas-Verdu et al. (2021) and Garcia-Alvarez-Coque et al. (2021), an important prerequisite for regional competitiveness in European rural regions is an excellent higher education level combined with strong public and private research and development. Xu et al. (2023) found that economic growth, investment in human capital and regional openness to innovation increase innovation efficiency in most regions of the European Union. On the contrary, the industrial structure, the level of urbanisation and the level of infrastructure can be identified as determinants that prevent the improvement of the innovation efficiency of regions. As argued Moagar-Poladian et al. (2017); Blažek & Kadlec (2019); Hervas-Oliver et al. (2021); Kijek et al. (2022), disparities between European regions constitute a great challenge for sustainable development and require identification of the factors responsible for this process. Our research shows that dividing public and private sector indicators according to groups of innovation performance might open a new dimension of the current research practice to consider how such indicators can affect the Summary Innovation index over the years separately.

5 CONCLUSION

Research has confirmed that innovation performance across NUTS 2 regions increases over time. The results demonstrated differences in the innovation performance of the regions of Western Europe and regional disparities that influence selected structural determinants from the perspective of the public and private sectors. The two main objectives of the paper were achieved. The groups of innovation performance and their spatial distribution in NUTS 2

https://doi.org/10.7441/joc.2023.03.06

Western European regions; and the influence of R&D indicators in the public and private sectors on the innovation performance of the regions of Western Europe in the period 2014-2021 were evaluated. The results showed that groups of innovative performance (strong and moderate innovators) relative to the E.U. average in 2021 prevailed in the NUTS 2 regions of Western Europe. Evaluation of innovation performance (according to four groups of innovators) in the NUTS 2 regions of Western Europe using the fixed effect model was found that have a statistically significant effect on the R&D indicators of the public sector (the most cited scientific publication and population (25-34) with completed tertiary education (for three groups of innovators) and public-private co-publications (for two groups of innovators). In the case of the private sector, they were considered important R&D indicators influencing the SII: SMEs introducing product innovations, employment in knowledge-intensive activities, EPO patent applications, and innovative SMEs cooperating with others). The results showed a different influence of the monitored R&D indicators on individual innovation performance groups in the public and private sectors. The SII is influenced by R&D predictors of the public sector, mostly in the group of innovation performance emerging innovators, followed by the innovation level of strong innovators, then innovation leaders, and moderate innovators. In the private sector, the selected R&D predictors mostly influence the SII strong innovators, along with the level of moderate innovators, and subsequently innovation leaders along with emerging innovators.

The findings are useful for policymakers and other stakeholders of the regional innovation systems strategy for a call to support R&D determinants by public administration authorities to increase innovation performance and, thus, the competitiveness of lagging NUTS 2 regions. The limitation of the research was the unavailability of data for all public and private R&D indicators sectors at the level of NUTS 2 regions. Several indicators related to innovation performance are mainly monitored at the national level. In comparison to our research, the studies already carried out examined regional innovation performance and competitiveness mostly on examples of different sample sets of regions (with a distinction between maritime, coastal, lagging, developing, developed, European Union, OECD, Visegrad group, or middle and Eastern Europe), in different periods or using other research methods. Due to the absence of processed research on innovation performance with an emphasis on the NUTS 2 regions of Western Europe according to the four groups of innovators, it was only partially possible to evaluate the results achieved in detail with another research. The authors see the direction of further study in evaluating regional innovation performance on the example of other European NUTS 2 regions (according to individual groups of innovators) and comparison with the regions of Western Europe. Alternatively, in analysing the innovation performance of the regions of Western Europe using spatial econometric models.

Acknowledgements: This work was supported by project VEGA 1/0683/21, “Generation gap and provision of public services and administration;” SGS Project SP2022/74, “Computational intelligence in the prediction of economic quantities, data mining and economic process modeling;” and by Tomas Bata University in Zlín under RO/2022/07, “Collaborative platforms and economic actors: building capabilities for new prospective indicators of competitiveness and resilience in the era of the COVID-19 pandemic.”

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https://doi.org/10.7441/joc.2023.03.06