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Visegrád countries' scientific productivity in the European context: a 10-year perspective using Web of Science and Scopus

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ABSTRACT

Measuring the growth of research productivity is a core element of performance in the higher education sector. This paper aims to analyse the scientific productivity of the Visegrád Group countries (2010-2019) based on data from the WoS and Scopus databases as well as data from secondary sources (demographic and socio-economic factors). Quantitatively, although Poland has the highest output, this is due to its comparative size, whereas output per researcher in Poland is lower than in other V4 countries. As regards the qualitative approach, Hungary and the Czech Republic are significantly more effective in terms of scientific collaboration and receive a greater number of European Research Council grants. Thus, bibliometric data in relation to cross-country characteristic indicators (socio-economic variables including expenditure on science and having prestigious universities) are related to the positions of the V4 countries. Practical implications suggest that university management within the Visegrád Group must develop and continue strategies to strengthen international collaboration between researchers in order to accelerate change in the dissemination of scientific output at the global level. Academic scholarly publishers may benefit from publishing research on specific issues important to different regions of the world in order to expand their audience and gain new potential resources.
Keywords: scientific productivity, Higher Education, bibliometrics, Visegrád countries

Key points

- Poland is the most productive of the Visegrád countries (Hungary, Czech Republic and Slovakia) in terms of publication output and citation, ranking 9th (WoS) or 8th (Scopus) for the period 2010-2019.
- Hungary is a leader among V4 countries in terms of international scientific collaboration reflected by economic (e.g. R&D spending), geographical (e.g. medium-sized country), and social (e.g. greater research resources) variables.
- Indexed output from the Czech republic is similar to that of the UK (3.4 documents per researchers compared to 3.7 for the UK) although citations and output per university are far lower.
- Socio-economic factors should be taken into consideration when comparing scientific country outputs and can affect the rankings of different countries.
- Analysis using two different tools (WoS/InCites and Scopus/SciVal) has no influence on the position of the Visegrád countries and their publication output rankings.

INTRODUCTION

Currently, as part of higher education (HE) transformation, a number of changes have shaped scientific activity and its quality, including publishing, grant and fellowship applications, international cooperation in the field of research, presentation, and sharing of scientific output (Tenopir et al., 2016). The pressure for reforms where the knowledge triangle (interaction between research, education and innovation) dominates scientific productivity is has important implications (Maassen and Stensaker, 2011). Scientific productivity could be expressed by communicating scholarly results to an international audience. It takes place mainly through the dissemination of books and articles in scholarly journals and publications that are indexed in professional and highly reputable scientific databases (Mabe, 2010). Achieving a high level of scientific productivity influences the image of capacity and development attributable to each country.

The level of scientific productivity varies between countries and is determined by several country-specific characteristics (e.g. socio-economic factors). The Visegrád Group members (Poland, Slovakia, the Czech Republic, and Hungary, V4 for short), where the post-transformation system has influenced research and science to adopt European trends, emphasise growth in terms of scientific productivity by adjusting national policies, funding and strategy (e.g. Dobbins, 2011; Jurajda et al., 2017). Although spending on science in V4 countries sees continuing growth, universities strive to win top places in world rankings such as the Academic Ranking of World Universities (ARWU), also known as the Shanghai Ranking, where productivity is measured by bibliometric indicators, including the number of publications and citations (Docampo, 2013).

Science evaluation is a complex process widely discussed by the scientific community around the world at both global and national level (e.g. Aagaard and Schneider, 2017; Krog Lind, 2019; Watermeyer and Chubb, 2019). Nowadays, bibliometric indicators are commonly used by many countries in the quantitative approach to manage strategies of scientific units and assess research performance (Glanville et al., 2011; Jamjoon and Jamjoon, 2016). Assessing research produced by European universities helps identify their drawbacks and strengths, which can result in allocating resources, improving research performance, developing strategies for growth and improving the competitiveness of the academic environment.

KEY CONCEPTS

Scientific productivity

The most common definition of scientific productivity can be expressed as the number of publications per researcher and as such is used by many as the basis for evaluation and measurement (e.g. Kwiek, 2015; Abramo and D'Angelo, 2014). Adjusting the quantitative approach to the academic and research environment, productivity is likely measured by the number of publications indexed in reputable reference databases, including the Web of Science (WoS) and Scopus. It can be analysed from the perspective of different factors such as institutions and countries (Wolszczak-Derlacz and Parteka, 2011; Kwiek, 2019; Merga and Mason, 2020), or individual researchers and scientific teams (e.g. Stvilia et al., 2011). Taking a wide range of these variables into consideration, research productivity may have an extended definition of producing research represented by publishing academic papers in reputable international journals and the number of citations gained by them, gaining research funding (e.g. national and international grants) and collaborating in scientific teams (Kwiek, 2018a). In this study, we defined productivity in quantitative (i.e. the number of publications and citations) and qualitative (i.e. international collaboration and international grants awarded) terms in order to estimate the products of research activities (Kwiek, 2015; Kwiek 2017; Larivière and Costas, 2016).

Higher Education systems of the Visegrád Group

In the V4 countries, the academic structure follows the path of the transitional Central-Eastern European model and introduced assumptions and principles of the Bologna Process, giving universities more autonomy. After the post-transformation period, the V4 countries suffered due to the lack of scientific infrastructure, financial support and access to knowledge. However, their efforts to follow European trends in science are increasingly visible.

There are 457 universities and colleges in Poland, both public and private. The HE system comprises both state and non-state institutions, and recently the results of the first competition in the "Excellence Initiative – Research University" programme awarded such a title to the ten best Polish universities. The assessment of scientific units in Poland began in the early 1990s and has been transformed several times so far (e.g. the *Higher Education and Science Development Programme for 2015–2030 by the Polish Ministry of Science and Higher Education)* to identify different aspects of scientific excellence (Kulczycki et al., 2017). The last revision of “The Constitution for Science” was introduced in 2018. Currently, the first evaluation based on the new regulations is scheduled for 2021 and will be performed at the level of individual disciplines. It includes the following three groups of achievements: scientific publications and patents, economic effects of research and development works, and assessment of the impact of scientific activity on the functioning of the society and economy. It indicates the importance and trends for researchers to publish more internationally in well-known journals (articles are scored based on the Impact Factor and CiteScore metrics).

According to the European University Institute website (www.cui.eu), the HE system in the Czech Republic now comprises 70 universities, about two-thirds of which are private (includes public, state, private and for-profit universities). In terms of scientific research evaluation, the Czech Republic is also undergoing transformation reforms. The Act on Methodology for Evaluating Research Organisations and RD&I Purpose-tied Aid Programmes (2017+) clearly underlines the strong position of publishing scientific output. Research evaluation includes several aspects such as research environment, international and national collaboration, research excellence, research performance, social relevance of research and impacts of research. It will be implemented using three major evaluation tools: bibliometric analysis, remote reviews (by foreign evaluators) and expert panels.

In Hungary there are 67 state and non-state universities. Currently, the Hungarian HE system is undergoing a fundamental transformation, with research institutions having limited autonomy (Rónay and Niemczyk, 2020). However, in general terms, the system follows the foundation and principles of the knowledge-based economy. In 2014, the government published a national higher education strategy “A Change of Pace in Higher Education. Guidelines for Performance-Oriented Higher Education Development”, which includes aims and goals up to 2030 such as knowledge exchange for economic and social development. In 2018, the Hungarian Academy of Science (the most prestigious learned society with major tasks, including sharing scientific output) issued regulations on the assessment of research results. This act encourages scholars to improve research quality by assessing efficiency in terms of scientific productivity based on a score system that includes: the number of national and international publications, citations, conference attendance, gaining research funding, and specialist organisation tasks in accordance with the scientific discipline.

According to the Euro Education website (www.euroeducation.net), HE institutions in Slovakia (33, including state-owned, private, and foreign) are autonomous and self-governing. They are funded mostly by public subsidies. In terms of evaluation, the Accreditation Commission is responsible for the assessment of scientific units which is modelled, to some extent, on the British Research Excellence Framework (REF) performed every six years. In Slovakia – as in Poland – the assessment is based on the comparison between scientific disciplines. The publication record is of the highest importance in the assessment. However, only the best articles published by top performance researchers (10% of employees on average) are evaluated in this system.

In all V4 countries, the academic career path is quite similar. The entry level is the doctoral degree, and the second major step in the scientific career is habilitation. The habilitation is a qualification at a higher level than the doctoral degree and it is necessary before obtaining the rank of Full Professor in several countries, especially in Eastern and Central Europe countries (e.g. Germany, Austria, Poland), but also in other countries such as Brazil, Italy or Finland. Candidates may be awarded the degree of *habilitatus doctor* (*docent* in the Czech Republic and Slovakia) which is equivalent to Associate Professor. To be successful, they need to have made some remarkable scientific achievements, submitted a habilitation monograph in a given scientific discipline and have a record of publications in peer-reviewed journals. In Poland, habilitation is no longer obligatory; however, it has a long-established tradition in the Polish HE system. Habilitation is necessary to apply for a professorship. The highest research position in the V4 countries is Professor. In Hungary, this position is called *kutatò professzor* (scientific researcher); there is no tenure-track career and obtaining scientific promotion hardly depends on the level of experience in research and teaching.

In conclusion, HE systems in V4 countries are still undergoing transformation. Scientific productivity is the leading component in scientific evaluation and is based on qualitative and quantitative criteria, incorporating bibliometric indicators for the evaluation of units and disciplines as well as individual researchers.

Bibliometric methods in university management

The wide range of bibliometric indicators provides a valuable and substantial input to decision-making policies (Holden et al., 2005). Managing scientific productivity and engaging knowledge in the creation, transfer, distribution and use of that productivity have become a crucial element and a key area of interest in building the competitive advantage of universities. Using metrics for university management may have a positive impact on, and potential to identify, the differences in the performance of scientific units and, for instance, in the allocation of national or institutional funding. Metrics may support decisions on hiring research teams, attract post-doctoral students, or be part of a motivational strategy to increase academic productivity (Moher et al., 2018).

WoS (owned by Clarivate Analytics) and Scopus (owned by Elsevier) are considered two of the most reputable databases; therefore, we decided to use them both in order to analyse scientific productivity. The WoS Core Collection contains eight main indexes that are cited among different types of scientific output and disciplines (divided into WoS categories). Currently, Scopus indexes 38,192 journals, 10,050 of which represent Social Sciences and Humanities. The WoS Core Collection indexes over 21,349 titles, with Social Sciences and Humanities being represented by 5,200 titles. In general, researchers may find more publishing opportunities in journals indexed by Scopus.

Research questions

This paper aims to identify and analyse scientific productivity of the V4 countries after the post-transformation period and during the HE system transformation. Several studies have highlighted that post-transformation countries are focused on quantity rather than quality in terms of academic productivity (e.g. Kozak et al., 2015; Jurajda et al., 2017).

According to Kwiek's proposal (2015; 2017), scientific productivity (or research productivity) should be understood as a set of four main indicators: the number of scientific papers, citations (the quantity component), international cooperation and the number of research grants (the quality component). We decided to investigate the years 2010–2019 in order to obtain a comprehensive view of academic performance. As a result, we formulated the following questions:

Q1. How many scientific publications indexed by Web of Science and Scopus were published in the V4 countries between 2010 and 2019?

Q2. How many citations did these scientific publications gain in the last ten years?

Q3. What was the impact of V4 researchers on international collaboration in the last ten years?

Q4. What is the number of European Research Council (ERC) grants received by researchers from the V4 countries between 2010 and 2019?

In addition, we evaluate the position of V4 countries among other European countries by considering country-specific characteristics affecting scientific productivity.

DATA AND METHODS

The bibliometric analysis was based on data from WoS and Scopus retrieved from their benchmarking tools - InCites and SciVal. All derived data (for the V4 countries, the EU28 countries plus Norway and Switzerland) were aggregated into a spreadsheet and analysed in alignment with the structure of the gathered datasets. We combined the primary data from InCites and SciVal with data from four secondary sources: ARWU (http://www.shanghairanking.com/), ERC (https://erc.europa.eu), World Bank Data (https://data.worldbank.org/), and Eurostat database (https://ec.europa.eu/eurostat/data/database) in order to normalise research productivity by several country-specific characteristics such as the number of researchers (head count and full-time equivalent), number of universities, or size of the economy as quantified by gross domestic product (GDP). It has to be stressed that these secondary sources are dynamic databases updated regularly, and we used the most recent factors available for this study.

Sample and procedure

The sample consisted of four V4 countries, which vary in terms of socio-economic and geographical characteristics as well as in terms of scientific resources associated with research productivity. The eight country-specific features are illustrated in Table 1.

To better illustrate the wealth of the V4 countries, we added the United Kingdom (UK), i.e. the leader in terms of bibliometric ranking. In comparison to many European countries, the UK has a highly competitive academic structure where university autonomy is integrated into the evaluation of research performance. Career paths are composed of several positions (e.g. PhD, Postdoc, Research Fellow, Senior Lecturer, Full Professor) and the tenure track is not formally structured. The most important part of the HE system in the UK is the REF, which evaluates scientific productivity based on faculty performance.

Table 1. Summary of country-specific characteristics.

Country-specific characteristics	V4 countries				ARWU ranking leader
	Poland	Czech Republic	Hungary	Slovakia	UK
Number of universities*	457	70	67	33	167
Number of universities in Top 1000 (2019 ARWU ranking)	10	9	5	1	153
Total researchers (head count) (2017)**	187,905	59,789	42,729	26,861	520,936
Total researchers (FTE)**	117,789	41,198	31,430	16,337	309,074
GDP (in billion USD) (2019)*	592,16	246,49	157,90	105,42	2827,11
GDP per capita (in billion USD) (2019)*	15,559	23,101	16,475	19,329	42,300
R&D expenditure in % of GDP (2018)**	1.21	1.93	1.53	0.84	1.70
Population size (million)*	37.97	10.70	9.70	5.40	66.65
Area (km^2)*	321,679	78,866	93,030	49,035	242,495

Note. * source: World Bank (accessed June 2020), ** source: Eurostat (accessed June 2020); GDP: gross domestic product, FTE: full-time equivalent, R&D: research and development

The data on 30 European countries were collected in January 2020 and ranked from the leading country (the UK, i.e. jointly for England, Wales, Northern Ireland and Scotland) in order to generate comprehensive country-specific statistics. Data concerning European grants were retrieved from the European Research Council (ERC) website. Taken together, the quantitative component provided detailed information on the citation and recognition of publications affiliated with V4 universities and enabled us to determine their position in relation to other European countries. The qualitative component used internationally authored publications as an indicator of collaboration, and the number of ERC grants was used as a proxy for recognising achievements of the scientific teams.

Variables and measurement

Quality and quantity bibliometric indicators used in our study are presented in Table 2. Quantity indicators show the number of publications and the number of citations while quality indicators reveal data on international collaboration and the number of ERC grants. The analysed indicators differ between the two tools used in the study mainly in names (e.g. scientific publications vs scholarly output). As of 2019, InCites indexed about 60.5 million records while SciVal indexed 74 million in the period under investigation (2010-2019). Data on research grants available on WoS/InCites and Scopus/SciVal are still incomplete and we decided to use direct data from the funding agency (three types of grants out of six available). The ERC provides grants that finance the most ambitious and ground-breaking research. The receipt of such a grant is very often considered an indication of great prestige and scientific excellence that researchers can aspire to; therefore, it can be recognised as a quality indicator of scientific productivity.

Table 2. Quantity and quality indicators of scientific productivity

Quantity indicators	**Databases**	**Description (overview)**
Publication indicator	WoS/InCites	Scientific publications: Scientific (research) articles, reviews, conference papers, book chapters, editorials, editorial lists, reports (42 types of documents) - documents Main publication metrics is the Impact Factor
	Scopus/SciVal	Scholarly output: Scientific (research) articles, reviews, conference papers, book chapters (14 types of documents) Main publication metrics is the CiteScore
Citations indicator	WoS/InCites	Number of citations received by documents
	Scopus/SciVal	Citation count sums up the number of citations received by an entity
Quality indicators		
International collaboration	WoS/InCites	Percentage of the number of international publications of an entity divided by the total number of publications of the same entity
	Scopus/SciVal	Percentage value of the degree to which the publications of a given entity have international co-authorship
International grants	ERC	Number of Starting Grants (StG) up to 1.5 million EUR Number of Consolidator Grants (CoG) up to 2 million EUR Number of Advanced Grants (AdS) up to 2.5 million EUR

RESULTS

Scientific productivity as the number of publications and citations

The first two research questions were dependent on quantity indicators. Scientific productivity in V4 was expressed by the number of documents and citations indexed in WoS and Scopus between 2010 and 2019 (Table 3). Note that the country of the publications is based on addressing features for the whole country-metrics (all addresses are contributed to the statistics; calculation is not weighted by a number of addresses and authors).

Data from Scopus and WoS gave the Czech Republic and Hungary the same ranking, but differed for Poland and Slovakia (Table 3). Although the data was similar there are some differences: for example, according to the data obtained from WoS, Poland published about 18.8% of what the ranking leader – UK researchers – published in the same period. According to Scopus, Poland's output accounted for approximately 21.2% of UK's output.

Table 3. The number of publications and citations retrieved from WoS and Scopus for the 2010-2019 period for V4 countries and the UK (the leader in the EU).

Country	Web of Science						Scopus		
	Rank	Documents	Times Cited	Documents per researcher*	Documents per university**	Citations per documents	Rank	Scholarly Output	Citation Count
UK	1	1,927,937	22,741,425	3.70	11,685	11.80	1	1,982,406	29,202,675
Poland	9	362,515	2,761,334	1.93	793	7.62	8	421,044	3,440,421
Czech Republic	14	203,060	1,647,779	3.40	2,901	8.12	14	220,693	2,053,542
Hungary	20	98,642	1,031,376	2.31	1,472	10.46	20	107,261	1,260,069
Slovakia	21	63,727	418765	2.37	1,931	6.57	21	72,802	556,540

Note. * Total researchers (head count in 2017) (source: Eurostat, accessed June 2020). ** Number of universities (source: World Bank, accessed June 2020)

The ranking of publications and citations presented here is consistent with the number of researchers, universities and top universities, and with GDP, but not with GDP per capita and R&D expenditure as % of GDP (as shown in Table 1). Equally, if quantitative productivity is adjusted per researcher or per university, the ranking of the V4 countries changes. As shown in Table 3, using the InCites data, when output per university and per researcher is considered the Czech Republic becomes a new leader, followed by Slovakia and Hungary, with Poland being relegated to the lowest position. For example, the indexed output from the Czech Republic is similar to that of the UK (3.4 documents per researchers compared to 3.7 for the UK). However, citations and output per university are far lower. This new order is also found when gross domestic product per capita (see Table 1) is applied.

Scientific productivity in international cooperation

The third question concerning the impact of researchers from V4 countries on international collaboration is very important in the global context. Table 4 presents a comparison of the collaboration indicator with the use of the two tools used in the study. This indicator retrieved from WoS shows the percentage of publications indexed in WoS in 2010–2019 where at least one of the authors has an affiliation with a country other than the corresponding author. The international collaboration criterion was the highest (52.63%) for Hungarian publications and the lowest (32.94%) for Polish ones. When all evaluated European countries are ranked in terms of international collaboration, this places Hungary and Poland at number 14 and number 29 respectively – using WoS data.

The data obtained from Scopus were similar and revealed that about 48.2% of indexed Hungarian publications were classified as international compared to 33% of Polish publications. This places Hungary in the middle of the ranking (number 16) and Poland occupies the last spot (number 30). In terms of international collaboration, it has to be highlighted that both InCites and SciVal provide data for the whole UK and separately for individual countries (publications including England are recognised as international).

Additional data from secondary sources for the Czech Republic, Slovakia and Hungary revealed that universities with a high number of researchers counted by head as well as based on FTE (full-time equivalent) collaborate to a greater extent. However, attention is paid to Poland due to a large number of smaller universities; thus, collaboration is very low and unnoticeable. Moreover, Poland is a large country (in terms of the area and population size) and has a broad internal publishing market compared to other V4 countries which are significantly smaller.

Table 4. Data summary on country-specific characteristics and collaboration for the V4 countries and the UK

Country	International collaborations in WoS		International collaborations in Scopus		Number of universities*	FTE** per university (authors' own calculation)
	Rank	Percentage of documents	Rank	Percentage of documents		
Hungary	14	52.63	16	48.2	67	469.1
UK	21	46.86	17	47.8	165	1,873.1
Slovakia	24	42.75	24	42.1	33	495
Czech Republic	26	41.77	26	40.2	70	588.5
Poland	29	32.94	30	30.0	457	257.7

Note.* source: World Bank, ** source: Eurostat; FTE: full-time equivalent

Scientific productivity as the number of international research grants

The last research question aimed to present the position of the V4 countries in terms of creative and ground-breaking research using the number of prestigious ERC grants obtained. We extracted data concerning three types of grants (Table 5). StGs are awarded to researchers up to 7 years after completing the PhD programme who want to work independently and become scientific leaders. CoGs are awarded to scientists with 7–12 years of experience who already have research teams and want to strengthen their position in the research environment, and the calls for proposals were made between 2013–2018. AdGs (the last call for proposal was made in 2018) are intended for experienced researchers with 10 years of substantial scientific records who want to lead a cutting-edge project. It should be noted that the ERC statistical data also include Iceland, Israel, Serbia, and Turkey (see Supplementary materials). In the three aforementioned types of grants, the UK is the European leader with a total of 1,726 grants.

Among the V4 countries, as in the case of the international cooperation indicator, Hungary has a stronger position as they received and managed 53 ERC grants (3% of the UK's rate). In addition, Hungary was the first country from the new EU 13 to win the prestigious Synergy Grant in 2013. The second place is occupied by the Czech Republic with 35 grants. Poland received a total of 27 grants. Slovakia has the lowest number of grants (only one Starting Grant).

The position of Poland is similar to Hungary only when it comes to StGs grants, while in subsequent categories Hungary won four and eight times more grants than Poland. The Czech Republic has three times more CoGs and AdGs grants than Poland.

Table 5. The number of ERC grants (StGs, CoGs, AdGs) received by the V4 countries and the UK

Starting Grants (StGs) [2010–2019]			Consolidation Grants (CoGs) [2013–2018]			Advanced Grants (AdGs) [2010–2018]		
Country	Rank	No.	Country	Rank	No.	Country	Rank	No.
UK	1	798	UK	1	389	UK	1	539
Hungary	17	22	Hungary	17	15	Hungary	16	16
Poland	18	21	Czech Republic	19	12	Czech Republic	19	6
Czech Republic	20	17	Poland	22	4	Poland	24	2
Slovakia	30	1	-	-	-	-	-	-

Compared to Poland, Hungary and the Czech Republic spent a higher percentage of gross domestic product on R&D (1.53% for Hungary, 1.93% for the Czech Republic, and 1.21% for Poland). What is more, the average ratio of researchers (Eurostat) to universities (World Bank) is also higher in the Czech Republic and Hungary compared to Poland (854.13, 637.75, and 411.17, respectively). Moreover, the percentage of Top 1000 universities from the AWRU ranking in the total number of higher education institutions is larger in the Czech Republic and Hungary than in Poland (13%, 7%, and 2%, respectively).

DISCUSSION

This paper aims to identify the scientific productivity of V4 countries (2010–2019). The findings were presented in comparison to the UK, which is the leader of European research. The V4 countries are visible in terms of the number of scientific publications and citations. However, not all V4 countries collaborate at the same level in scientific terms. Additionally, the number of ERC grants awarded differs between the V4 countries. The use of two citation-based databases and their tools (WoS/InCites and Scopus/SciVal) did not have a significant impact on the rank of the selected countries. To date, few studies on research productivity in the V4 countries were conducted; however, we did not find any publications that cover this kind of research for all Visegrád Group countries.

From the science output perspective, the results showed that among V4 countries the results of Poland were rather good, being in the top ten of the ranking and at the average European rate in terms of publications and citations. It is worth noting that half of the indexed papers with Polish affiliations were cited. This may be elucidated by the characteristics of the academic environment in Poland: Poland is described as a rather big country with many HE institutions and a high number of academic staff. Thus, the results obtained correspond to economic variables and geographic features (absolute values). A significant number of indexed papers was probably influenced by the process of the evaluation of Polish scientific units, which was based, to some extent, on the publication of papers in top-tier journals with Impact Factor (Korytkowski & Kulczycki, 2019). Now moving on to the remaining V4 countries, the Czech Republic is in the middle of the ranking while Hungary and Slovakia are ranked 20th and 21st respectively. Overall, these results are reasonable and again may be influenced by governmental policies on the assessment of scientific units in order to stimulate research production of greater quality (de Rijcke, S. & Stöckelová, 2020). Even though the comparison of evaluation systems is not the topic of this paper, some of the main directions (e.g. incorporation of high-impact publications, gaining research grants) could affect and lead to an increase in scientific productivity in these countries. Thus, we cannot exclude a possible explanation that publication pressure experienced by researchers from V4 countries can be linked to the number of publications produced.

However, the ranking is different when the results are shown in the light of socio-economic variables. It is very interesting to note that the results in relation to the number of documents, the number of universities or the number of researchers and GDP per capita show that the Czech Republic is the leader of V4. On the other hand, if one collates the number of citations with the number of documents, Hungary is the leader among the V4 countries. Thus, quantity indicators provide a new perspective in terms of quality national indicators. In other words, scientific productivity (publications and citations) corresponds with higher expenditure on research and stronger universities (e.g. indexed by the ARWU ranking). This results in better research performance and is reflected in papers' citations. Researchers who collaborate in large international teams to a higher extent publish and read more papers and are cited more frequently (Wuchty et al., 2007). The relationship between revenues and bibliometric outputs is proved by e.g. Lepori et al. (2019), who stressed that more invested resources produce more output and stimulate the battle of international rankings.

International cooperation, as a qualitative factor expressed by the number of publications with at least one affiliation with another country, relegates Poland to the lowest position among the V4 countries and all evaluated countries. Despite performing well in terms of quantity indicators, the position of Poland in the internationalisation of science and the acquisition of European grants is unfavourable, which was previously pointed out by Kwiek (e.g. 2017; 2018a). International recognition is highly rated by university management authorities, and participation in international projects and publications is necessary. Smaller countries collaborate more frequently than Poland, which is larger and has a relatively strong national publishing market (Kwiek, 2019). In addition, the linkage of FTE with the number of universities is also convergent and corresponds to findings on economies of scale (e.g. Wolszczak-Derlacz, 2017). Another possible explanation could be associated with Poland's lower GDP for R&D when a large number of Polish universities impedes collaboration and funding has to be distributed among more universities. Many studies pointed out that scientific collaboration is more visible in small- and medium-sized countries (e.g. Kwiek, 2018b). This might be explained by the findings from other studies that larger research centres with traditions, resources, wealth, and regional high tech have higher research productivity and attract more international researchers (e.g. Smeby and Trondal, 2005). Moreover, scientific collaboration is often related to socio-economic factors such as geographical proximity, linguistic and common history; thus, according to Kwiek (2020), collaboration patterns can be still observed between Germany and Austria, the Czech Republic and Slovakia, or Spain and Portugal. In addition, the study by Gorraiz et al. (2012) reveals that the common history and country-specific characteristics could influence and tie scientific collaboration e.g. between Hungary and Austria. Moreover, cross-border scientific collaboration in terms of research is practised in many countries where it is influenced by sharing resources, division of labour among scientific teams, and geographical and cultural proximity (Marginson, 2020).

Our analysis portrays Hungary as a collaborative country in scientific terms. This is supported by a previous study by Glänzel et al. (1999), who indicated that Hungary has been open to international scientific collaboration for a long time. Naturally, Hungary is a smaller country than Poland, and its university network (number of universities) is not dispersed, thus it is easier to manage and more attractive in terms of accelerating collaboration at the highest level. The performance of the Czech Republic and Slovakia was similar. They produced a smaller number of internationally co-authored papers and despite not being at the top of the ranking, their numbers in relation to the country-specific factors were still over 40%.

When it comes to winning European grants, especially by experienced scientists, Hungary and the Czech Republic perform better while Poland is placed at the bottom of the ranking. These results correspond to some extent with those obtained by Luczaj and Bahna (2020), where, according to the data retrieved by them from Eurostat, the share of international researchers in the Czech Republic is 5.48% and in Slovakia is 3.03%, rendering these countries more internationalised than the remaining Visegrád Group countries (Hungary 2.17%, Poland 1.64%). The low ranking of Poland in terms of ERC grants is also reflected in a relatively low impact of Polish researchers in the global context. Hungary has the best performance in international cooperation among the Visegrád Group and this can be explained by the fact that at the beginning of the 21st century, Hungary took a big step forward by transforming its HE system, including the establishment of the Science and Technology Policy College. To sum up, the good position of Hungary demonstrates that higher expenditure on science results in obtaining international grants and indexing in well-known rankings of universities, which reflect HE of the highest quality. Additionally, part of the management strategy to increase academic productivity included the evaluation of scientific units, the encouragement of researchers to publish and share scientific output, and the improvement of scientific collaboration at the international level (Pusztai & Szabó, 2008).

There is a noticeable gap between the V4 countries and the Eurozone leader (the UK). In the area of HE, the V4 countries need to underpin and continue transformation and development to adapt to European trends. As knowledge-based organisations, universities can build a strong position by improving the quality of research and their global recognition (Altbach, 2015). From the perspective of quantity indicators, this analysis reveals that V4 has a high scientific potential and – despite medium investments in science – it is increasingly present and recognised among other countries. The element of collaboration, which is necessary and desirable to increase scientific productivity, must be redefined, especially in Poland. The internationalisation of scientific research enables scientists to conduct pioneering research and strengthen the position of their universities at the global level (Seeber et al., 2016). This may result in more grants, employing world-class scientists, increasing competitiveness and cooperation with business and industry, among others, as well as engaging V4 authors in international academic publishing by serving on editorial boards, reviewing scientific papers, and expanding the co-authorship network.

Limitations

This study has several limitations that need to be considered. First of all, our evaluation has been narrowed to the V4 countries but it could be extended to include more countries in the future. This study has only examined a convenience sample of indicators. A further study regarding financial aspects of research funding would be worthwhile. Another potential area for further research might be an examination of publication patterns for V4 researchers and collaboration analysis (at the discipline and country level). This perspective may be expanded to the V4 countries given that there are relatively few studies taking into account such an approach.

Practical implications

The publication of scientific output is important from a social point of view, especially for universities that include social responsibility in their mission. Moreover, despite using innovations and new tools and platforms, the reputation and trust of academic institutions are still expected and relevant (Nicholas et al., 2015). In the area of HE management, further efforts are needed to adapt to European trends; however, V4 science has potential and is visible at the European level. Internalisation trends are observed in terms of publishing where an assessment of scientific units in many countries leads to a larger number of publications produced in collaboration with authors from different universities and countries. Thus, international publishers may expect an inflow of manuscripts from different countries and nationals. The idea of diversity garners the interest of a broader audience, which results in the expansion of the readership for the publishing industry. According to Holmes (2019), publishers can benefit from the diversity of content and expand their audiences, thus get a new potential financing source. The publishing industry is also under pressure when it comes to, for instance, Plan S and transformative agreements (Wise and Estelle, 2020). Therefore, expanding its audience to authors publishing scientificdata from other countries than those with the strongest position in economic terms and highly developed ones may have a positive effect on further development and diversification of a journal (by authors, reviewers or editorial board). In this regard, our study provides information on the scientific productivity of the V4 countries that could be an interesting direction or a starting point for further comparative research with other countries or groups of countries in terms of publications and knowledge production. Authors can also promote themselves and their work in top journals as well as bring international attention to their region.

Moreover, practical implications for universities and publishers suggest that focus should be placed on collaboration as well as on rapid scholarly publication to catalyse the changing scientific activities and to foster research competition and development. Researchers under publishing pressure want to publish in prestigious journals in order to be cited and promote their research at the international level. Thus, publishing high-quality research from different countries may help to build publishers' brand and recognisability among the global and developing academic market.

Contributions

MSŻ prepared concept of the study, provided and analysed data, and wrote and critically reviewed the manuscript . BB prepared concept of the study, analysed data, interpreted the results, wrote and critically reviewed the manuscript. Both authors reviewed the final manuscript.

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Supplementary materials

Full data for 30 EU countries retrieved from WoS and Scopus, and from the ERC website can be found in supplementary materials.

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Appendices

Appendix A. The number of publications and citations retrieved from WoS and Scopus for 2010-2019 period by EU28 and Norway and Switzerland

Web of Science				**Scopus**			
Country	Rank	Documents	Times Cited	Country	Rank	Scholarly Output	Citation Count
United Kingdom	1	1927937	22741425	United Kingdom	1	1982406	29202675
Germany	2	1571743	19644292	Germany	2	1694213	24163601
France	3	1058324	13140322	France	3	1177841	16214333
Italy	4	988470	11227845	Italy	4	1077275	14359079
Spain	5	824524	9337046	Spain	5	889804	11586975
Netherlands	6	572053	8714116	Netherlands	6	584677	10821867
Switzerland	7	427792	6918540	Switzerland	7	438960	8463723
Sweden	8	365423	5202557	**Poland**	8	421044	3440421
Poland	9	362515	2761334	Sweden	9	388490	6526400
Belgium	10	315557	4382226	Belgium	10	323683	5422808
Denmark	11	247487	3730183	Denmark	11	255698	4618609
Austria	12	231829	2922250	Austria	12	242293	3661575
Portugal	13	213169	2138951	Portugal	13	231944	2757896
Czech Republic	14	203060	1647779	Czech Republic	14	220693	2053542
Norway	15	182358	2399631	Norway	15	208129	3084109
Finland	16	177013	2392663	Finland	16	201231	3121512
Greece	17	172758	1864058	Greece	17	192149	2436631
Romania	18	152188	783949	Romania	18	150859	982209
Ireland	19	143748	1659531	Ireland	19	139989	2142948
Hungary	20	98642	1031376	Hungary	20	107261	1260069
Slovakia	21	63727	418765	Slovakia	21	72802	556540
Croatia	22	53626	451054	Croatia	22	66130	573466
Slovenia	23	52837	523236	Slovenia	23	60344	668518
Bulgaria	24	36996	306682	Bulgaria	24	44756	388524
Lithuania	25	33968	253093	Lithuania	25	34625	317760
Estonia	26	26531	390690	Estonia	26	29617	478185
Cyprus	27	18681	209611	Cyprus	27	22631	287609
Latvia	28	18292	101555	Latvia	28	18828	147420
Luxembourg	29	15814	192282	Luxembourg	29	17851	265306

Malta	30	5445	40425	Malta	30	6592	73053

Appendix B. Percentage of papers recognized as international (with co-authors from different countries) retrieved from WoS and Scopus for 2010-2019 period by EU28 and Norway and Switzerland

Web of Science			Scopus		
Name	Rank	International Collaborations [%]	Name	Rank	International Collaborations [%]
Luxembourg	1	74.71	Luxembourg	1	73.4
Switzerland	2	65.8	Switzerland	2	64.2
Cyprus	3	63.88	Cyprus	3	63.1
Belgium	4	62.43	Belgium	4	61.1
Austria	5	61.06	Austria	5	59.8
Sweden	6	60.04	Sweden	6	58.5
Denmark	7	59.38	Denmark	7	58.0
Norway	8	58.11	Estonia	8	55.8
Estonia	9	57.72	Netherlands	9	55.8
Finland	10	56.77	Finland	10	55.6
Netherlands	11	56.5	Norway	11	55.3
Malta	12	55.83	Ireland	12	54.0
France	13	53.08	Malta	13	53.5
Hungary	14	52.63	France	14	50.7
Slovenia	15	49.98	Portugal	15	49.5
Ireland	16	49.45	Hungary	16	48.2
Bulgaria	17	49.25	United Kingdom	17	47.8
Portugal	18	48.80	Germany	18	46.9
Germany	19	48.79	Slovenia	19	46.3
Greece	20	46.95	Greece	20	46.2
United Kingdom	21	46.86	Bulgaria	21	45.6
Spain	22	45.90	Spain	22	44.5
Italy	23	44.75	Italy	23	43.2
Slovakia	24	42.75	Slovakia	24	42.1
Croatia	25	42.39	Lithuania	25	40.6
Czech Republic	26	41.77	Czech Republic	26	40.2
Lithuania	27	40.15	Latvia	27	38.2

Latvia	28	37.39	Croatia	28	37.2
Poland	29	32.94	Romania	29	43921
Romania	30	28.86	Poland	30	30.0

Appendix C. The number of ERC grants (StGs, CoGs, AdGs) received by EU28 and Norway and Switzerland

Starting Grants [2010-2019]			Consolidation Grants [2013-2018]			Advanced Grants [2010-2018]		
Country	Rank	No	Country	Rank	No	Country	Rank	No
United Kingdom	1	798	United Kingdom	1	389	United Kingdom	1	539
Germany	2	652	Germany	2	295	Germany	2	388
France	3	510	France	3	237	France	3	281
Netherlands	4	397	Netherlands	4	156	Switzerland	4	199
Israel	5	265	Switzerland	5	119	Netherlands	5	191
Switzerland	6	249	Spain	6	118	Italy	6	146
Spain	7	209	Italy	7	105	Spain	7	117
Italy	8	198	Israel	8	97	Israel	8	105
Belgium	9	160	Belgium	9	74	Sweden	9	74
Sweden	10	148	Sweden	10	62	Belgium	10	71
Austria	11	126	Denmark	11	45	Austria	11	58
Denmark	12	85	Austria	12	44	Denmark	12	53
Finland	13	66	Finland	13	37	Finland	13	36
Norway	14	53	Portugal	14	30	Norway	14	27
Ireland	15	51	Norway	15	26	Ireland	15	17
Portugal	16	44	Ireland	16	24	Hungary	16	16
Hungary	17	22	Hungary	17	15	Greece	17	13
Poland	18	21	Greece	18	13	Portugal	18	13
Greece	19	18	Czech Republic	19	12	Czech Republic	19	6
Czech Republic	20	17	Turkey	20	5	Slovenia	20	5
Turkey	21	11	Luxembourg	21	4	Cyprus	21	3
Romania	22	5	Poland	22	4	Estonia	22	3
Estonia	23	4	Cyprus	23	2	Luxembourg	23	3

Slovenia	24	4	Estonia	24	2	Poland	24	2
Luxembourg	25	3	Iceland	25	2	Turkey	25	2
Croatia	26	2	Croatia	26	1	Bulgaria	26	1
Cyprus	27	2	Romania	27	1	Croatia	27	1
Iceland	28	1	Serbia	28	1	Latvia	28	1
Serbia	29	1	Slovenia	29	1	Lithuania	29	1
Slovakia	30	1	-	-	-	Iceland	30	0
Bulgaria	31	0	-	-	-	-	-	-