RESEARCH ARTICLE

The relationship of public investments in science and scientometric indicators from the perspective of Croatian universities

Miroslav Rajter
University of Zagreb, Research Office, Zagreb, Croatia

Aim: This study addresses the hypothesis that the investments in science are positively correlated with the indicators of productivity and performance of the universities.

Methods: A cross-sectional design was used with the data from 27 EU countries. The percentage of GDP invested in science in higher education in 2019 and investments expressed as €/inhabitant were used. The criterion variables were total number of publications in Web of Science for 2020; number of publications categorized as article, review or note (ARN); change in the number of publications compared to 2016 in total and for Organisation for Economic Co-operation and Development (OECD) research areas; productivity per inhabitant; productivity per researcher; productivity per researcher in higher education system; and number of Academic Ranking of World Universities (ARWU) TOP1000 universities per inhabitant. Descriptive data and Pearson and Spearman correlations were calculated. Additionally, partial Spearman correlations for detailed examinations were used.

Results: Most of the productivity indicators were positively correlated to the investment in science. The absolute investment in science in €/inhabitant is more important than investment expressed as the percentage of GDP. Unexpectedly, the correlations between investments and the growth rate in productivity were negative indicating that the less developed countries have achieved a larger growth in productivity in the examined 5-year period.

Conclusion: The results indicate that the investments in science as the percentage of GDP is important, but the absolute amount of money also has an important role in the prediction of scientific productivity. However, since the absolute amount of investments is limited in the less developed countries, they should be more focused on building the strategies that capitalize on specific strengths and potentials. This further accentuates the need for science policy change in Croatia with the strategic focus on aligning the resources to the expected results.

Correspondence to:
Miroslav Rajter
University of Zagreb, Research Office, Trg Republike Hrvatske 14, 10000 Zagreb, Croatia
mrajter@unizg.hr

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Introduction

The Croatian research landscape mainly consists of universities and research institutions. Currently, there are 25 public research institutions and 12 universities, out of which 9 are public (Agency for Science and Higher Education, 2021). While there are many external contributors, such as companies and private institutions, the main research output comes from public research institutions and universities. The focus of this analysis is public universities.

The financing of public universities is based on the systematic performance-based allocation of resources (Vlada Republike Hrvatske, 2018). Based on reports from the Ministry of Science and Education (MZO, 2019; 2020), the primary goals of this type of financing are: relevance for the current and future needs of the labour market, economy and society; excellence of science and arts related work; and science, arts and higher education as initiators of change in society and economy. It was presumed by the decision from the government of Croatia that each university would sign a "programme contract", however only a few universities signed this thus entitling them to full financial support, whilst the other universities are entitled only to "fundamental" financing. The calculation of fundamental financing is based on the number of publications (only articles, reviews and note - ARN) in Web of Science (for STEM research areas) and Scopus (for STEM, Social Sciences and Humanities (SSH) and Arts); number of scientists; average productivity and the allocated sum per publication, which is 7,500 HRK (cca. 1,000 €) for SSH and 13,500 HRK (cca. 1,800 €) for STEM and Arts (the rationale for this decision was unavailable). This model of financing equation is given by (MZO, 2019):

$$Total = \frac{NoP}{NoS} \times ApP \times NoS \tag{1}$$

With *NoP* being the number of publications, *NoS* is the number of scientists and *ApP* is the allocation per publication. While some aspects of this model can be criticized, such as the choice of bibliographic databases and the targeted types of publications, they can be considered as political and strategic decisions. Further, this method of allocating financial resources based on publication output also has several serious flaws. The first flaw is that this formula has a fundamental error where the number of scientists is used in a manner where it does not have any effect on the total amount of financing. The second flaw is that the field of arts is financed based on scientific output, which is minimal because predominantly the arts field produces art-related output as opposed to scientific papers.

The primary goal of the financing of scientific work from universities is the strategic investment into the development of the scientific landscape. The basis for this paper is the document on the analysis of the Croatian public expenditure in science (World Bank, 2019), which was compiled by the World Bank in collaboration with experts from the Ministry of Science and Education and experts from universities and research institutions. This analysis identified several key problematic areas and established some points for the development of the research landscape, however it ignored the fact that Croatia is lagging in investments in science as a country. The data on the investments in science in higher education per inhabitant in 2019 (Eurostat, 2021d) ranked Croatia 23 out of 27 countries with investments of 47.90€ per inhabitant, while the EU average was 150.34€ per inhabitant. When building a good strategy, it is important to consider the complete picture without the omission of the key elements that influence the entire process. Thus, the primary aim of this paper was to analyse the correlation of investments in the Croatian research sector with several key scientometric indicators of performance, where the main question was whether the increase in investments is correlated with the productivity and reputation, and if so, to what extent.

For this paper, three indicators were analysed. The selected indicators are most commonly used in the evaluation of results on the national level and are therefore the most relevant. The first indicator is general productivity, counted as the number of publications categorized as ARN in Web of Science. To normalize this indicator, the productivity per author was also used because the number of authors per paper is very different for different fields of science and because the Croatian government's regulation on scientific career advancement imposes different requirements on scientists regarding the number of authors (Nacionalno vijeće za znanost, visoko obrazovanje i tehnološki razvoj, 2017). For example, papers authored by social scientists would be scored with one point if the paper has up to three authors, with ½ of a point if the paper has up to six authors and with relative contribution points if the paper has more than six authors. Constrastly, in the medical sciences the number of authors per paper is not important and the scientists in this field must be the first, lead or corresponding author on at least one-third of the papers. The productivity of scientists is not the ideal criterion for quality; however, this is the most important indicator for national funding in Croatia. Along with the number of published papers, the citation rate is often used as an indicator of quality, however the number of citations is time dependent and does not reflect simultaneously the investments in science and was therefore not used in this paper. The third indicator is the number of universities in the top 1,000 of the Academic Ranking of World Universities (ARWU), more commonly known as the Shanghai list. The position of a university in international rankings is often considered as an indicator of its quality. The university rankings are often criticized (Centre for Science and Technology, 2021; Gadd, 2020; Pusser & Marginson, 2013) mainly because of the improper interpretation of results with consequences on funding, immigration statuses and collaborations. Additionally, the superficial simplicity of the rankings is often (ab)used in the media and communication with the public and therefore represent an important factor that universities incorporate into their strategies concerning public relations. The ranking systems can be divided into two categories – those that rely on external sources of data, which are generally more objective, but measure fewer indicators, and those that rely on the data collected from universities, which are more comprehensive, but are prone to low data quality and integrity. ARWU is considered to be one of the most influential rankings in the Croatian landscape that relies on external sources of data. This ranking system is based on four criteria (ARWU, 2021). The first is the Quality of Education that represents the alumni of an institution who won Nobel Prizes and Fields Medals. The second is the Quality of Faculty that represents the number of staff who won Nobel Prizes and Fields Medals and the number of Highly Cited Researchers. The third criterion is the Research Output that represents the number of papers published in Nature and Science and number of articles indexed in the Science Citation Index-Expanded and Social Science Citation Indexes. The fourth criterion is the Per Capita Performance that represents the weighted scores of previous indicators divided by the number of the full-time equivalent (FTE) academic staff.

In the context of the main aim of this study, the main hypothesis is that the investments in science will have a strong and positive correlation with the selected scientometric indicators, namely total productivity, productivity per author and the relative number of universities in the Shanghai TOP1000 list.

Methods

Sample

For the purpose of this study, the 2019 data for 27 EU countries was used for the investments in science and population indicators and 2020 and 2016 data was used for the productivity indicators. This means that each country was treated as a single entity. The rationale for the selection of countries was that they share common basic principles, legal functioning, and cultural values. Another specific reason is that neither country (except for Malta) has English as their official language which has a presumed influence on the quantity of publications indexed in the Web of Science.

Measures

Within this study, two main sets of measures were used. As the predictor measures, the investments in science in higher education as the percentage of GDP (Eurostat, 2021d) was used as a general measure of the investments in science for 2019, which is the most recent reliable data. Based on the population in 2019 (Eurostat, 2021b) and the absolute GDP in 2019 (Eurostat, 2021a) the investments in science in higher education (expressed in euros) per inhabitant were calculated. This measure normalizes GDP and investments for each country.

For the criterion variables, the following metrics were used: total productivity in 2020 in the Web of Science, productivity in terms of publications categorized as ARN; a change in productivity in comparison to 2016 for the two previous indicators and for research fields using OECD (Organisation for Economic Co-operation and Development) research schema which is the most similar to the Croatian national schema; number of publications per inhabitant; and number of publications per FTE researcher and FTE researcher in higher education (Eurostat, 2021c). Web of Science, InCites, and Clarivate are trademarks of their respective owners and referred to herein with their permission. Along with the productivity indicators, the number of universities listed in the 2021 ARWU TOP1000 list (ARWU, 2021) was used. To normalize this indicator, the number of universities was expressed as the number of universities per 1 million inhabitants.

Results

The data was analysed and presented using Excel and R (R Core Team, 2021) with packages: *ggplot2* (Wickham, 2016), *rnaturalearth* (South, 2017) and *ppcor* (Seongho, 2015). **Table 1** presents the basic descriptive data for key variables.

Table 1. Descriptive statistics for predictor and criterion variables with the Shapiro-Wilk test of normality and a reference value for Croatia

Variable	M	SD	Min	Q1*	Q2	Q3	Max	SW p†	HR value‡
Investments in HEI§ as %GDP	0.42	0.224	0.05 (RO‖)	0.24	0.36	0.56	0.99 (DK)	0.338	0.36
Investments in HEI as EUR per inhabitant	146.18	130.047	5.25 (BG)	58.19	88.96	231.48	529.39 (DK)	0.002	47.90
Total number of publications	39,600.7	50,044.77	1,069 (MT)	6,517	22,643	44,330.5	192,691 (DE)	0.000	8,238
Total number of ARN¶ publications	25,356.3	32,517.80	520 (MT)	4,235.5	13,661	29,928.5	128,804 (DE)	0.000	5,067
Change compared to 2016									
Total number of publications	0.11	0.120	-0.12 (LV)	0.07	0.11	0.16	0.46 (CY)	0.048	0.15
Total number of ARN publications	0.30	0.121	0.12 (FR)	0.22	0.29	0.35	0.73 (CY)	0.002	0.34
Natural sciences	0.26	0.128	0.07 (FR)	0.17	0.25	0.32	0.58 (CY)	0.096	0.37
Medical sciences	0.42	0.247	0.17 (SK)	0.24	0.38	0.53	1.29 (CY)	0.000	0.50
Engineering	0.34	0.155	0.07 (RO)	0.24	0.34	0.41	0.70 (CY)	0.575	0.34
Agronomical sciences	0.35	0.294	-0.05 (SI)	0.18	0.29	0.36	1.34 (BG)	0.001	0.55
Social sciences	0.39	0.192	0.08 (SI)	0.23	0.37	0.52	0.81 (SK)	0.547	0.39
Humanities	0.20	0.250	-0.07 (PT)	0.03	0.14	0.28	1.07 (LU)	0.000	0.27
Papers per 1000 inhabitants	2.76	1.283	0.85 (BG)	1.80	2.46	3.70	5.91 (DK)	0.395	2.02
ARN per 1.000 inhabitants	1.72	0.862	0.49 (BG)	1.05	1.55	2.27	3.92 (DK)	0.285	1.24
Papers per researcher	0.48	0.274	0.22 (BG)	0.38	0.42	0.54	1.72 (CY)	0.000	0.57
ARN per researcher	0.29	0.123	0.13 (BG)	0.22	0.29	0.33	0.80 (CY)	0.000	0.35
Papers per HEI researcher	1.55	0.755	0.60 (LV)	1.02	1.44	1.76	4.44 (CY)	0.000	1.36
ARN per HEI researcher	0.94	0.398	0.32 (LV)	0.67	0.90	1.03	2.06 (CY)	0.052	0.84
ARWU TOP1000 universities per 1mil inhabitants	0.66	0.462	0.00 (BG, LV, MT)	0.26	0.66	1.03	1.63 (LU)	0.311	0.25

* Quartiles.
† P value for Shapiro-Wilk test of normality (values below 0.05 indicate deviation from normal distribution.
‡ Reference value for Croatia.
§ Higher education industry.
‖ Country codes: BG – Bulgaria; CY – Cyprus; DE – Germany, DK – Denmark; FR – France; LV – Latvia; LU – Luxemburg; MT – Malta; PT – Portugal; SI – Slovenia; SK – Slovakia.
¶ Article, review or note.

The data shows that the investments in science in HEI range from 0.05% in Romania to 0.99% in Denmark as a percentage of GDP. The absolute values in EUR show even larger differences where in Romania the expenditure is 5.74€ compared to 529.39€ in Denmark. Croatia was, as mentioned in the introduction, below average with 0.36% of the GDP and in the bottom quartile with 47.90€ per inhabitant. In terms of scientific productivity, the absolute values of the number of publications are of no particular interest because they are dependent on the country size, but when focused on the changes in the productivity compared to 2016, an average increase in productivity of 11% in the EU 27 was observed, mostly attributed to the change in the total number of publications categorized as ARN, where the total change was 30%. The highest increase was present in the medical sciences, and the lowest in humanities. This increase can, at least partially be explained by the increasing trend in the number of co-authors in publications in the medical sciences which consequently increased the number of published papers. In terms of maximum values, there was dramatic increase in almost all research areas ranging from 58% to 134%. This increase was present in Cyprus, Malta and Luxembourg. In such cases, several factors can influence the productivity, since those three countries are smaller, the smaller absolute increase can dramatically inflate the percentage, and this can be caused by the change in the scientific management, the opening of new research positions or the increase of the number of local journals indexed in the Web of Science. In Croatia, the total number of publications increased by 15.3% and the number of ALR publications by 34.2%. Regarding the research areas, the number of ARN publications increased from 27.1% in humanities to 50% in the medical sciences. Although it can be hypothesized that this increase is, at least partially, attributed to the increase in local productivity in journals of lower impact that have been recently added to the Web of Science, such an analysis is out of the scope of this study. Normalized indicators of productivity show that the productivity ranged from 0.85 publications per 1,000 inhabitants in Bulgaria to 5.91 in Denmark. Croatia has a productivity of 2.02 publications per 1,000 inhabitants, ranking it in the second quartile of the distribution. Both the productivity per researcher and the productivity per HEI researcher were shown. The productivity per researcher is technically a more accurate indicator because this encompasses more scientifically productive people than only HEI researchers. However, the data shows that the ratio of HEI researchers to all researchers per country varied widely, ranging from 15% in Bulgaria to 62.8% in Latvia. These data indicate the possibility that there are different definitions of researchers among countries, thus the productivity per HEI researcher was analysed to introduce less accurate but a more stable definition. Unfortunately, the data for productivity from the HEI sector was not available, thus the total productivity indicator was used. This indicator shows that the relative productivity ranged from 0.32 ARN publications per HEI researcher in Latvia to 2.06 papers in Cyprus. Croatian productivity was 0.83 ARN papers per HEI researcher ranking it at 17th place. The final indicator is the number of universities listed in the ARWU TOP1000 universities per 1,000,000 inhabitants. This indicator shows that Bulgaria, Latvia, and Malta had no universities ranked on this list, while the highest numbers were 1.63 (one university) in Luxembourg and 1.47 (13 universities) in Austria. The ratio in Croatia was 0.25 with the University of Zagreb as the only ranked Croatian university.

To examine the hypothesis, the correlations between the indicators of the investment in science and the criterion measures were calculated. Since most variables were not normally distributed and the sample was relatively small, both Spearman and Pearson correlations were calculated (**Table 2**).

Table 2. Pearson and Spearman correlation coefficients of indicators of productivity with the investments in science

Variable	Investments in HEI* science as %GDP		Investments in HEI as EUR per inhabitant	
	Pearson r	Spearman ρ	Pearson r	Spearman ρ
Total number of publications	0.229	0.504§	0.203	0.508§
Total number of ARN† publications	0.250	0.521§	0.225	0.522§
Change compared to 2016				
Total number of publications	-0.056	-0.146	-0.071	-0.189
Total number of ARN publications	-0.392‡	-0.494§	-0.411‡	-0.501§
Natural sciences	-0.379	-0.384‡	-0.479‡	-0.489‡
Medical sciences	-0.415‡	-0.383‡	-0.380	-0.375
Engineering	0.011	-0.030	-0.159	-0.175
Agronomical sciences	-0.392‡	-0.195	-0.443‡	-0.475‡
Social sciences	-0.327	-0.333	-0.479‡	-0.433‡
Humanities	-0.372	-0.487‡	-0.168	-0.422‡
Papers per 1.000 inhabitants	0.671§	0.581§	0.826§	0.825§
ARN per 1.000 inhabitants	0.744§	0.636§	0.880§	0.846§
Papers per researcher	-0.075	0.049	-0.044	0.150
ARN per researcher	0.067	0.172	0.088	0.253
Papers per HEI researcher	-0.122	-0.096	0.084	0.242
ARN per HEI researcher	0.010	0.074	0.233	0.397‡
ARWU TOP1000 universities per 1 million inhabitants	0.500§	0.499§	0.699§	0.793§

* Higher education industry.
† Article, review or note.
‡ P<0.05.
§ P<0.01.

Before analysing the correlations, it has to be noted that this sample was relatively small reflected in the critical correlation coefficient (r) of 0.381, with α=0.05, for the Pearson correlation and an r = 0.323 for the Spearman correlation. Consequently, this study had enough power to detect only medium to large effects. Since the data was mostly non-normally distributed, the Spearman correlations should be interpreted from the results. Regarding the total number of publications, high positive correlations can be possibly explained by the fact that the larger countries had more researchers and invested more in science. To determine this, partial Spearman correlations were calculated (**Table 3**) in addition to the correlations presented in **Table 2**. Partial correlations are useful here because they control for potentially confounding variables.

When controlling for the total population, the correlation of the total number of publications with percentage GDP and EUR/inhabitant rose, as shown in **Table 3**. A similar increase was observed for the number of researchers and HEI researchers (**Table 3**). These findings can be interpreted as investments in the scientific workforce were positively correlated with national productivity; however, the total investments still had an important role.

Table 3. Partial Spearman correlations of the total number of publications (TP) with investments in HEI* as the percentage of GDP (%GDP) and investments in HEI as EUR per inhabitant (€/i)

Control variable	$r_{TP\text{-}\%GDP}$	$r_{TP\text{-}€/i}$
Total population	0.683‡	0.803‡
Number of researchers	0.317	0.386
Number of HEI researchers	0.155	0.392†

* HEI - Higher education industry.
† P<0.05.
‡ P<0.01.

The surprising finding from this study is related to the negative correlations of investments with the relative growth of the number of publications. To further examine this finding, the countries regarding their change in the total number of ARN publications were presented (**Figure 1**). The map below shows that a larger change occurred in southern and eastern countries with the highest being in Cyprus and Malta. It can be hypothesized that this represents a cultural shift of researchers to publish in journals indexed in the Web of Science, but also that the number of journals that are indexed in the Web of Science in those countries has increased.

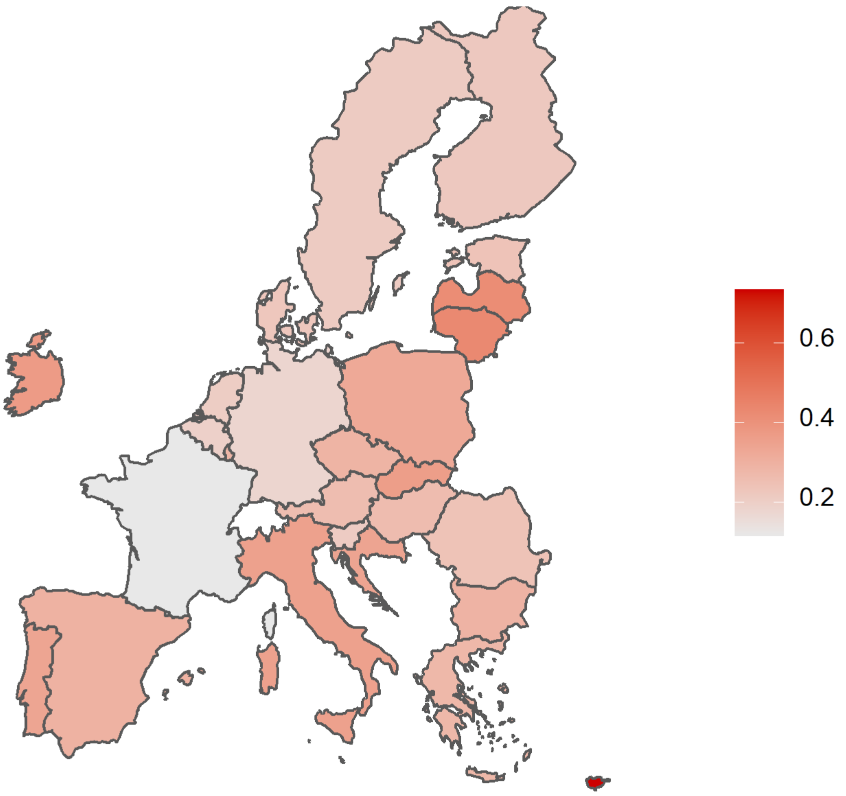

Figure 1. The map of EU countries representing the change of ARN publications in 2020 compared to 2016 (Source: Author, data from Web of Science and/or InCites, provided by Clarivate).

Regarding the normalized productivity, our results show that the investments in science were highly correlated with the number of publications per inhabitant and that they had low to medium correlations to the number of researchers. To further examine this, the partial Spearman correlations of investments with the relative productivity per inhabitant were calculated with controlling for the number of researchers, number of HEI researchers, ratio of researchers in the population and ratio of HEI researchers in the population (**Table 4**).

Table 4. Partial Spearman correlations of the productivity per inhabitant (P/i) with investments in HEI as the percentage of GDP (%GDP) and investments in HEI as EUR per inhabitant (€/i)

Control variable	$r_{P/i\text{-}\%GDP}$	$r_{P/i\text{-}€/i}$
Number of researchers	0.594†	0.867†
Number of HEI* researchers	0.615†	0.873†
Ratio of researchers in population	0.232	0.608†
Ratio of HEI researchers in population	0.343	0.747†

* Higher education industry.
† $P<0.01$.

Our results show that the correlations between investments and the productivity per inhabitant did not change substantially when controlling for the total number of HEI researchers. When controlling for the ratio of researchers in the population and the number of HEI researchers in the population, the correlation of total productivity per inhabitant with investments as percentage GDP decreased and were not statistically significant (**Table 4**). On the other hand, the correlations of investments in EUR/inhabitant remained very high even after controlling for the ratio of researchers and HEI researchers (**Table 4**). Perhaps national productivity is dependent on the investments as a percentage of the GDP due to the increased size of the workforce; however, even when accounting for the workforce size, the absolute investments play a very important role enabling researchers to work.

The final indicator was the relative number of universities listed in ARWU TOP100 universities. The results showed high correlations with both investment variables meaning that the more the countries invested in science, the more prestigious their universities were.

Discussion

Considering the results from this study, it can be concluded that the main hypothesis of this study was partially confirmed. The data from 27 EU countries showed that the investments were mostly positively related to scientific productivity and prestige. However, the unexpected result that the investments were negatively correlated to the growth of productivity can be explained by the hypothesis that in countries that are underinvesting in science there is a larger space for growth regarding their scientific journals that have been indexed or will be indexed by the Web of Science or Scopus. Another indication of the results from this study is that the absolute amount of money invested in science was a stronger predictor of productivity and prestige. This is because the scientists work in an international environment where the costs of materials and publications are the same. Based on the fact that the EU27 percentage of GDP for HEI science was 0.48% or 150.34€/inhabitant, Croatia should invest 3.14 times more in the percentage GDP or 1.13% to achieve the European €/inhabitant average which would place Croatia at first place in the EU. This illustrates the fact that it can be politically unreasonable to expect the absolute amounts of investments in science to be the same in Europe because of strong disparities in the economic strengths of the countries; however, this does not provide an excuse for governments not to increase their investments. On the other hand, an endeavour to achieve the European €/inhabitant average provides a strong case that the strategies for investments should be more focused on cultivating the desired results. As mentioned in the introduction, the current Croatian system of scientific funding does not focus on quality but on the pure quantity of publications categorized as ARN. The total financing of universities in 2019 in Croatia was approximately 1,600€ per scientist per year (MZO, 2019; 2020). Furthermore, this has a paradoxical effect in that the authors of low-impact papers are being substantially funded. For example, the CMS collaboration, which publishes papers in very large collaborations, has published 117 papers in Web of Science with authors from the University of Split. This collaboration effectively constituted 13.8% of the total financing of the University of Split in 2019. In 2019, there were 231 ARN papers with more than 1000 co-authors where at least one author was from Croatia. Since these papers are counted for each university independently, this means that each paper can be counted more than once if the co-authors are from different universities within Croatia and this takes a substantial amount from the scarce budget allocated for science. Examples such as this show that the strategy of investing is important and that the countries should be conscious in providing their scientists with adequate resources based on their merit and potential. The investments in the research landscape are also important, especially that the journals funded by the national budget have to be oriented towards quality and indexation in the relevant databases. The strategy should consider the current needs and potential, as well as honour the developmental path for excellent science. This means that although less developed countries can learn the methods from more developed countries, the decision makers must consider the total developmental status of the country and make their plans accordingly.

This study has several main limitations. The first limitation is the small sample size which prevents the detection of small and small to medium effect sizes. Although the non-significant effects cannot be considered as reliable, they can provide a starting point for the design of future studies and power analyses. The second and more important limitation is the operationalization of key variables. Based on the available data the total productivity of countries was used, while the indicators of investments in science were used only for the higher education sector. The decision to do this was based on the better objectivity of the indicators for higher education and the applicability of the current Croatian system of science funding to the universities. The recommendation for future studies would be to extract data only for universities. Further, the measurement of productivity was based on the Web of Science database, which is restrictive, but in line with the current system of science funding in Croatia. Future studies would benefit from collecting the data from other databases. Moreover, there were no measures of quality, such as impact factors, citation rates, etc.

In this study, we have examined the correlation of investments in science in higher education with the scientific productivity of 27 EU countries and their success on ARWU ranking. The main hypothesis that the investment in science positively correlates with the productivity indicators was partially confirmed, where most of the absolute and relative indices of productivity were positively correlated with the investment in science except for growth rates, which were negatively correlated. The main explanation for this negative correlation was the hypothesis that in lesser developed countries, more journals are being indexed in the Web of Science thus increasing the productivity in this database. In total, the findings from this study show that not only is the investment expressed as the percentage of GDP important, but also the absolute amount of money invested in scientists. The countries with fewer resources available for investing should direct more attention to building an effective strategy for the development of science.

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ORCID

Miroslav Rajter https://orcid.org/0000-0002-2608-3196

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