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Research Article

A Worldwide Analysis of Top Scientists across Scientific Fields

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ABSTRACT

The scientific impact and rankings are considered important metrics for determining national recognition and prestige, as well as for determining scientific priorities and funding. This paper analyzes the distribution of leading scientists across all scientific fields and countries, examining the similarity graphs between them. Our analysis also reveals further regional and continental patterns. By measuring the correlation between top scientists with GPD data, we show that the ratio of scientists maintains a high correlation with the GDP per capita. We also study the link between the scientific performances of a country (in terms of top research personnel it hosts) with its economic wealth. Finally, we analyze the case of Greece and show that the scientific impact of a country changes significantly when we take into consideration its scientific personnel that has migrated abroad (i.e., brain-drain).

Keywords: Scientific Fields, Bibliometric analysis, Top Scientists, GDP per capita, brain-drain, Greece.

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INTRODUCTION

The scientific impact and rankings of individual persons, institutions, or even nations are considered important and vital metrics not only for their international recognition and prestige, but also for determining scientific priorities and funding. For instance, governments and funding agencies need systematic research performance evaluations, which are taking into consideration to optimize research allocations, re-orient research support, rationalize research organizations, restructure research in particular domains, or augment research productivity.[1] Such research performance evaluations usually consider both quantitatively and qualitatively indicators related to scientific publications and their impact internationally. The rankings resulting from these performances are widely used by the academic community to assess their impact internationally, and is also directly linked to their international recognition and prestige, which is reflected in their host institutions and their countries.

Typically, the primary metrics for quantifying, assessing and evaluating the scientific performance of individual entities, institutions or countries, are strongly related to scientific publications: either strong academic indicators (such as publications count, citations count or their combination) or alternative metrics (i.e., altmetrics) based on evidence from the social web. Even though these metrics are useful for assessing the recognition and prestige within the academic community, they lack significant other factors which may lead to unfair decisions when used as a policy to allocate funding and decide scientific priorities.[2] One such factor is the migration of scientific personnel (also known as brain-drain).[3] Under certain conditions, immigrant scientists are recoverable assets who can play a significant role in developing opportunities at home; one such condition is, for example, that the funding is not imbalanced in favor of the prestigious institutions of the richer countries, in which case the losses will only continue to increase.[2] Therefore, it is useful to provide scientific rankings of nations that are not limited to typical metrics, but also consider certain demographics, such as the living standards of each country and immigrant scientists that work abroad.

In this paper, we perform an extensive and exploratory worldwide analysis of 34 major scientific fields. In particular, we study the distribution of leading scientists across countries and scientific fields, taking into account demographic data such as the population and the economic level of the countries. In addition, we further explore the case of Greece, which we position in the world academic map of all sciences. Our approach is based on the typical academic metrics that are typically used to measure the scientific performance, which are further enriched with demographic data, such as living standards and the scientific personnel that has immigrated abroad. The results evidently show

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that the research personnel are highly correlated with the GDP of the host country and that the scientific ranking of a country changes if we take into consideration the immigrant scientific personnel.

This is the first study, to the best of our knowledge that presents a comparative analysis for the leading scientific personnel in major scientific fields worldwide, which is based on a combination of demographic data with scientific performance. In addition, we also focus on the case of Greece, mainly because is a country that brings out a considerable number of top scientists and, at the same time, has suffered significantly by brain-drain effect as a result of the recent economic crisis.[4]

The main contributions of our work are:

We analyze the scientific fields that comprised of the most top scientists and we show the similarity graphs between the different fields.

We perform a worldwide analysis and performance comparison of the countries with the most top scientists across all scientific fields. This analysis reveals further regional and continental patterns.

We present the correlation between top scientists with GPD data and show that the ratio of scientists maintains a high correlation with the GDP per capita. Our focus is both at a macro-scale (i.e., for different countries), as well as at a micro-level (i.e., for Greece as a case study). As shown in Table 1, there are many different metrics proposed for measuring and ranking the scientific impact.

BACKGROUND

Ranking Scientific Impact

There are many different metrics proposed for measuring and ranking the scientific impact. An overview of the citations as performance measures and their relation to research quality can be found in.[12] One of the simplest, yet widely-used strategy, is to count the citations and use this counter as a reference for comparison. Besides that, several other metrics propose to tackle specific shortcomings; For example, the MNCS (Mean Normalised Citation Score) provides a normalization metric across different scientific sub-fields and its goal is to overcome variations in speed and/or frequency of citation accumulation across different fields of science.[6] Hirsch's h-index is a metric that distinguishes frequent strong publishers and publishers with fewer but more impactful papers. Finally, there are also a number of higher-level metrics for academic citation, such as JIF[8] which is a journal-level metric that calculates the average of the interest in all papers published in a journal. Besides academic metrics, the use of alternative metrics (i.e., altmetrics) provides evidence, based on analytics from the social web. For instance, the use of mentions, posts and shares in online social networks can be aggregated to score the impact of publications.[9] Impact Story provides a combined view of academics' citations and social media footprint in order to try to provide meaningful context around a person or institution's academic impact.[10] Semantic Scholar is a research search engine, that also enables academic impact monitoring, such as citation importance classification and graphs of citation velocity and acceleration.[11]

The evaluation of scientific innovation and its impact at country-level has also been studied[13-18] The majority of the approaches use citation counts for country comparisons, which are fractionalized either equal to each author either by allocating a larger share to the most prominent collaborator, who tends to have made the greatest contribution.[13-17] Other approaches use alternative indicators, such as readership counts from the social reference sharing site Mendeley,[18] as these accumulate more quickly than citations.

The role of Demographics in Scientific Performance

Several studies have shown that scientific performance is strongly associated with the economic development of a country,[19-23] while others indicate that only a certain threshold of wealth is needed.[24]

In[20] the author uses R&D investment as a measure of inputs and the number of citations as a measure of scientific impact. The author also uses citations per unit of Gross Domestic Product (GDP) as a measure of output/outcome. In[25] the authors assess efficiency, considering as a measure of input the R&D investment and a number of productivity indicators, from publications and citations per researcher (the same measure is also used by)[20] to patents and citations per unit of GDP, as measures of outcomes. In[26] the authors include the number of patents per unit of GDP as a measure of outcome of science and technology. In[27] the authors show that the most important factor that explains the university system excellence is the economic potential in terms of GDP per capita.

Besides economic development, several other factors have been shown to affect the scientific performance of countries. For example, countries that do not speak English as mother tongue seems to have a handicap in producing highest-quality papers.[28,29] Also, poor governance in the form of political authoritarianism exerts a significant detrimental influence across various scientific

Table 1: Popular metrics for measuring scientific impact.

Academic impact metrics
Citations count[5]
Mean Normalised Citation Score (MNCS)[6] Hirsch's h-Index[7]
JIF[8]
Altmetrics / Social based metrics
Altmetri[9]
Impact Story[10]
Semantic Scholar[11]

domains fields.[28] On the contrary, the degree of respect for the civil and political liberties have a positive impact on the quality of scientific output.[28]

Studying the Brain-drain Effect

Brain drain is the international migration of scientific personnel, in search of better opportunities. Especially for the case of Greece, it has been a significant concern and has been studied extensively the recent years.[30-33]

Undoubtedly brain-drain, can be useful,[34] especially when originating from developing countries. There are definite advantages, including the ability to spend time in different countries. On the other hand, countries are not only losing their human assets on educated scientific professionals, but also the contributions of these workers to different aspects, such as nations development, impact and domestic product;[35,36] an estimation of the deficit at a global level has been studied by Ioannidis.[37] Zhatkanbaeva *et al.*[38] have studied the impact of globalization on brain drain in developing countries. Appelt *et al.*[39] explore the relationship between mobility, collaboration, and impact, showing that brain circulation contributes to international co-authorship, however it is a "complex and multidimensional phenomenon...". In any case, scientists who have emigrated for several reasons are recoverable assets who can play a significant role in developing opportunities at home.[34]

Datasets

Scientific Bibliometrics Data

In this study, we used data[1] from Research.com (accessed in November 2022).[40] The Research.com is an online database that uses the Discipline h-index to rank the top computer scientists using a different threshold per science field to ensure that the top 1% of scientists in each discipline are included in the ranking. To perform these rankings, Research.com uses data from Microsoft Academic Graph (acquired on December 6, 2021). The h-index[7] is denoted as the number of scientific publications that have at least h citations. This indicator is able to combine both the impact and productivity of scientific work. The Discipline H-index (D-index) is calculated by considering only the publications and their citation values deemed to belong to an examined discipline. Research.com uses 24 science categories that are alphabetically listed hereafter:

1. Animal Science and Veterinary
2. Biology and Biochemistry
3. Business and Management
4. Chemistry
5. Computer Science
6. Earth Science
7. Ecology and Evolution
8. Economics and Finance
9. Electronics and Electrical Engineering
10. Engineering and Technology
11. Environmental Sciences
12. Genetics and Molecular Biology
13. Immunology
14. Law and Political Science
15. Materials Science
16. Mathematics
17. Mechanical and Aerospace Engineering
18. Medicine
19. Microbiology
20. Neuroscience
21. Physics
22. Plant Science and Agronomy
23. Psychology
24. Social Sciences and Humanities

Demographics Data

The population data and the GDP per capita (Gross domestic product per capita), which measures the average income per inhabitant and is linked to the economic development of countries, have been obtained from the International Monetary Fund (IMF[2]) for the year 2021. For the needs of our study, we normalize the proportion of top scientists to the country's population (i.e., top scientists per one million population), and we set a threshold of (at least) five top scientists for a country to appear in a scientific field. According to the research database Research.com, there are 142,544 scientists worldwide in 24 scientific fields in 58 countries worldwide, of which 421 work in Greece in 17 scientific fields.

Analysis

Table 2 shows the 39 countries with at least 5 top scientists per million population; about 16 countries have a ratio of at least 100 scientists per million population. It is important to notice that the population ratio of scientists maintains a high correlation with the GDP per capita; we calculate the Pearson linear correlation at 0.70. Figure 1 shows the geographical distribution according to the proportion of scientists per 1M population in each country;

[1]The data, that can be used to regenerate the paper figures and Tables, are publicly available at: https://docs.google.com/spreadsheets/d/1AD-un9iBMEjtOR7CD6expGiuoLlFx3tKCLJj2PqbCak

[2]https://www.imf.org/en/Home

Table 2: The countries with at least five top scientists per million population (ranked by scientists' ratio).

Rank	Country	Top Scientists (#)	Population (M)	Ratio of Top Scientists per population	GDP per capita ($)
1	Switzerland	2465	8,67	284,31	92.249
2	Australia	5556	25,77	215,62	63.464
3	Denmark	1259	5,84	215,58	68.202
4	Sweden	2137	10,45	204,46	60.816
5	Netherlands	3534	17,48	202,23	57.997
6	Finland	1103	5,53	199,31	53.774
7	United Kingdom	11971	67,35	177,74	47.329
8	United States	59025	332,18	177,69	69.227
9	Norway	905	5,42	167,13	89.042
10	Canada	6001	38,23	156,99	52.015
11	Belgium	1800	11,56	155,78	51.849
12	Singapore	810	5,45	148,51	72.795
13	Iceland	50	0,37	135,50	69.422
14	Israel	1144	9,37	122,13	52.152
15	New Zealand	552	5,11	107,98	48.317
16	Austria	934	8,95	104,40	53.332
17	Germany	8104	83,20	97,41	51.238
18	Ireland	474	5,04	94,07	100.129
19	France	5520	65,45	84,34	45.188
20	Italy	4158	59,24	70,19	35.473
21	Spain	3100	47,40	65,40	30.090
22	Portugal	493	10,29	47,90	24.296
23	Japan	5375	125,51	42,83	39.301
24	Greece	438	10,68	41,02	20.263
25	Taiwan	744	23,38	31,82	33.143
26	Slovenia	54	2,11	25,60	29.298
27	Estonia	34	1,33	25,54	27.962
28	South Korea	1459	60,14	24,26	35.004
29	Czech Republic	248	10,50	23,62	26.849
30	Hungary	172	9,73	17,68	18.732
31	Luxembourg	10	0,64	15,75	136.701
32	Qatar	41	2,62	15,66	68.622
33	Cyprus	13	0,90	14,44	30.957
34	South Africa	370	60,14	6,15	6.965
35	Saudi Arabia	216	35,46	6,09	23.507
36	China	8585	1412,60	6,08	12.562
37	Poland	227	37,84	6,00	17.946
38	United Arab Emirates	60	10,19	5,89	41.205
39	Malaysia	164	32,70	5,02	11.408

as we can see 2 out of 3 countries are European. We notice that 41.4% of scientists work in the USA, while 36.1% work in Europe (Figure 2).

Figure 3 shows the percentage of scientists working in the US, Europe, China and the rest of the world, clustered by scientific field. As we can see, in the US the top scientists are distributed in five scientific fields (60.1% in Economics and Finance, 56% in Law and Political Science, 55.2% in Psychology, 51.9% in Medicine and 50.2% in Social Sciences and Humanities). In the USA there are a total of 15 scientific fields with rates of more than 40% worldwide. In Europe, the 40% limit is exceeded by the field of Veterinary Medicine and Animal Sciences which gathers the highest percentage with 44.7%, Microbiology with 43.2%, Ecology and Evolution with 42.5% and Environmental Sciences with 40.1%. In China, Materials Science stands out with a percentage of 25.3% which is very close to Europe (29.4%) and the USA (26.2%).

The Rank of Scientific Fields Worldwide

As shown in Figure 4, the field of "Biology and Biochemistry" gathers the most top scientists worldwide, reaching 12.3%, followed by Medicine with 11.4% and Chemistry with 9.3%. On the contrary, the scientific fields of "Mechanical and Aerospace Engineering" and "Business Administration" have the fewest top scientists, at about 0.9% and 0.95% respectively.

Figure 5 illustrates the science fields, in which the most top scientists appear by country, for the 25 countries with the largest population ratio of scientists. The horizontal axis shows the percentage for each country. Biology and Biochemistry with Medicine is first in 17 of the 25 countries. Greece is the only country out of the 25 that has the highest ratio of scientists in the field of Engineering and Technology and Norway in Environmental Sciences.

The 25 countries with the largest population ratio of scientists were then used to draw conclusions regarding the similarity of the ratio of scientists between countries and, respectively, how related the sciences are to each other. The two Similarity Matrices were calculated using the linear correlation of fit vectors. For the case of the correlation of the countries, for each country corresponds a vector of 24 positions with the proportion of scientists of the country in each scientific field. Accordingly, the corresponding vector for the sciences with 25 positions has been created. Figure 6 depicts the graph with the highest scientific similarity of the 24 fields. The pair of sciences with the highest correlation is "Biology and Biochemistry" with Microbiology at 0.97. This means that the performance of the 25 countries in these two sciences is quite similar. The fields of "Veterinary and Animal Sciences" and "Plant Sciences and Agriculture" seem to have the least similarity with other sciences, showing the highest correlation of 0.85 between them. Besides that, "Biology and Biochemistry" also shows a high linear correlation of more than 0.9 with most sciences (in total 10). This result shows that "Biology and Bio-chemistry" is the most" related/central science" in the sense that has the most similar behaviour with the most sciences. As we can see, there are five main groups of sciences emerging, the largest of which consists of the positive and health sciences that group 11 fields,

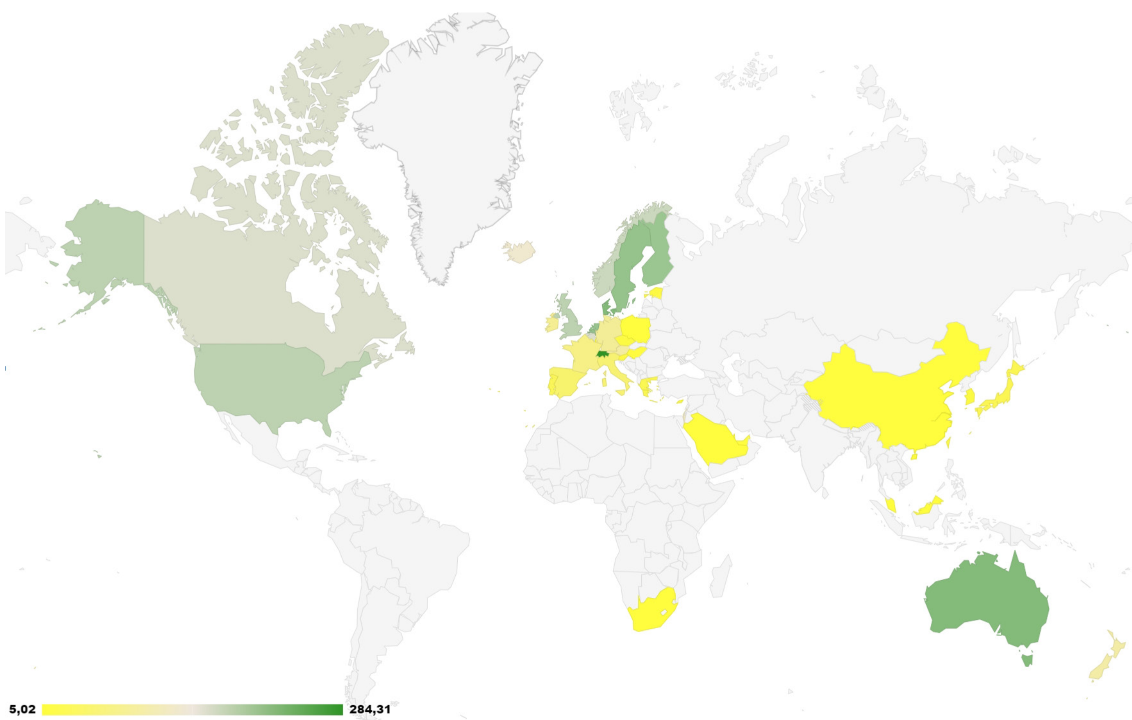

Figure 1: The geographical distribution of the top scientists according to the proportion of scientists per 1M population, as shown in Table 2.

while the technological sciences also create a second group of five fields. It can be observed that all the reported science pairs of Figure 6 are similar sciences having common scientific topics.

Figure 7 plots the similarity graph of the 25 countries with the largest population ratio of scientists based on the 24 scientific fields. The pair of countries with the highest correlation is Germany and Switzerland with 0.99, which means that their performances in the 24 scientific fields are almost identical. Also, the following country pairs show a particularly high linear correlation of 0.98 France with Germany, UK with USA, Netherlands with USA, Canada and Australia. Iceland appears to have the least similarity with other countries showing a higher correlation of just 0.55 with New Zealand. Switzerland also shows a high linear correlation above 0.9 with most countries (total 15). This result shows that "Switzerland" is the most "related/central country" in the sense that has the most similar behaviour with the most countries. In total, there are six main groups of countries, with the largest consisting of the countries centered on Switzerland, grouping nine countries mainly from central Europe. It can be observed, as it was expected, that many of the reported country pairs of Figure 7 are similar neighbour countries e.g. (Denmark, Sweden), (Switzerland, Austria), (Belgium, Germany), (Spain, Portugal) etc.

The case of Greece

Greece ranks in the 28th position worldwide and in the 18th position in Europe in terms of the number of top scientists in the world; if we take into account the ratio in the population of each country then Greece ranks 24th worldwide and 18th in Europe. There are 421 top Scientists working in Greece, the vast majority of which (99%) are of Greek nationality (only 4 of them have a different nationality), which is not the case for other countries with high economic development, due to the fact that they attract a vast number of top scientists from abroad. It is important to note that all the countries ranked higher than Greece also have a larger GDP per capita and are also able to attract a large number of scientists from abroad. In addition, the GDP per capita of Greece constitutes about 1/3 of the average of the top 25 countries.

The consequences of Greece's lower economic development compared to the rest of the countries enlisted in this study, had a significant impact on the brain drain effect, which is indicated by a large number of scientists that migrate abroad in search of higher salaries and more stable academic environments. According to a recent study,[41] there are a total of 63951 Greek scientists who have published at least 5 articles included in the Scopus database, of which 55% work in Greece, while 45% work abroad. The intersection of this dataset with ours, revealed 1139 leading Greek scientists working abroad in various science fields. This number is about 2.5x greater than the number of scientists working in Greece. More specifically, there are 609 people working in the USA, 35% more than those working in Greece, if we consider all 24 scientific fields (447). Due to a lack of data, it is virtually impossible to make a corresponding identification for all nationalities, in order to make the corresponding comparisons. But we can examine what emerges about our nationality, if we add the Greeks abroad to those at home.

Greeks working inside Greece

According to Figure 8, the top scientists in Greece are mainly involved in Engineering and Technology, Computer Science, Medicine, Chemistry and Environmental Sciences, making up about 70% of the total top scientists that work in Greece. If we take into account the absolute number of scientists, Greece stands between 21st and 23rd in Engineering and Technology, Environmental Sciences, Computer Science and Medicine (Figure 6). The position of Greece is much higher in the technology sectors and considering the normalized ratio of scientists per population it is placed in the 14th, 16th and 18th place worldwide in the fields of Engineering and Technology, Environmental Sciences, and Computer Science, respectively (Figure 9).

Greeks working outside Greece

According to Figure 10, the aggregation of Greeks obtained by summing the data of Greece with the Greek scientists abroad

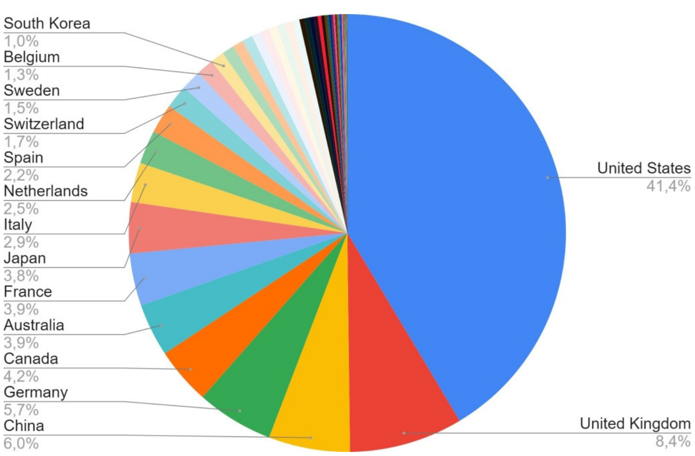

Figure 2: The Top-15 countries with at least 1% of top scientists.

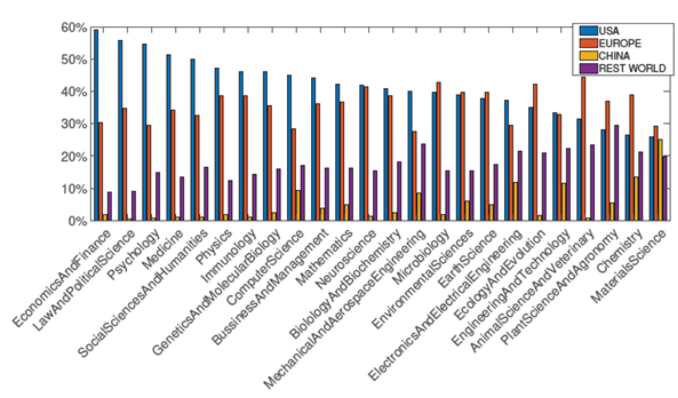

Figure 3: The rate of top scientists working in the US, Europe, China and the rest of the world.

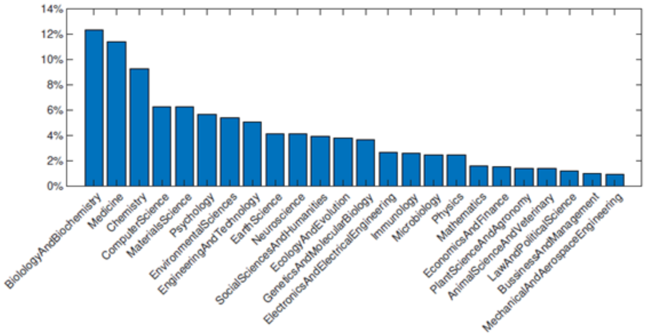

Figure 4: The rank of scientific fields worldwide, ordered by the ratio of top scientists.

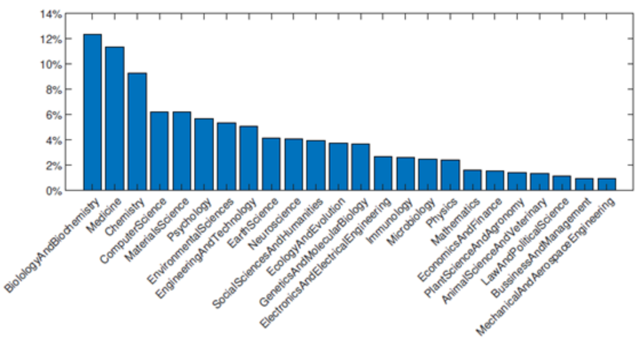

Figure 5: The scientific fields that have the most top scientists for the Top-25 countries. The x-axis represents the corresponding rate.

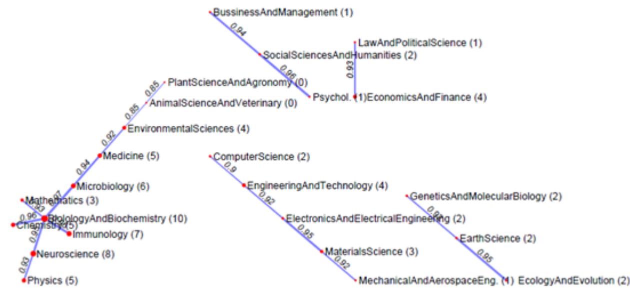

Figure 6: The similarity graph of scientific fields for the Top-25 countries. The number in parenthesis is the actual number of scientific fields that have high correlation (greater than 0.9).

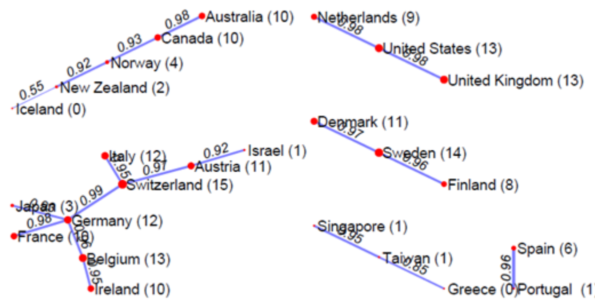

Figure 7: The similarity graph of the Top-25 countries. For each of the 25 countries, we also list the number of countries that exhibit high similarity (greater than 0.9).

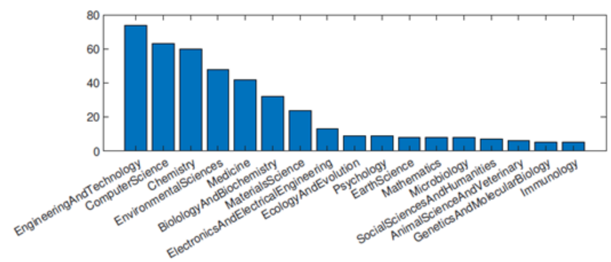

Figure 8: The absolute number of top scientists that work in Greece for each scientific area.

would place Greece in the 12th place worldwide and in the 8th place, at about 150 scientists per million population, slightly behind Canada and Belgium at about 155 top scientists per million population. If the same is performed for all nationalities then the Greeks as a nationality would probably be in the first positions worldwide, because in the first countries on the list a large number of leading scientists of other nationalities work due to the high salaries they enjoy according to Table 2.

Analyzing the ranking of countries by scientific field, the Greeks would placed in the Top-10 positions in 10 scientific fields (Figure 11). More specifically, the Greek nationality is:

- In the first place worldwide in Engineering and Technology,
- In the second place worldwide in Computer Science, Electronic and Electrical Engineering and Mechanical and Aerospace Engineering,
- In the fifth place worldwide in Mathematics,
- In the sixth place in Economics and Finance and in Physics.
- In the eighth place in Business Administration, Chemistry and Materials Science.

Figure 12 shows the total number of Greek scientists, as well as those working in Greece; the percentage of those working in Greece is shown in red. As we can observe, if we exclude Environmental sciences (in which the percentage of leading scientists that work in Greece is 55%), in all other 23 science fields, the amount of Greeks abroad outnumber the amount of Greeks working in Greece. In the following three science fields, the percentage of Greeks working abroad exceeds 90%:

- In Law and Political Science, all 9 leading Greek scientists work abroad.
- In Neuroscience, 39 out of the 41 leading Greek scientists, work abroad, which corresponds to 95%.
- In Economics and Finance, the percentage of Greeks working abroad reaches 91%.

Finally, Figure 13 depicts the GDP per capita with the Population Ratio of Scientists (PRS) for the countries with GDP per capita greater than Greece. It is impressive that Greece seems, despite

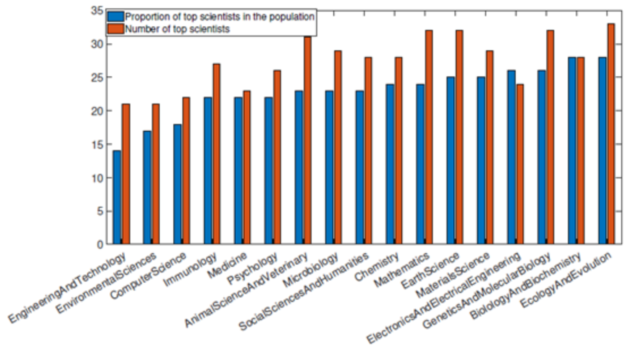

Figure 9: The position of Greece for each scientific field (showing at least 5 leading scientists), when ranked by top scientists and their proportion per 1M population.

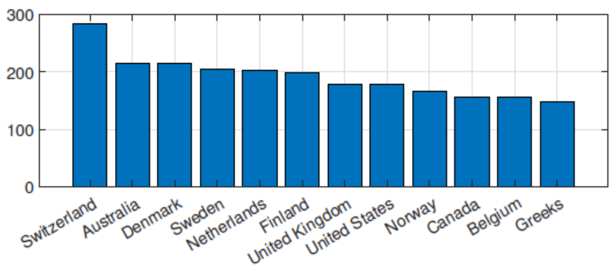

Figure 10: The countries with the highest ratios of top scientific personnel. Greece ranks in the 12th place if we consider Greeks that work abroad.

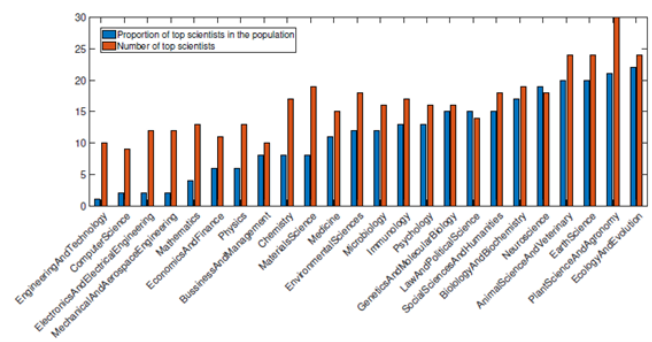

Figure 11: The position of Greeks for each scientific field, when ranked by the top scientists and the top scientists per 1M population.

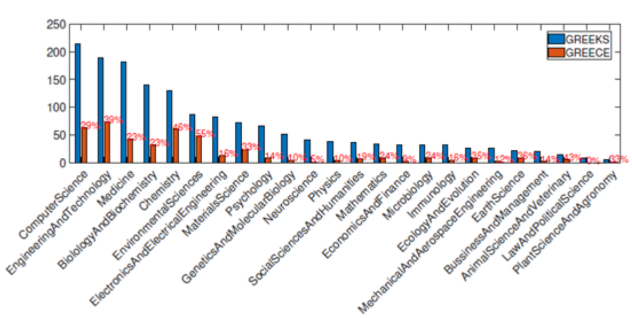

Figure 12: The number of Greeks that work in and out of Greece for each scientific field.

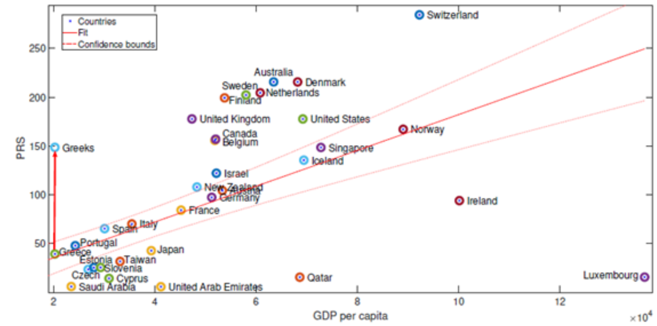

Figure 13: The correlation of GDP per capita with the population ratio of scientists.

the small economic development, to show a very high number of leading scientists, if we consider the Greeks abroad. The next country with a higher PRS than the Greeks is the United Kingdom, but with more than twice the GDP per capita.

CONCLUSION

In this paper, we analysed the distribution of leading scientists across all scientific fields and countries, taking into account typical academic metrics and demographic data of each country We focused both at a micro-level, by taking Greece as a case study, as well as at a macroscale, considering several different countries. Overall, the results show that 41.4% of scientists work in the USA, while 36.1% work in Europe. The correlation between top scientists and GDP data showed that GDP highly affects research performance. In particular, the population ratio of scientists maintains a high correlation with the GDP per capita (we calculate the Pearson linear correlation at 0.70).

We also performed a worldwide analysis and performance comparison of the countries with the most top scientists across all scientific fields. This analysis revealed many regional and continental patterns. For example, it appeared that the vast majority of top scientists (76%) are employed in US or Europe. In addition, US employ a percentage of more than 40% top scientists in 15 scientific fields. Besides that, we have also observed continental differences in terms of research portfolios. As a matter of fact, in the US the top scientists are distributed in five scientific fields (60.1% in Economics and Finance, 56% in Law and Political Science, 55.2% in Psychology, 51.9% in Medicine and 50.2% in Social Sciences and Humanities), while in Europe, the 44.7% belongs to the field of Veterinary Medicine and Animal Sciences, followed by Microbiology with 43.2%, Ecology and Evolution with 42.5% and Environmental Sciences with 40.1%. In China, Materials Science stands out with 25.3% which is very close to Europe (29.4%) and the USA (26.2%). At the granularity of countries, an analysis of the top-25 countries showed that geographically neighbouring countries are more likely to follow a similar research portfolio; the highest correlation is observed between Switzerland and Germany, followed by France and Germany, Denmark and Sweden, Switzerland and Austria, Belgium and Germany, and Spain and Portugal. Finally, our study analyzed and correlated the scientific fields that comprised with the most top scientists. It stands out that the field of "Biology and Biochemistry" gathers the most top scientists worldwide, reaching 12.3%, followed by Medicine with 11.4% and Chemistry with 9.3%. The pair of sciences with the highest correlation is "Biology and Biochemistry" with Microbiology.

As part of our future work, we plan to extend our research by analysing in-depth more countries scientometry e.g. USA, China, India, Switzerland, Germany, France, United Kingdom. This will be helpful to explore the peculiarities, as well as the resemblances that hold between different countries.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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