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Bibliometric analysis of the Czech research publications from 1994 to 2005

JIRI VANECEK

Technology Centre of the Academy of Sciences of the Czech Republic, Prague (Czech Republic)

We have compared bibliometric data of Czech research papers generated from 1994 to 2005 with papers from six other EU countries: Austria, Hungary, Poland, Finland, Ireland and Greece. The Czech Republic ranked the fifth in number of papers per thousand inhabitants and the sixth in number of citations/paper. Relatively the most cited were Czech papers from fields Engineering and Mathematics ranking the third, and Computer Science, Environment/Ecology and Molecular Biology ranking the fourth among 7 EU countries. Our analysis indicates that Czech research is lagging behind the leading EU countries, but its output is proportional to the R&D expenses.

Introduction

Research and development (R&D) in the Czech Republic receives growing support from public sources. From 1994 till 2005, the R&D funding increased more than 5 times from 106 to almost 580 million of euro. Also the funding of Czech R&D from EU sources is growing. As in most OECD countries, there is an increasing emphasis on the effectiveness of government-supported research. Systematic evaluations are therefore needed as basis for optimization of research allocations, re-orienting the research support and restructuring research in particular fields.

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Address for correspondence:
JIRI VANECEK
Technology Centre of the Academy of Sciences of the Czech Republic
Rozvojova 135, 165 02 Prague 6, Czech Republic
E-mail: vanecek@tc.cz

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R&D in the new member countries has been the centre of interest for more than 10 years. Their research and innovation system capabilities have been mapped and benchmarked at different times [RADOSEVIC, 2004; MUST, 2006]. These studies were evaluating the R&D system in all new member countries. Our evaluation has focused on the Czech Republic only, but we are analysing the Czech R&D system in a complex way and in more details. We have recently published the analysis of patents generated by the Czech inventors and compared it to patent output by selected EU countries [VANECEK, 2008]. In the present study we are analyzing bibliometric data of research papers.

The major goal of our study is to evaluate the results of the Czech research, compare them to results of other "post-communist" countries and determine, to which extend is the Czech R&D approaching to the level of "old" member countries. Both number of publication and their impact have been examined. The secondary goal has been to determine the best performing fields of research in the Czech Republic.

Methods

In order to evaluate basic research performance in the Czech Republic, we have extracted the bibliometric data of science and technology papers published from 1994 to 2005 from the Science Citation Index Expanded (SCIE) database of the Institute for Scientific Information (Thomson Scientific, Philadelphia, PA, USA). The data included the number of papers and the number of citations they have received and were obtained from the SCIE during June 2006. After careful cleaning, the bibliometric data of the papers generated in the Czech Republic were compared to papers generated in three countries of the Central European region – Austria, Hungary and Poland, and in other three small or medium sized EU countries – Finland, Ireland and Greece. The publications were assigned to each country according to the affiliation of their authors as recorded in the Web of Science database on the basis of what has been indicated in the by-line of the publication. In case of internationally co-authored papers a full count was credited to each contributing country.

The main criteria for selection of the countries for comparison was their population size. The Czech Republic has about 10 million inhabitants and for any small national economy it is impossible to be successful in all fields of R&D and has to select key areas and concentrate their effort to these priorities. Another word, small countries have (or should have) different R&D strategies than the large countries. For this reason, we have chosen countries with population equal or smaller than that of the Czech Republic. Austria, Hungary and Greece have almost the same number of inhabitants as the Czech Republic, while Finland and Ireland have even smaller population. The only exception is Poland, which has about 38 million inhabitants.

Another selection criterion has been economical status of the country and its recent history. For our comparison, we have selected some countries which share the same recent history as the Czech Republic, i.e. Hungary and Poland which are also recovering from the centrally planned socialistic economy. In contrast to these, we have included the countries which experienced uninterrupted development of free enterprise for several decades. Among these, Austria and Finland both represent the countries with high economy standards, but R&D investments are considerably higher in Finland than in Austria. Ireland is experiencing very successful economic development while Greece is lagging behind in the economical development as well as in R&D.

In the SCIE database, the journals (and the papers they contain) are classified into over 170 scientific categories. In order to make bibliometric data more comprehensible, we have grouped these categories into 20 broad fields of science according to the definitions described by Thomson Scientific in the Methods for Essential Science Indicators. Because this study was focused on science and technology, we have not included publications assigned to the fields Economics & Business or Social Sciences. As some journals are assigned to more than one field, the sum of total publications from each field may be larger than the total publication number for particular country.

Results

The highest number of science and technology papers published from 1994 to 2005 has generated Poland with 131,708 papers, followed by Austria (97,815 papers), Finland (93,581 papers), Greece (68,231 papers), Czech Republic (56,563 papers), Hungary (52,903 papers) and Ireland (38,875 papers). In comparison of the number of research papers normalized by number of inhabitants, the Czech Republic ranked the fifths among seven EU countries. Although the Czech authors increased their annual output of scientific papers from 1994 to 2005 by more than 50%, the other EU countries increased their annual output with the same rate and some even more rapidly (Figure 1). The Czech Republic is generating more papers per inhabitant than Poland and since 2002 it is also outperforming Hungary, but it is loosing up on most of other EU countries including Greece.

When the publication output was normalized by number of R&D personnel, the differences among the EU countries diminished to a large degree (Figure 2a). This indicates that productivity of R&D personnel is similar in all compared countries. Czech Republic still ranked the fifth among seven EU countries. When the number of papers was normalized by gross domestic expenditures on R&D (GERD) in each country, the ranking of the countries changed considerably (Figure 2b). Due to the lower price level, especially to the lower salaries of R&D personnel, the Poland, Hungary and Greece moved to the leading positions and the Czech Republic ranked the fourth among seven countries.

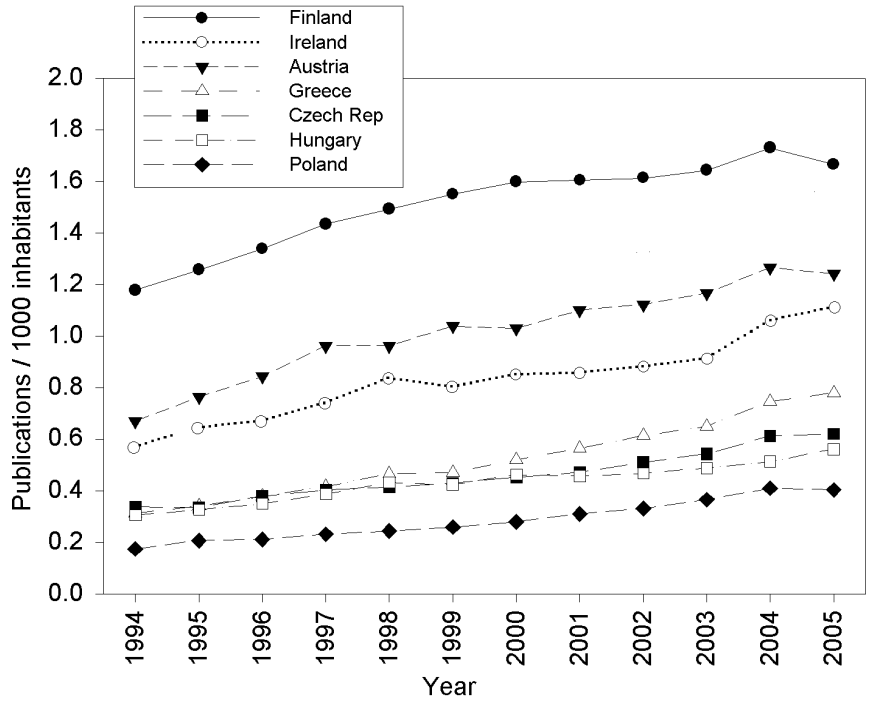

Figure 1. Evolution of annual output of research papers by 7 EU countries in the years 1994 to 2005. The papers were assigned to each country when at least one of the authors claimed his address in that country. The number of papers was normalized by the number of inhabitants of each country

Impact of publications is measured by number of citations they receive [NARIN, 1976; GARFIELD & WELLJARNS-DOROF, 1992; COLE & COLE, 1973; WADE, 1975; MARTIN, 1996]. Comparison of the total impact of all publications published from 1994 to 2005 has revealed very weak position of the Czech Republic. The highest number of citations received publications from Finland (1,084,299 citations), followed by Austria (913,723 citations), Poland (739,115 citations), Greece (403,908 citations), Hungary (368,081 citations), Ireland (341,255 citations) and the last was the Czech Republic with 328,423 citations. In average, each of the Czech publications was cited 5.8 times which ranked the Czech Republic on 6th place out of seven EU countries (Figure 3). Austrian, Irish and Hungarian publications were cited significantly more and Finnish papers were cited even two times more than the Czech ones.

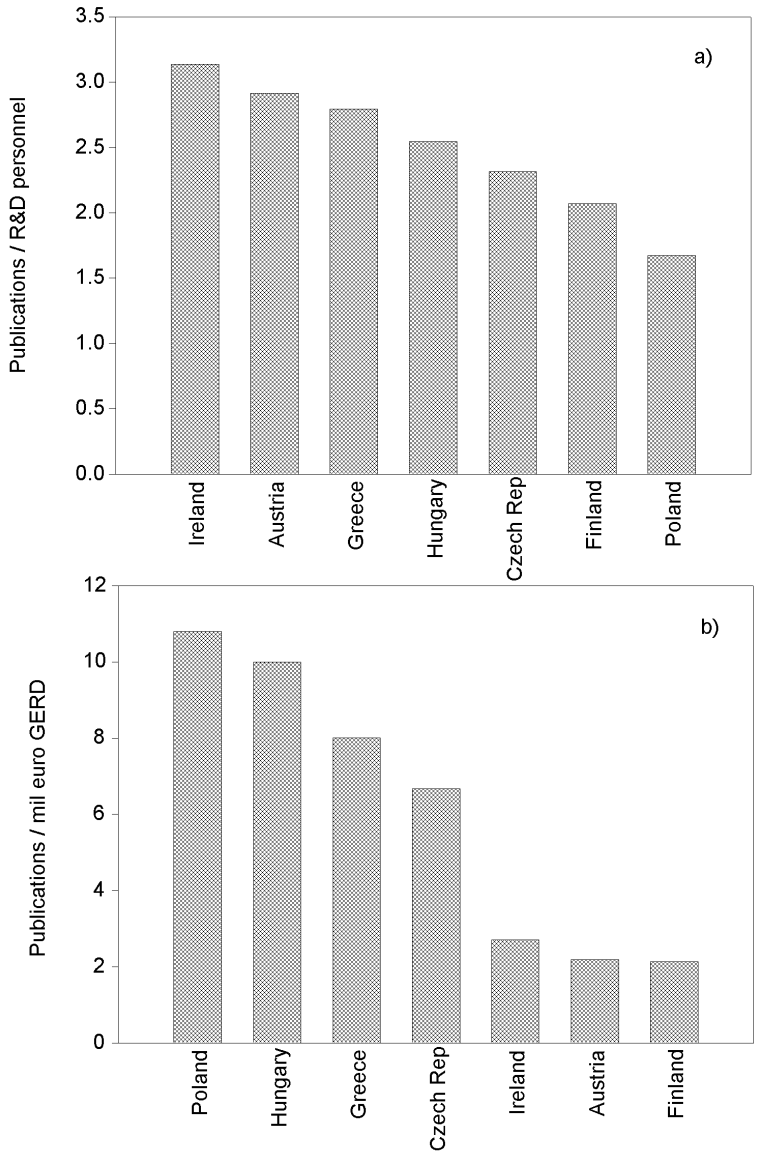

Figure 2. Comparison of number of research papers published by 7 EU countries from 1994 till 2005 normalized (a) by number of R&D personnel or (b) by gross domestic expenditures on R&D (GERD) in each country. See the legend to Figure 1 for details

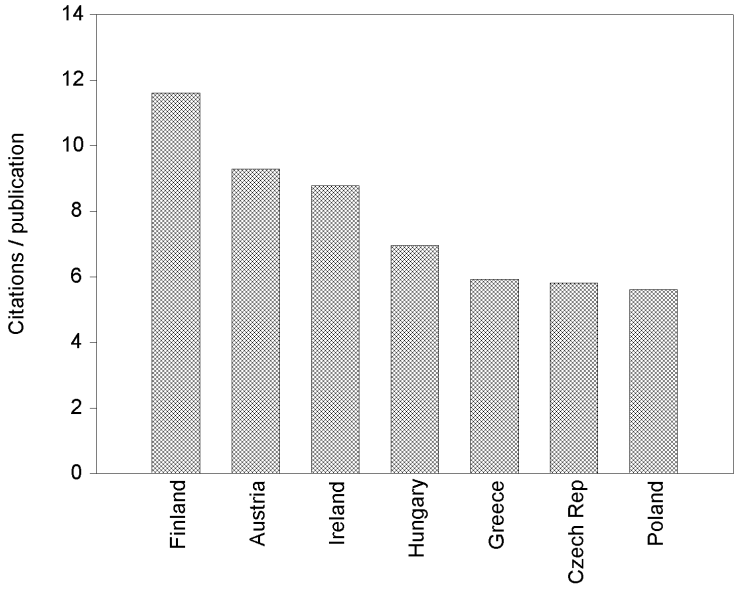

Figure 3. Average number of citations per publication in 7 EU countries. All citations from 1994 till 2005 of papers published from 1994 till 2005 were counted. See the legend to Figure 1 for details

The above data show that the Czech publications have lower impact than those of the other compared EU countries. However, the time-dependent analysis is giving somewhat more encouraging results. Citation impact of the Czech papers is gradually increasing and papers published after 2000 are cited more than those from Greece or Poland (Figure 4). However, the remaining countries in our comparison are performing much better than the Czech Republic even in the recent papers.

Various bibliometric studies reported that for specific fields and countries internationally co-authored papers tend to have higher citation rates than those published by authors from a single country [NARIN & AL., 1991; GLÄNZEL, 2001]. We have observed the same for publications of the Czech (co)authors (data not shown). Even bigger differences were observed when the papers with foreign corresponding author were analyzed (Figure 5). Among the papers of the Czech (co)authors, the most cited were papers of the corresponding authors from English speaking countries (Ireland, Scotland, England and USA) or from Portugal. These papers were 3- to 4-fold more cited than the papers with Czech corresponding address. Moreover, all papers with corresponding authors from the "more developed" countries were more cited than papers with Czech corresponding address. Because the corresponding author is usually the main person responsible for shaping the paper, this observation indicates that the foreign corresponding authors are more selective in choosing data for publication while

the Czech authors tend to publish results of lesser importance. Besides, the corresponding authors from English speaking countries may be able to publish papers in journals with higher impact partially due to their correct English.

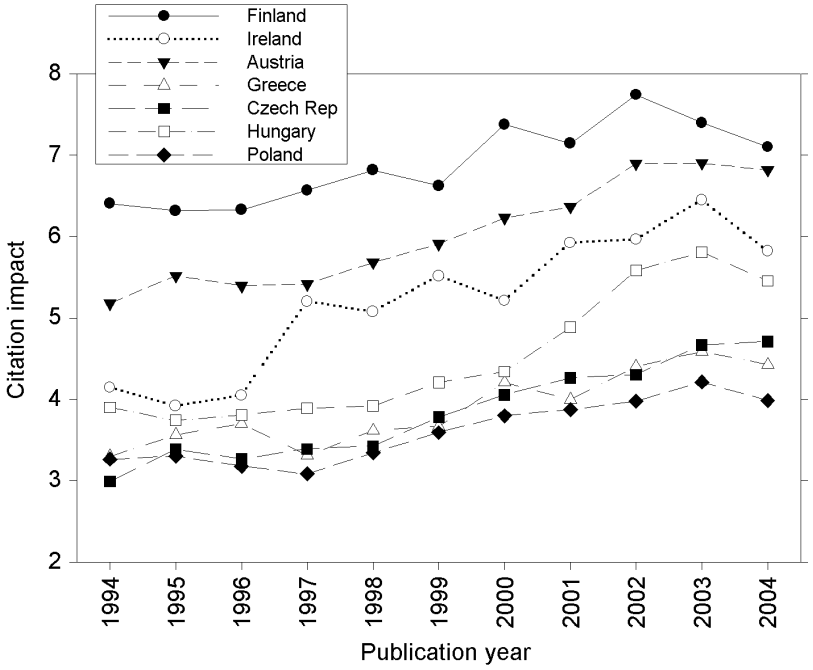

Figure 4. Evolution of the citation impact of the research papers published by 7 EU countries from 1994 to 2005. For each publication year the citations were counted for 4 years only (i.e. the year of publication and three following years). See the legends to Figure 1 for details

It is well known that citation frequency varies depending on scientific field [GLÄNZEL & SCHUBERT, 2003; PODLUBNY, 2005]. We have, therefore, determined the number of publications and the average number of citations they received for each of the 20 broad fields of science. The Czech Republic generated relatively most publications in Agricultural Sciences and Chemistry where in number of papers ranked the third among 7 EU countries, and in Materials Science, Microbiology, Physics and Plant & Animal Sciences where it ranked the fourth (Table 1). Relatively productive was the Czech Republic also in Biology & Biochemistry, Environment/Ecology, Geosciences, Immunology, Mathematics, Molecular Biology, Neuroscience, Psychiatry/Psychology and Space Sciences, where it ranked the fifths in number of papers per million inhabitants. Other fields were rather less productive.

Table 1. Number of publications from 1994 to 2005 per mil inhabitants broken by 20 broad fields of science. Comparison of 7 EU countries

	FIN	AUS	IRL	HU	GR	POL	CZ	Rank CZ
Agricultural Sciences	501	199	553	195	224	74	256	3
Biology & Biochemistry	1731	1007	765	502	407	190	491	5
Chemistry	1673	1354	946	1136	805	892	1208	3
Clinical Medicine	5567	4236	3443	835	2015	419	700	6
Computer Science	544	348	260	159	351	115	132	6
Environment/Ecology	989	310	230	110	270	92	176	5
Engineering	1141	612	700	307	700	232	279	6
Geosciences	514	363	248	96	234	66	192	5
Immunology	639	453	299	114	160	64	137	5
Materials Science	756	601	462	206	293	286	426	4
Mathematics	391	412	310	350	258	157	264	5
Microbiology	696	398	529	138	179	66	260	4
Molecular Biology & Genetics	1742	1118	795	569	384	264	463	5
Multidisciplinary	92	94	94	34	25	12	20	6
Neuroscience & Behavior	1172	695	442	339	183	111	225	5
Pharmacology	796	445	375	245	215	116	149	6
Physics	1883	1579	1034	826	901	928	1028	4
Plant & Animal Science	1183	648	609	360	293	218	447	4
Psychiatry/Psychology	793	390	599	92	138	33	95	5
Space Sciences	324	141	137	67	118	79	96	5

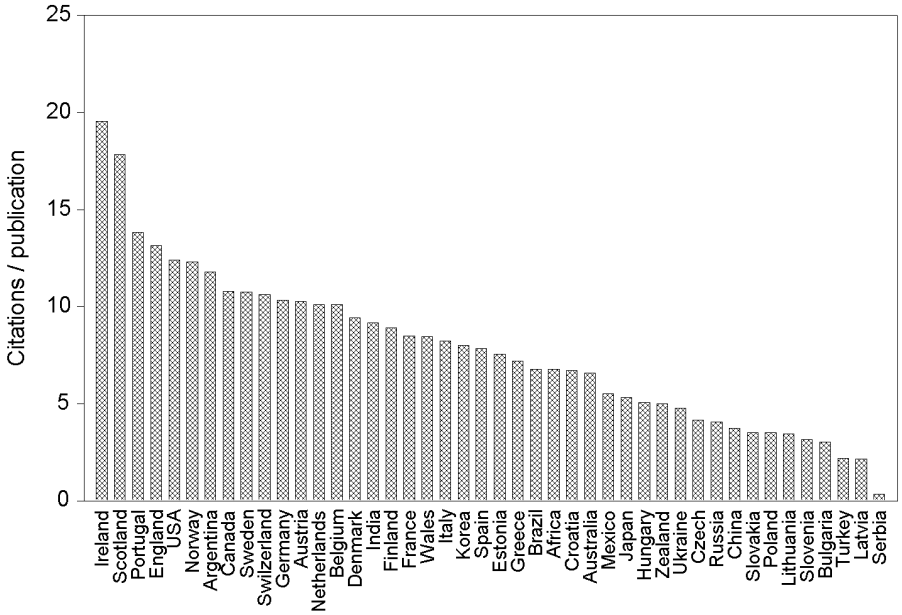

Figure 5. Number of citations per publication ranked by country of the corresponding author. All evaluated publications have at least one Czech author

It is known, that the traditional socialist profile is more specialized in Chemistry and Physics whereas Clinical Medicine is the predominant field for western countries. We have therefore examined closely the specialization trends in these fields. In the period from 1994 to 2005, the share of the Czech papers belonging to Clinical Medicine increased more than 3 times to about 18% of all S&T papers (Figure 6). However, the share of Medicine papers in western countries was more than 25%. The share of Chemistry papers in Czech publications decreased from about 25% to about 18% in 2005, while Physics stagnated around 17%. Similar changes occurred in other two post-communist countries, Hungary and Poland, while in the western countries the shares in both of these disciplines was below 15% of all publicatios.

Citation analysis of individual fields has shown, that relatively most cited were average Czech papers from Engineering and Mathematics ranking the third, and from Computer Science, Environment/Ecology and Molecular Biology ranking the fourth among 7 EU countries (Table 2). Czech papers from Chemistry, Clinical Medicine and Pharmacology ranked 5th in average number of citations and the remaining fields were doing rather poorly taking the last two positions.

Table 2. Average number of citations per paper published broken by 20 broad fields of science and 7 EU countries. Only citations to papers published from 1994 to 2005 were included

	FIN	AUS	IRL	HU	GR	POL	CZ	Rank CZ
Agricultural Sciences	7.7	5.6	7.5	2.8	4.8	3.5	2.1	7
Biology & Biochemistry	13.8	10.7	7.7	6.3	6.4	5.4	6.3	6
Chemistry	8.5	8.5	8.7	6.1	7.3	5.5	6.7	5
Clinical Medicine	13.0	8.0	7.9	6.0	5.3	5.3	5.4	5
Computer Science	5.0	4.0	2.6	4.1	2.9	2.5	3.3	4
Environment/Ecology	10.0	7.7	6.2	6.2	5.3	5.2	6.3	4
Engineering	4.5	4.5	3.5	3.8	3.3	3.4	3.8	3
Geosciences	8.0	6.5	8.8	6.3	5.8	4.6	4.9	6
Immunology	13.0	14.2	15.7	8.0	8.2	5.6	7.0	6
Materials Science	5.9	6.2	5.4	4.4	4.3	3.2	4.1	6
Mathematics	3.9	3.7	2.9	2.5	2.7	2.5	3.1	3
Microbiology	13.6	13.2	13.2	8.7	7.4	6.7	6.9	6
Molecular Biology & Genetics	17.8	17.0	17.3	9.3	9.1	7.8	9.4	4
Multidisciplinary	77.2	46.5	49.4	30.6	45.4	23.6	22.8	7
Neuroscience & Behavior	12.9	11.2	10.4	10.5	4.9	5.9	4.4	7
Pharmacology	10.0	8.7	9.3	6.7	5.4	5.9	6.5	5
Physics	9.8	10.0	7.3	8.3	7.3	6.9	6.4	7
Plant & Animal Science	7.7	6.5	5.6	5.1	4.9	3.3	4.8	6
Psychiatry/Psychology	7.3	5.5	5.6	5.4	3.1	3.8	2.6	7
Space Sciences	9.8	8.8	12.3	16.1	7.1	12.3	6.8	7

However, even inside single field of science there are enormous differences in number of citations (Figure 7). About one third of the papers analyzed in our study have not been cited at all and more than half of all papers have received less than three citations (data not shown). In most cases, less than 1% of papers received at least 10 times more citations than the average in the same field (compare Tables 2 and 3).

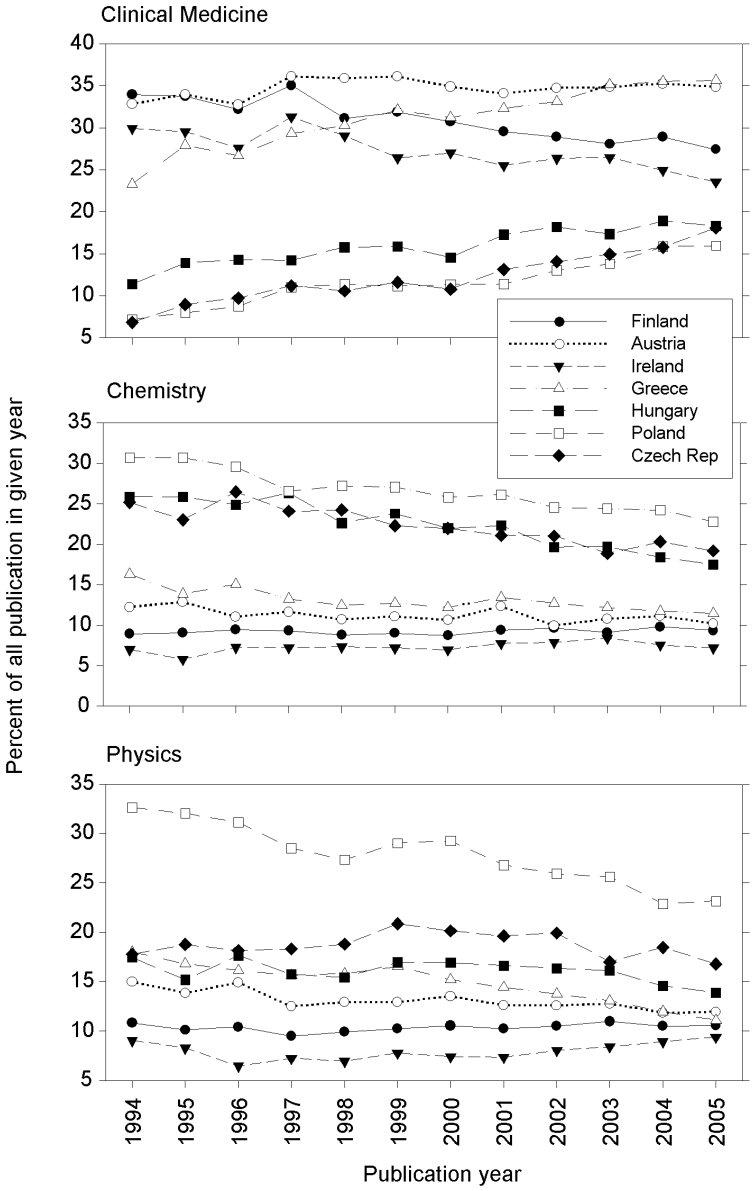

Figure 6. Changes in research specialization profile in 7 EU countries during 1994 to 2005 period. The relative share of papers belonging to each of the three selected fields (Clinical Medicine, Chemistry or Physics) were calculated as the percentage of all S&T papers published in given year in the given country. See the legends to Figure 1 for details

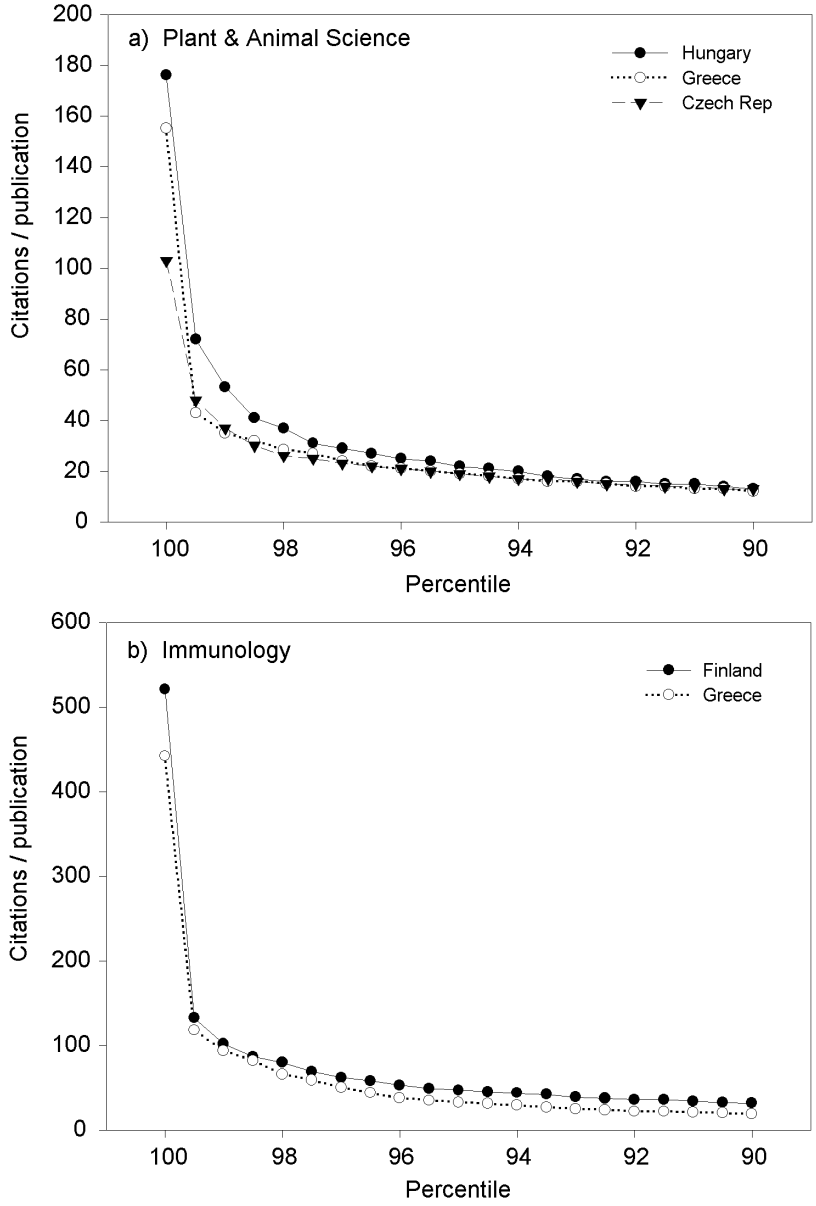

Figure 7. Distribution of citations to the leading papers published in two science fields.
a) Plant and animal science: similar average citations per publication generated by three EU countries (Hungary = 5.1, Greece = 4.9, Czech Republic = 4.8) but different number of citations of the top ranking papers. b) Immunology: different average citations/publication generated by two EU countries (Finland = 13.0, Greece = 8.2) but similar number of citations of the top ranking publications

In this respect, the citation profiles in all fields are similar. However, in some cases similar average number of citations per publication may be hiding large differences in number of citations of the leading papers (Figure 7a) or similar number of citations of the top ranking publications may still result in considerably different average citations per publication (Figure 7b). Therefore, we have analyzed the citation profiles of publications in all 20 scientific fields for all 7 EU countries. We have arbitrarily chosen citations of the 99th percentile as the representative for the top-impact publications (Table 3). As expected, this analysis gave in most fields the same rank of order for 7 EU states as comparison of citation averages. However, in some fields, the results were somewhat different. The top-impact Czech publications in Chemistry, Clinical Medicine, Immunology, Materials Science, Neuroscience and Plant & Animal Science ranked somewhat better than the average papers in the same fields (compare Tables 2 and 3). On the contrary, top Czech publications in Engineering, Geosciences, Molecular Biology and Pharmacology were doing somewhat worse than the average publications.

Table 3. Number of citations of top ranking publications broken by 20 broad fields of science and 7 EU countries. See the legend to Table 2 for the details

	FIN	AUS	IRL	HU	GR	POL	CZ	Rank CZ
Agricultural Sciences	65.2	47.0	61.0	27.1	35.7	30.0	19.7	7
Biology & Biochemistry	117.6	95.2	72.0	61.6	59.9	47.0	58.0	6
Chemistry	64.0	69.0	70.2	44.0	52.0	41.0	57.0	4
Clinical Medicine	129.0	86.0	94.5	71.1	56.5	67.0	73.0	4
Computer Science	56.0	39.2	27.2	41.7	27.0	28.0	30.0	4
Environment/Ecology	66.0	66.1	55.2	44.8	39.7	46.6	48.0	4
Engineering	38.0	39.9	32.5	35.2	29.0	32.0	35.0	4
Geosciences	59.0	51.9	62.0	53.2	49.7	44.7	36.7	7
Immunology	102.0	137.7	134.8	74.3	93.8	66.4	87.8	5
Materials Science	51.0	54.8	49.0	34.9	34.0	27.0	34.0	5
Mathematics	30.0	32.0	27.3	23.0	26.0	23.0	28.0	3
Microbiology	102.2	111.0	106.0	66.9	55.0	63.6	58.0	6
Molecular Biology & Genetics	165.1	170.3	166.9	94.7	89.4	72.6	81.4	6
Multidisciplinary	651.8	413.4	665.1	390.7	656.5	241.4	203.9	7
Neuroscience & Behavior	107.0	108.0	94.0	104.3	44.7	58.0	59.9	5
Pharmacology	80.0	69.3	81.2	59.9	51.7	49.0	51.7	6
Physics	81.8	90.0	71.6	82.0	59.3	67.0	58.4	7
Plant & Animal Science	56.0	57.0	50.5	53.1	35.0	30.0	37.0	5
Psychiatry/Psychology	80.1	59.7	63.7	68.6	39.2	50.0	34.0	7
Space Sciences	71.0	54.4	107.3	187.2	67.0	104.1	44.1	7

Inside the broad science fields were some categories where the Czech researchers generated highly cited publications. The most cited Czech papers of all 7 EU countries were generated in Spectroscopy (belonging to the field of Chemistry), Forestry and Entomology (field of Plant & Animal Sciences) and Instruments & Instrumentation (Engineering). The second most cited were the Czech papers from Mining & Mineral Processing (belonging to the field of Geosciences), Limnology (Environment/Ecology), Infectious Diseases (Immunology), Computer Science, Theory & Methods (Computer Science), and Engineering, Civil (Engineering). Above average cited papers, i.e. those

ranking in citations on third position were in categories Mathematics, Applied Mathematics and in Mathematics, Interdisciplinary Applications (all belonging to the field of Mathematics), Nuclear Physics and Particles & Fields (Physics), Remote Sensing (Space Sciences), Polymer Science and Electrochemistry (Chemistry), Water resources and Environmental Sciences (Environment/Ecology), Reproductive Biology (Biology & Biochemistry), Ornithology (Plant & Animal Sciences), Materials Science, Characterization & Testing and Coating & Films (Materials Science), Software Engineering (Computer Science), and Pediatrics and Public, Environmental & Occupational Health (all belonging to the field of Clinical Medicine). For obvious reasons, we have included in the above comparison only those categories of research which have generated in the Czech Republic at least 50 publications from1994 to 2005.

Discussion and conclusions

Most of bibliometric studies compare the output of one country with the average values in the world database. This is also the case of the annual report on the state of the Czech R&D by the RESEARCH AND DEVELOPMENT COUNCIL OF THE CZECH REPUBLIC [2005]. However, we have chosen "more personalized" approach comparing research productivity in the Czech Republic to the research in six other individual EU countries. This approach allows determining the position of the Czech research inside its own geopolitical area. To enhance direct comparison, we have mostly chosen small or medium-sized European countries. Austria and Hungary have almost the same number of inhabitants as the Czech Republic and all three countries are located in the Central Europe and have similar historical roots. However, while Austria has experienced uninterrupted development of free enterprise, Hungary and Czech Republic are recovering from the centrally planned socialistic economy. Poland, although it is 4 times bigger than the Czech Republic, has been included in the comparison, because it shares the same recent history and because is located in the same area. Remaining three countries have been included in the comparison because each of them represents certain type of economy. Finland and Ireland are smaller than Czech Republic but they both went recently through very successful economic development while Greece – although being EU member since 1981 – is lagging behind.

Although we have aimed for long-term evaluation of trends, we had to limit our analysis to research papers published from 1994 to 2005. Because the Czech Republic emerged from Czechoslovakia in 1993, it would be difficult to collect precisely the Czech papers published before this year. Even 1993 would be too early, because it has been shown that most of the authors still stated Czechoslovakia as their home country in 1993 publications [HARMANEC & AL., 1999]. As we have retrieved our data from the Web of Science during summer 2006, we could not collect any publications or citations more recent than the end of 2005.

Present study indicates that Czech research is lagging behind the leading EU countries in number of research publications as well as in the number of citations they receive. Total number of papers generated by the Czech research is increasing every year but the increase is not fast enough. The Czech Republic is therefore not closing the gap on EU-15 countries. The main reason for low number of papers may be lack of R&D personnel, because after normalization by personnel the differences between EU countries become much smaller. The cost of publication is obviously considerably lower in the post-communist countries, this being presumably due mainly to the lower salaries.

Czech papers also belong to the least cited. The average number of citations is similar as in papers generated in Greece and Poland and only slightly lower than Hungarian papers. However, Austrian and Irish papers are cited about 50% more and Finnish papers receive almost 2 times more citations. This shows that the Czech publications have lower impact than those of the leading EU countries and suggests that the Czech authors have target(s) set too low and tend to publish results of lesser importance than the foreign authors. This conclusion is further supported by the finding that within publications of the Czech (co)authors, the papers with the corresponding authors from leading countries are up to 5 times more cited than papers with Czech corresponding address.

However, the number of total citations per paper is hiding significant differences among publications engaged in various fields of science. It is well known that there are considerably different citing customs in various fields and that various countries predominate in various fields of science [GLÄNZEL & SCHUBERT, 2003; PODLUBNY, 2005]. Namely the medium-sized and small countries have to specialize as they cannot do everything on world-class level. They do not have enough resources for it, nor human nor economic. One of the main reasons for this study was the search for strong and excellent fields inside of the Czech research. There were only two broad fields where the Czech Republic ranked better-than-average (i.e. the third or better out of seven countries) in number of publications – the Agricultural Sciences and Chemistry. However, because the papers from Agricultural Sciences were the least cited from all seven countries, we can hardly speak of "strong field". The citation impact of Chemistry papers was relatively higher, but it neither could be regarded as excellent. Above average broad fields in citations per paper were Mathematics and Engineering where the Czech Republic ranked the third out of seven countries. The Czech research scored best in few narrow categories within the broad research fields as Spectroscopy, Forestry, Entomology and Instruments & Instrumentation where it ranked the first out of seven countries or in Mining & Mineral Processing, Limnology, Infectious Diseases, Computer Science, Theory & Methods and Civil Engineering where the Czech papers were the second most cited.

However, average number of citations does not reveal the top-impact papers which significantly shape the progress in given field or discipline. Measure of impact is number of citations the paper receives. About one third of the papers analyzed in our study have not been cited at all and more than half of them received less than three citations. These papers have very small chance to influence the development of the field. On the opposite side there are papers cited at least 10 times more than the average paper in the given field, which make less than 1 percent of publications. These papers with high impact have obviously the greatest chance to shape the advancement of the science field. In the search for excellent research, we have therefore tried to compare this highest impact papers from each country. We have voluntarily chosen the number of citation received by the 99th percentile of papers as the criterion. In most fields, this approach brought the same results as comparison of average number of citations. However, in some cases the analysis of top papers revealed few additional excellent fields with high-impact publications of Czech authors.

In conclusion, the Czech basic research is not very productive as far as number of papers or their impact is concerned. Even worse is, that regardless of the growing support of the Czech R&D the analysis of the trends does not show signs of narrowing the gap between the Czech Republic and the western countries in either of the above mentioned parameters. Among the main reasons of this situation may be the low number of the researchers and their low salaries. Both these attributes are remnants of the socialist era and have not been solved by the democratic governments yet. Slow rate of improvement may be also due to the unsufficient impact of the evaluation of past R&D projects on future financing of new projects. However, this is also relic of the socialist era when research results have not been regularly evaluated not mentioning the effect of the evaluation on funding of new projects.

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