Progress in Estonian science viewed through bibliometric indicators (2004–2014)

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Abstract. This supplementary information provides more detailed picture about the progress of the Estonian and its neighbours’ sciences viewed through the analysis of bibliometric indicators provided by the *Essential Science Indicators* (*ESI*; Thomson Reuters) database for the period from 2004 to 2014. Evaluated by the *High Quality Science Index* (*HQSI*), which combines the mean citation rate of published papers and the percentage of articles that reaches the top 1% citation rate, Estonia occupies the 16th position in the *ESI* ranking of 86 countries or territories which were able to publish more than 4,000 papers during the 11 years long observation period. The highest quality of science is done in Iceland and Switzerland. Estonia occupies a similar position with Germany and France. The impact of papers authored by Estonian scientists has grown rapidly and for the first time average citation per paper exceeds *ESI’s* mean citation rate by 5%. The main driving force behind the growth of Estonian scientific excellence are biological sciences. Two third out of 42 scientists, affiliated with one of Estonian institutions, who have reached the top 1% of total citations in one of research fields, are biologists or ecologists. It is argued that the success of Estonian basic science during the last 11 years is, partly at least, because scientific assessment and decision-making has preserved its sovereignty and experienced relatively few interventions from non-scientific authorities.

Previous analyses have witnessed a significant progress of Estonian science during the first few decades after liberation from the Soviet occupation (Allik, 2003, 2008, 2013). Estonian scientists had achieved the highest impact – measured in terms of citations per paper – (7.87) compared to all other former Communist bloc countries including Hungary (7.83), Latvia (5.92), Lithuania (4.95), and Russia (3.98) sixteen years after liberation in 2007. Analysis also demonstrated that because science funding policies were quite different in three Baltic States their scientific performances diverged substantially. In the period of 1990-2007, Estonian and Lithuanian scientists more than tripled the number of articles they published in journals indexed by the Thomson Reuters’ *Web of Science* (Allik, 2008). However, the number of articles from Latvia during the same period had decreased relative to the general increase of published articles in the world. While Latvia failed to increase the productivity and Lithuania to improve the quality of their scientific publications, Estonia succeeded in reducing the gap both in the productivity and impact of its publications as compared to the world leading countries. Nevertheless, the three Baltic states were far ahead of their Eastern neighbour Russia whose science has stagnated approximately on the same level as it was at the moment of disintegration of the Soviet Union (Markusova, Ivanov, & Varshavskii, 2009; Markusova, Jansz, Libkind, Libkind, & Varshavsky, 2009; Wilson & Markusova, 2004).

In spite of an impressive progress, the impact of the articles published by Estonian scientists was still 17.2% below the *Essential Science Indicators* (*ESI*) average by the year 2007 (Allik, 2008). Because *ESI* selects countries, institutions, journals, and scientists based on their citations records, the average here does not mean mediocre. To be included in the *ESI*, means a large number highly cited papers which is a privilege of scientifically most advanced nations. Scandinavian countries, which have served as a role model for the Baltic states ever since their re-independence (if not earlier), not only for science, were still far ahead and still out of a reachable distance. In order to close the gap with the world leading countries it was necessary that the impact of Estonian papers grow faster than the world average and especially the impact of those countries who were ahead of Estonia in terms of scientific quality. This paper provides an observation of the further progress of Estonian in comparison to other countries since the previous survey for the period 1997-2007 (Allik, 2008).

Thus, the purpose of this paper is to examine the performance of Estonian science eight years after the previous analysis was conducted (Allik, 2008) covering again a 11-year period from 2004 to 2014. This period also includes many important changes. For example, Estonia joined both the European Union and NATO in 2004. Estonia joined the euro area on 1 January 2011. In 2000–2008, Estonia's economy saw an average growth of 7% per year, which placed Estonia among one of the fastest growing economies in Europe. However, in the autumn 2008 the economic crisis stroked resulting with 14.1% the overall decrease in GDP growth rate in the next year. Economic growth turned again positive in the beginning of 2010 and the annual GDP grew by 2.6% compared to the previous year. However, in spite of a modest economic growth during the last years, the budget for the basic research in Estonia has remained on the pre-crisis level. If we take into account inflation then there has been 10-20% less money for the basic research than in 2008.[1] We do not possess information how all these events have affected Estonian science. My goal is to analyse performance of Estonian science during the latest available 11 years from 2004 to 2014 seen through bibliometric indicators.

METHODS

The analysis is based on the latest release of the *Essential Science Indicators* or *ESI* accessed through the Library of the University of Tartu. During the course of a year, the data series presented in *ESI* covers 10 years plus a successive number of recent two-month periods, eventually reaching an 11-year time span. At the end of the year, the compilation reverts to a 10-year data set, dropping off the oldest year of the series. The analysis used *ESI* data, which was updated on March 5, 2015 to cover an 11-year period from January 1, 2004 to December 31, 2014.

During this 11-year period *ESI* recorded about 9.4 million articles, notes, and reviews, published in roughly 11,000 indexed journals (http://archive.sciencewatch.com/about/met/.) *ESI* categorizes these journals into 22 broad disciplines. Each journal is assigned to one of the 22 disciplines. Humanities are not included in any of these 22 broad disciplines and therefore, not included in the subsequent analysis. In the case of multidisciplinary journals, special processing is carried out to assign individual papers to fields based on the predominate field of the papers' citations and references. The total number of citations received by these 9.4 million indexed items is about 85 million.

ESI identifies the "essential core" of journal articles, scientists, institutions, countries, and journals from this large data corpus by setting selection criteria (a certain number of citations) for each of the disciplines. These thresholds are set to select some constant fraction of items. For example, for highly cited papers, *ESI* selects the top 1% of articles by total citations in each annual cohort from each of the 22 disciplines. Of the roughly 4 million scientists' names appearing in the 11 years of *WoS* data surveyed, about 60,000 are listed in *ESI*. This represents the top 1% of authors in terms of total citations in each of the disciplines over the 11 years. Each scientist name that have passed the top 1% threshold appears, on average, in 1.3 disciplines. Because there is no effective algorithm to separate non-unique names, some of those who are listed in *ESI* are in fact composite of several scientists with identical names. About 700,000 institutional affiliations were scanned in the 11-year data file, and about 4,000 of these were selected for *Essential Science Indicators*, also representing the top 1% in each discipline (unification of institutional names is undertaken to obtain more accurate statistics). Each of the selected institutions appears, on average, in 3.1 disciplines.

For countries and territories, about 150 were selected out of about 200 registered, and for journals about 5,000 of the 10,000 (constituting what is called *Core Collection*), both representing the top 50% by discipline and total citations over the 10-year period.

ESI is limited to the journal articles indexed in the *WoS* only. No books, book chapters, or articles published in journals not indexed by the *WoS* are taken into account in *ESI*, either in terms of publication or citation counts.

RESULTS

Scientific productivity from 1990 to 2014

In the previous report (Allik, 2008), productivity of scientists in three Baltic countries were reported for the first 16 years of independence 1991-2007 (see Figure 1). It is interesting to see what has happened to the productivity of Estonian, Latvian, and Lithuanian scientists after 2007.

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[1] http://pluss.postimees.ee/2998407/urmas-varblane-eesti-mudaliiga-ja-korgliiga-vahel

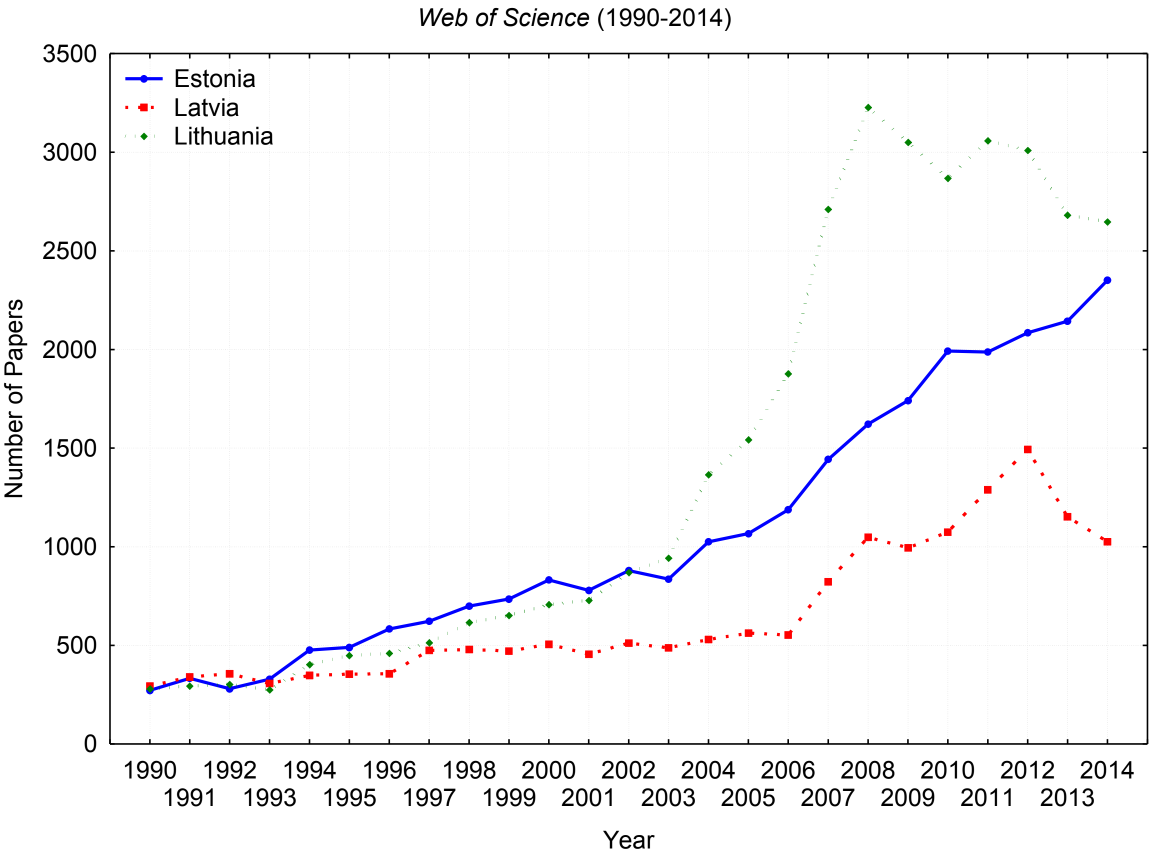

Fig. 1. Total number of publications in the *Web of Science* (*Core Collection*) database authored by Estonian, Latvian, and Lithuanian scientists.

Figure 1 demonstrates the total number of publications in the *WoS Core Collection* databases authored by Estonian, Latvian, and Lithuanian scientists. The content of these absolute numbers is not transparent because the total number of publications indexed by the *Core Collection* was increased from about 1.9 million in 2007 to about 2.2 million in 2014. The number of papers authored by Latvian and Lithuanian researchers has slightly declined during the last couple of years. A further analysis is needed to establish what is behind these small fluctuations. It seems that on a large scale the scientific productivity in all three Baltic States has approaching a level of saturation. If anything certain then it is that differences in productivity between Baltic States have slightly diminished. Another conclusion is that the absolute numbers of published papers tell us relatively little about the quality of science behind these papers.

Ranking of countries by their scientific quality (2004-2014)

Table 1 presents ranking of countries or territories based on bibliometric indicators. The number of published papers, citations, and the number of citations per paper are shown in the first three data columns. Traditionally, *ESI* presents statistics separately for the constituents of the Great Britain – England, Scotland, Wales and Northern Ireland. In the Table 1 these four separate entities were summed together representing the Great Britain. Because the same papers can be counted twice or more times dependent the authors' affiliations with different parts of the Great Britain, the summed values are inflated.

The fourth column demonstrates increase in the citation per paper relative to 2007 (Allik, 2008). The fifth column ("Percentage of highly cited papers") show the proportion of papers from each country which have reached the top 1% of articles by total citations in each annual cohort from each of the 22 disciplines. The absolute number of these papers can be easily found. For example, Estonian researchers published 13,297 papers from which 258 or 1.94% reached the top 1% by the number of citations.

As it is argued in one of the recent papers, the percentage of highly cited papers is a good indicator of scientific quality (Allik, 2013). For example, it could be demonstrated that if scientists of one country produce relatively small number of highly influential papers (compared with the mean impact of its published papers) then they are of moderate quality. It is obvious that only a combination several indicators could achieve sufficient reliability (van Leeuwen, Visser, Moed, Nederhof, & van Raan, 2003; Wagner & Leydesdorff, 2012). Because correlation between the number of citation per paper (the 3rd column) and the percentage of highly cited paper (the 5th column) were sufficiently high (r=.82, p < .00001) we can combine these two indicators into a composite measure – the *High Quality of Science Index* (*HQSI*). Before summation, the number of citations per paper and the percentage of highly cited papers were separately transformed according to the following formula: (X-M)/SD where M is the mean value of all X-s either citations per paper or the percentage of highly cited papers and SD is their standard deviation. Thus, to compute *HQSI* the both components were first normalized (the mean of the transformed values equals to zero and standard deviation equals to one) and then their mean was found (see the last column in Table 1). Countries and territories are ranked according to *HQSI*.

Table 1. Main bibliometric indicators of 86 countries ranked according the High Quality of Science Index. Only countries and territories are listed, which have published more than 4,000 papers indexed in ESI during the period 2004-2014

Rank	Country	Papers	Citations	Citations Per Paper	Increase 2007-2014 (%)	Percentage of highly cited papers	High Quality Science Index
1	ICELAND	7,625	148,551	19.48	50.2	3.08	2.90
2	SWITZERLAND	236,443	4,575,219	19.35	30.3	2.52	2.40
3	DENMARK	130,038	2,304,081	17.72	31.4	2.30	1.99
4	NETHERLANDS	328,008	5,920,452	18.05	34.8	2.23	1.97
5	USA	3,652,510	63,537,290	17.40	22.8	1.84	1.55
6	SWEDEN	219,516	3,627,388	16.52	30.0	1.91	1.50
7	BELGIUM	180,153	2,911,238	16.16	41.5	1.94	1.48
8	PERU	6,416	83,066	12.95	61.0	2.34	1.39
9	AUSTRIA	122,686	1,859,794	15.16	40.8	1.82	1.24
10	SINGAPORE	94,832	1,281,462	13.51	110.5	2.05	1.22
11	IRELAND	65,000	932,156	14.34	44.3	1.82	1.13
12	CANADA	575,899	8,754,572	15.20	31.3	1.67	1.12
13	NORWAY	99,241	1,438,442	14.49	35.0	1.73	1.07
14	FINLAND	108,892	1,645,728	15.11	25.7	1.63	1.07
15	GERMANY	950,932	14,573,151	15.33	37.0	1.60	1.07
16	ESTONIA	13,297	161,886	12.17	54.7	1.94	0.95
17	AUSTRALIA	425,004	5,821,629	13.70	34.3	1.69	0.93
18	FRANCE	673,460	9,732,498	14.45	35.7	1.49	0.85
19	GEORGIA	4,593	42,819	9.32	105.3	2.24	0.83
20	KENYA	10,981	138,480	12.61	47.3	1.74	0.83
21	ISRAEL	128,908	1,869,213	14.50	34.3	1.44	0.82
22	NEW ZEALAND	75,608	978,997	12.95	41.7	1.53	0.69
23	UGANDA	5,952	73,404	12.33	37.9	1.61	0.68
24	ITALY	553,773	7,625,504	13.77	37.0	1.36	0.65
25	PHILIPPINES	8,381	93,353	11.14	50.7	1.75	0.65
26	ARMENIA	6,113	59,917	9.80	65.8	1.95	0.64
27	GREAT BRITAIN	991,276	15,096,368	15.23	39.5	1.01	0.54

28	TANZANIA	5,895	71,838	12.19	70.9	1.42	0.50
29	SPAIN	466,916	5,792,507	12.41	42.9	1.31	0.43
30	COSTA RICA	4,257	54,803	12.87	46.5	1.22	0.41
31	HUNGARY	61,262	713,108	11.64	48.7	1.19	0.23
32	GREECE	106,835	1,215,302	11.38	74.7	1.17	0.17
33	CYPRUS	6,782	60,486	8.92	51.4	1.52	0.15
34	LUXEMBOURG	5,452	54,801	10.05	41.6	1.34	0.14
35	PORTUGAL	97,861	1,086,445	11.10	56.4	1.16	0.13
36	SOUTH AFRICA	80,542	808,600	10.04	51.7	1.25	0.06
37	URUGUAY	6,700	72,041	10.75	35.8	0.94	-0.11
38	JAPAN	842,873	9,835,789	11.67	31.9	0.79	-0.12
39	CZECH REP.	93,448	920,763	9.85	57.1	1.04	-0.14
40	INDONESIA	10,855	97,634	8.99	40.1	1.14	-0.17
41	LATVIA	5,024	41,805	8.32	40.6	1.21	-0.19
42	CHILE	50,696	494,165	9.75	29.8	0.95	-0.23
43	SRI LANKA	4,651	40,126	8.63	62.2	1.12	-0.24
44	QATAR	4,459	26,409	5.92	157.5	1.48	-0.28
45	GHANA	4,512	41,615	9.22	65.0	0.95	-0.30
46	ARGENTINA	75,215	738,384	9.82	47.2	0.85	-0.31
47	COLOMBIA	24,300	192,395	7.92	29.2	1.14	-0.31
48	THAILAND	51,635	492,058	9.53	66.6	0.84	-0.36
49	SAUDI ARABIA	46,509	253,527	5.45	43.5	1.44	-0.38
50	SLOVENIA	33,211	292,274	8.80	56.3	0.90	-0.40
51	LEBANON	7,950	65,178	8.20	63.3	0.97	-0.42
52	CHINA	1,496,549	11,962,020	7.99	89.4	0.95	-0.47
53	VIETNAM	13,480	99,006	7.34	28.0	1.02	-0.49
54	SOUTH KOREA	417,597	3,607,771	8.64	57.9	0.79	-0.52
55	MEXICO	101,391	847,354	8.36	44.1	0.74	-0.60
56	BULGARIA	23,029	189,131	8.21	59.2	0.74	-0.62
57	TAIWAN	246,831	2,179,052	8.83	59.1	0.65	-0.62
58	CROATIA	31,134	229,688	7.38	60.0	0.86	-0.63
59	SLOVAKIA	30,201	245,366	8.12	55.6	0.71	-0.66
60	BANGLADESH	10,364	77,952	7.52	56.0	0.79	-0.67
61	POLAND	206,617	1,599,609	7.74	36.3	0.71	-0.71
62	UN. ARAB EMIR.	10,505	72,625	6.91	82.9	0.82	-0.72
63	VENEZUELA	12,313	102,017	8.29	48.0	0.59	-0.74
64	BELARUS	11,203	70,834	6.32	83.8	0.88	-0.74
65	LITHUANIA	18,186	115,875	6.37	28.7	0.86	-0.76
66	JORDAN	10,365	64,421	6.22	98.6	0.88	-0.76
67	ETHIOPIA	5,929	41,047	6.92	43.3	0.73	-0.80
68	CUBA	8,390	63,241	7.54	59.0	0.61	-0.82
69	PAKISTAN	41,760	232,384	5.56	54.6	0.86	-0.87
70	MALAYSIA	56,571	304,068	5.37	35.7	0.86	-0.89

71	CAMEROON	5,580	42,347	7.59	35.0	0.52	-0.89
72	INDIA	429,760	3,138,659	7.30	67.9	0.53	-0.92
73	BRAZIL	318,813	2,328,220	7.30	33.3	0.51	-0.94
74	OMAN	4,304	27,276	6.34	79.0	0.65	-0.94
75	SERBIA	33,550	164,615	4.91	7.6	0.87	-0.94
76	MOROCCO	14,121	90,987	6.44	64.8	0.61	-0.97
77	ROMANIA	59,827	322,372	5.39	31.7	0.71	-1.02
78	TURKEY	221,558	1,429,125	6.45	70.2	0.54	-1.03
79	EGYPT	57,317	358,546	6.26	62.9	0.50	-1.08
80	KUWAIT	6,857	44,962	6.56	65.2	0.42	-1.11
81	IRAN	163,688	904,017	5.52	69.4	0.56	-1.13
82	RUSSIA	297,770	1,707,661	5.73	44.1	0.44	-1.21
83	UKRAINE	50,617	262,045	5.18	58.3	0.47	-1.26
84	TUNISIA	24,577	138,085	5.62	77.8	0.38	-1.27
85	NIGERIA	17,676	95,457	5.40	73.1	0.41	-1.27
86	ALGERIA	16,316	84,392	5.17	65.3	0.33	-1.38

There were 86 countries or territories out of about 150 listed in *ESI*, which published more than 4,000 papers in about 11,000 indexed journals.[2] Expectedly, scientist working in the United States published the largest number of scientific papers (more than 3.6 million) that also collected the largest number of citations (over 63 million). Each paper authored by the US scientists was cited 17.4 times on average. The second largest science in the World – China – published nearly 1.5 million papers, which were cited only 8 times per paper on average. However, papers with the highest impact were written and published by scientists working in Iceland and Switzerland. Each of their papers was cited over 19 times and about 3% of papers reached the top 1% by the total citations. Russia continued its decline from a World scientific superpower to a category of ineffectiveness.

Perhaps the most remarkable is that the number of papers published during the last 11 years (297,770) by Russian scientists was less than the number of papers published by Dutch scientists (328,008). To say nothing about more than three times higher citation rate of each published paper. Finding all Scandinavian countries on the top of the ranking is also not surprising.

It seems that the Nordic model of capitalism – free trade combined with a welfare state, individual autonomy, and basic human rights – need to be supplemented with an additional ingredient, which is high quality of science.

Estonian science occupies the 27th position in the impact (citations per paper) ranking. Every paper authored by at least one Estonian scientist was cited 12.17 times which is larger than on average (11.59). For a comparison, Latvian papers were cited 8.32 and Lithuanian papers 6.37 times. However, in the ranking by *HQSI* Estonia holds the 16th position just behind Germany and ahead of Australia and France. Latvia occupies the 41st position and Lithuania the 65th position in the HQSI world ranking. On the very bottom of the list is Russia holding the 82nd position in the company of Iran and Ukraine.

The growth of scientific impact

One important indicator is the growth rate of citations per paper. As a baseline, the world average citation rate was 9.50 for the period 1997-2007 (Allik, 2008). Eight years later, the average citation rate was 11.59 for the period of 2004-2014, which is 22% increase relative to the previous observation period. In comparison, the impact of Estonian papers has increased 54.7%. Figure 2 demonstrates that Estonian papers were cited 17.5% less than an average paper in the world for the period 1997-2007. However, for the period 2004-2014 an Estonian paper is cited 5% more than the world average. If this growth rate will continue it will be only a matter of time to close the gap that still exists between Estonia and, for instance, Scandinavian countries.

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[2] Without the threshold of 4,000 papers, the highest impact papers were published by scientists working in Bermuda which is a British Overseas Territory. Approximately 300 papers were cited more than 8,000 times. However, it makes no sense to include Panama, Vatican, Seychelles, and Monaco, just to give few examples, as important centers of international science. With more than 3,000 papers were Azerbaijan, Iraq, Kazakhstan, Uzbekistan, Ecuador, Nepal, Bosnia and Herzegovina, and Senegal.

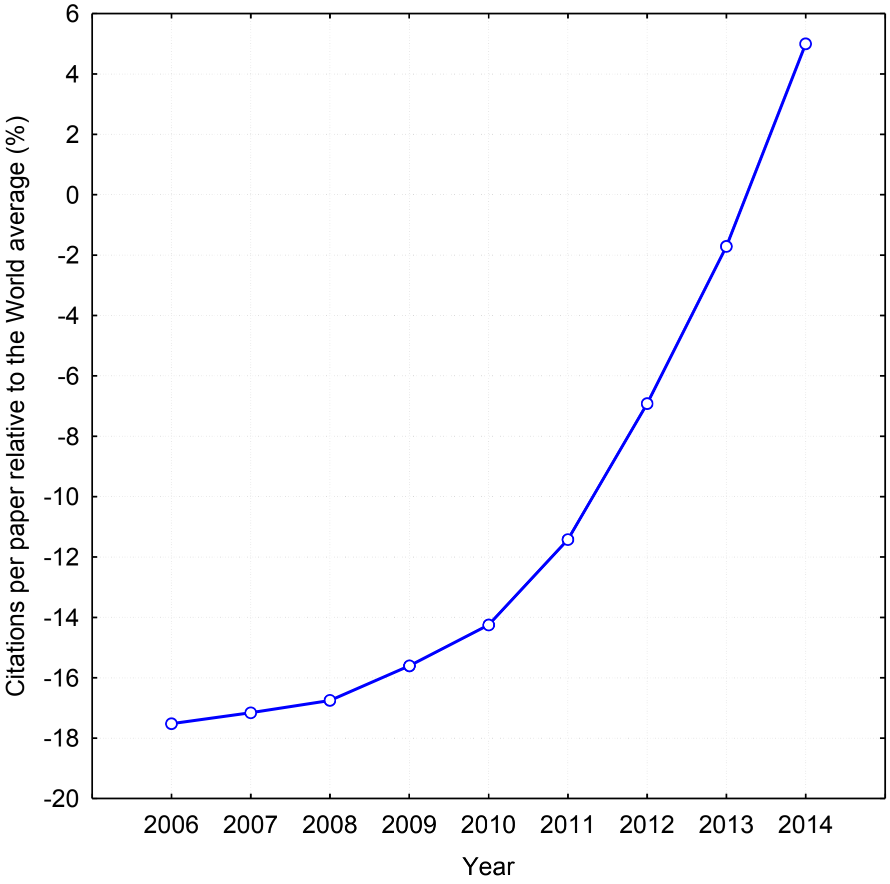

Fig. 2. The impact of Estonian papers relative to the *ESI*'s average.

Who is behind the growth of Estonian science?

The next task is to understand which fields are behind not only quantitative but also qualitative growth of Estonian science. Table 2 lists all 22 fields of Estonian science in their ranking order to the world citation rate (the last column). First three columns show number of papers, citations, and citations per paper in each field. In the 4th column "C/P relative to 2007 (%)" the increase of the field impact relative to 2007 is shown. The 5th column "Percentage of highly cited papers (%)" demonstrates how many papers out of papers shown in the first column have reached the top 1% citation rate in the respective year cohort.

Please note that Estonia passed the threshold established for countries or territories in all 22 fields of science. It is not common that countries succeed in all areas of research. For example, Latvia did not pass the established threshold in three fields: Agricultural sciences, Mathematics, and Space Science. It is almost self-evident that "traditional" biology is a driving force of the scientific excellence in Estonian science. Each Estonian paper published in Environment/Ecology and Plant & Animal Science receives about 40% more citations than papers in these fields in general. In addition to these two fields, Clinical Medicine, Molecular Biology and Genetics, Physics, Pharmacology & Toxicology, and Psychiatry/Psychology are also above the world average. The fastest growth rate of impact was in the Computer Science in which the impact of papers increased more than 200%.

Material science in Estonia is a puzzle. In 2007 the mean citation rate of papers published by Estonian material scientists was 43.5% above the World average in this field. This was the most successful field of Estonian science. However, for the period 2004-2014 the average citation rate per paper was dropped to minus 26% below the World average. There are several possible factors contributing to this rather significant decline. Without a detailed analysis one can only speculate about reasons of the drop in visibility. One can notice, for example, that the leaders in this field (Jaan

Aarik, Kaupo Kukli, Väino Sammelselg and some others) were in the top 1% in 2007 but now they are slightly below the top 1% threshold line. It is also possible that a paradigmatic shift has happened and the main players have moved to another research problems. In any case, it is interesting case to analyse how a particular field can rise and decline during a relatively short period.

Table 2. Performance of different fields of Estonian science during 2004-2014

Field	Papers	Citations	Cit/Papers (C/P)	C/P relative to 2007 (%)	Percentage of highly cited papers (%)	Relative to World (%)
Environment/Ecology	1,058	18,502	17.49	74.20	3.02	40.48
Plant & Animal Science	1,371	16,883	12.31	82.91	2.41	39.41
Clinical Medicine	1,235	21,556	17.45	89.06	3.32	35.48
Molecular Biology & Genetics	520	16,500	31.73	40.52	5.00	23.95
Physics	1,452	17,874	12.31	123.41	3.86	16.79
Pharmacology & Toxicology	194	2,580	13.3	26.55	3.09	5.47
Psychiatry/Psychology	344	4,292	12.48	118.18	1.74	2.63
Microbiology	191	2,851	14.93	37.35	0.52	-3.43
Neuroscience & Behavior	394	6,232	15.82	24.37	1.52	-12.35
Chemistry	1,238	13,634	11.01	29.23	0.40	-13.10
Biology & Biochemistry	629	9,138	14.53	15.41	1.27	-13.67
Computer Science	189	851	4.5	246.15	0.53	-14.77
Agricultural Sciences	303	2,011	6.64	49.89	1.65	-15.74
Mathematics	291	971	3.34	62.14	0.34	-16.50
Engineering	505	2,445	4.84	60.80	1.98	-17.97
Immunology	233	3,681	15.8	45.89	0.86	-19.88
Geosciences	1,070	9,413	8.8	79.96	0.84	-21.01
Materials Science	530	3,691	6.96	-5.82	0.19	-25.96
Space Science	218	2,501	11.47	31.69	0.46	-32.37
Social Sciences general	1,072	4,397	4.1	50.74	0.56	-35.02
Multidisciplinary	46	1,005	21.85	223.70	0.00	-36.90
Economics & Business	214	878	4.1	-	0.93	-43.91
All Fields	*13,297*	*161,886*	*12.17*	*54.64*	*1.94*	*5.00*

Ranking of institutions

Only four Estonian institutions – University of Tartu, Estonian University of Life Sciences, National Institute of Health Development, and National Institute of Chemical Physics and Biophysics – were able to join approximately 4,000 leading institutions representing the top 1% in one discipline at least. Table 3 demonstrates that University of Tartu has reached the top 1% in 9 different disciplines, Estonian University of Life Sciences in two, and both the National Institute of Health Development and National Institute of Chemical Physics and Biophysics in one.

Table 3. Estonian institution reaching the top 1% in various disciplines

Rank	Field	Papers	Citations	C/P	C/P relative to World (%)
	University of Tartu				
1	Molecular Biology & Genetics	423	14,157	33.47	168.84
2	Plant & Animal Science	785	11,304	14.4	63.08
3	Psychiatry/Psychology	268	3,674	13.71	12.75
4	Clinical Medicine	849	10,465	12.33	-4.27
5	Chemistry	760	8,935	11.76	-7.18
6	Biology & Biochemistry	399	6,009	15.06	-10.52
7	Neuroscience & Behavior	341	5,024	14.73	-18.39
8	Environment/Ecology	628	12,713	20.24	-20.94
9	Social Sciences general	695	2,649	3.81	-39.62
	All Fields	*7,628*	*95,972*	*12.58*	8.54
	Estonian University of Life Sciences				
1	Plant & Animal Science	531	5,594	10.53	19.25
2	Environment/Ecology	197	3,319	16.85	-34.18
	All Fields	*1,079*	*11,359*	*10.53*	-9.15
	National Institute of Health Development				
1	Clinical Medicine	140	2,452	17.51	35.95
	All Fields	*349*	*4,353*	*12.47*	7.59
	National Institute of Chemical Physics and Biophysics				
1	Physics	521	12,235	23.48	122.77
	All Fields	*932*	*18,698*	*20.06*	*73.08*

It is slightly worrying that the leading scientific institution in Estonia – University of Tartu – has reached the top 1% only in nine out of 22 disciplines.[3] This mean that in 13 broad research areas the number and quality of papers was not enough to collect a sufficient number of citations. It is even more disturbing that two other Estonian universities – Tallinn University of Technology and Tallinn University – failed to reach the top 1% in any of 22 fields of science. This failure is unlikely attributable to some technical problems (for example using several alternative names such as Tallinn Technological University). The reason is simply that researchers working in these two universities failed to publish enough influential papers that would promoted them among the top 4,000 institutions in one of broad fields of science.

Estonian scientists in the top 1%

Table 4 demonstrates that 42 scientists, who are affiliated with one of Estonian institutions, have reached the top 1% of total citations in one or two fields of science. Unfortunately, this list may be incomplete. Because *ESI* does not provide option to search scientists based on their affiliations and institutions by countries, the search was done manually looking through a list of potential candidates. Colleagues also noted several omissions in the previous lists, which were distributed among colleagues.

More than three quarters of listed researchers are affiliated with University of Tartu. Twelve fields out of 22 are present here. This means that in 10 fields nobody succeeded to reach the top 1% by the number of total citations. This list explains why Environment/Ecology and Plant & Animal Science are the top field in Estonian science when it concerns bibliometric indicators.

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[3] University of Turku in Finland is approximately of the same size as University of Tartu. Researchers from the University of Turku has reached the top 1% in 12 different fields. They have also better bibliometric record: their 14,216 papers were cited 209,869 times or 14.76 times per paper.

Table 4. List of the top 1% of Estonian authors (alphabetically ordered) in terms of total citations in the disciplines in which they have exceeded the threshold during the whole period 2004-2014

	Name	Field 1	Field 2
1	Anto Aasa	Plant & Animal Science	
2	Kessi Abarenkov	Plant & Animal Science	
3	Rein Ahas	Environment/Ecology	
4	Jüri Allik	Psychiatry/Psychology	
5	Michael Brosche	Plant & Animal Science	
6	Henri-Charles Dubourgier	Environment/Ecology	
7	Marlon Dumas	Computer Science	
8	Tõnu Esko	Molecular Biology & Genetics	
9	Andrea Giammanco	Physics	
10	Aveliina Helm	Environment/Ecology	
11	Angela Ivask	Environment/Ecology	
12	Toomas Kivisild	Molecular Biology & Genetics	
13	Mario Kadastik	Physics	
14	Anne Kahru	Environment/Ecology	Pharmacology & Toxicology
15	Hannes Kollist	Plant & Animal Science	
16	Urmas Kõljalg	Plant & Animal Science	
17	Ülo Langel	Pharmacology & Toxicology	Biology & Biochemistry
18	Ivo Leito	Chemistry	
19	Jaan Liira	Environment/Ecology	
20	Ülo Mander	Environment/Ecology	
21	Andres Metspalu	Molecular Biology & Genetics	
22	Mari Moora	Environment/Ecology	
23	Andrew Morris	Molecular Biology & Genetics	
24	Reedik Mägi	Molecular Biology & Genetics	
25	Mait Müntel	Physics	
26	Ülo Niinemets	Environment/Ecology	Plant & Animal Science
27	Martti Raidal	Physics	
28	Anu Realo	Psychiatry/Psychology	
29	Liis Rebane	Physics	
30	Mari Nelis	Molecular Biology & Genetics	
31	Peeter Nõges	Environment/Ecology	
32	Risto Näätänen	Neuroscience & Behaviour	Psychiatry/Psychology
33	Erast Parmasto	Plant & Animal Science	
34	Markus Perola	Molecular Biology & Genetics	
35	Toomas Podar	Clinical Medicine	
36	Meelis Pärtel	Environment/Ecology	
37	Harold Snieder	Molecular Biology & Genetics	

38	Martin Zobel	Environment/Ecology	Plant & Animal Science
39	Kaido Tammeveski	Chemistry	
40	Leho Tedersoo	Plant & Animal Science	
41	Margus Viigimaa	Clinical Medicine	
42	Richard Villems	Molecular Biology & Genetics	

Fourteen researchers out of 42 are in the top 1% in Ecology & Animal Science in addition to 11 who reached the top 1% in Plant & Animal Science.

Unfortunately, two researchers (Henri-Charles Dubourgier and Erast Parmasto) who have reached the top 1% status have passed away. Five researchers (Anne Kahru, Ülo Langel, Ülo Langel, Risto Näätänen, and Martin Zobel) were successful in two different fields. It is also remarkable that 20 percent of the Estonian top scientists are women (Kessi Abarenkov, Aveliina Helm, Angela Ivask, Anne Kahru, Mari Moora, Anu Realo, Liis Rebane, and Mari Nelis). This is especially noteworthy in light of the fact that the *Estonian Academy of Sciences* has only two women among its 79 current members.

The above list of the top 1% Estonian scientists tells us something about the openness of the system. There are several foreigners (Michael Brosche, Henri-Charles Dubourgier, Marlon Dumas, Andrea Giammanco, Andrew Morris, Risto Näätänen, Markus Perola, and Harold Snieder) who were invited to work either part or full time in Estonia. Several originally Estonian researchers (for instance Ülo Langel and Toomas Kivisild) have the main affiliation with institutions abroad but have another affiliation here in Estonia.

Discussion and some conclusions

Science is notoriously one of the most inefficient institutions ever invented by the human society. Approximately a half of about two million scientific papers published every year in journals indexed by the *Web of Science* have a pessimistic prospect – nobody is going to cite them (Garfield, 2005). Not in the next or any following years. Not even by the author or authors of these papers. Of course, not every scientific impact leaves a traceable path in form of citations. There are many channels of scientific communication aside of journals and books. Nevertheless, even an orthodox has to admit that writing articles and books is by far the most important tool of fulfilling the essential task of science – making results public so that knowledgeable colleagues can verify obtained results and theoretical claims. If a paper is dull, poorly written, and contains no new information, then there is no a good reason to read it. Alternatively, if poor writing obscures the message or it is too small to notice then there is a good excuse to miss it from the list of references. However, this distressing inefficiency has clear implications for the science policy. It is not very wise to use the number of publications *per se* as a trustful indicator of scientific performance.

There are many examples of mistakes. For instance, Estonian Parliament (*Riigikogu*) recently approved the science and innovation strategy for the period 2014-2020.[4] One of the targets set to the scientific community was to reach productivity of 1,600 publications per million of population in high quality publications by the year 2020. "High quality" most likely means journals indexed by *WoS*. Knowing that about 1.3 million people are living in Estonia it is easy to conclude that it was expected that Estonian scientists will be able to produce about 2,100 papers each year (equivalent to 1,600 per million) by the end of the period. Not only was this target achieved already in 2012 (partly due to widening the scope of *WoS* itself) but also it was not a very good idea to use purely quantitative indicators – number of publications – which quality, as we saw above, may be problematic. Much more telling is the impact that published papers may have on thinking of other scientists. Of course, instead of bare numbers of citation it would be desirable to know how many papers authored by Estonian researchers report new important discoveries, made significant theoretical breakthroughs, or inspired new research that would not be possible without these results. Unfortunately, in the absence of better indicators citations remain one if not the best proxy of the scientific impact. Based on this proxy, there are all reasons to believe that Estonian science, in general, has done extremely well. The growth rate of the impact (relative to the *ESI*'s average) was about 7% last year, which predicts that the next year Estonia is almost certainly at least 10% above of the World average. According to the *HQSI*, Estonian science occupies the 16th position on the same level with science done in Germany, Australia, and France. Compared to other socio-economic rankings, this is a very advanced position.

For example, in the latest *Human Development Index 2013* (*HDI2013*) Estonia occupies the 33rd position[5] and in the latest *Democracy Index* occupies the 34th position belonging to the group of countries titled

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[4] https://www.riigiteataja.ee/akt/329012014002

[5] http://en.wikipedia.org/wiki/Human_Development_Index

as “Flawed Democracies.”[6] Obviously, compared with many other relevant rankings, Estonian science is positioned remarkably well.

How it comes that Estonia’s real GDP per capita was 13,100 euros in 2014,[7] which is still slightly less than in 2007, while the impact of Estonian scientific papers published in the elite journals indexed by *ESI* has increased 54.7%? There is no doubt that the high quality science is a privilege of affluent countries. One could easily add the latest scores of the *HDI2013* to Table 1 and see that the correlation between *HQSI* and *HDI2013* is positive and sufficiently high, $r(86) = .46$, $p < .0001$. Indeed, wealthy countries were people are educated, live long and healthy life are more successful in producing high quality science results. However, this link between country’s wealth and science is far from simplistic. Estonia is a telling example how an outstanding growth in the quality of scientific publications was achieved in spite of diminishing financial support. Thus, it is not money alone what is needed for outstanding results in research. Beside highly educated, healthy, and prosperous population, a good government is in demand. What is a good government? According to one of the best definitions this is the impartiality of institutions that exercise government authority (Rothstein & Teorell, 2008). Indeed, it may sound slightly surprising but *Worldwide Governance Indicators 2013* (*GWI2013*), which measures how impartial are institutions in the society in exercising their authority, is the strongest predictor of *HQSI*. Good governance includes the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them (Kaufmann, Kraay, & Mastruzzi, 2010). As I said, the correlation between *HQSI* and *GWI2013* is even higher ($r(86) = .684$, $p < .0001$) than the above mentioned correlation between the *HQSI* and the *HDI*. Perhaps the most relevant, when *HQSI* is predicted simultaneously from *HDI2013* and *GWI2013* only the latter has a significant effect on *HQSI*.

Nevertheless, a rapid growth of the impact of papers written by Estonian scientists is perplexing. Looking at a stagnated budget, which has not increased since 2008, the opposite outcome would have been more likely. Apparently, it belongs to a category of miracles – a rapid growth of scientific impact without additional funding. However, one needs to be cautious to propose a theory that scarcity of means acted as a strong motivator for an outstanding achievement. There is a temptation, especially for politicians, to take Ernest Rutherford’s famous quote “We don’t have money, so we have to think” for its face value.

Obviously, there are many factors and their combinations behind the success of Estonian basic science. In one important respect, Estonia is deviant from other European countries. Data show that national project-based research funding to higher education is about 20% on average and rarely goes beyond 50% in any of OECD countries. In Estonia, however, more than 80% of research funding is project-based coming from the Estonian Ministry of Education and Research (Raudla, Karo, Valdmaa, & Kattel, 2015). It is relatively well documented that an extremely high percentage of project-based funding had a negative effect on the Latvian science (Kristapsons, Martinson, & Dagyte, 2003). A relatively small amount of the total funding, which was allocated exclusively for short-term grants, created uncertainty that was one of the main reasons of an unprecedented brain drain from Latvia. However, looking at the recent success of Estonian science documented by the bibliometric indicators it is impossible to say that project-based funding made any damage to Estonian science. An inevitable consequence of project-based funding is a relatively strong competition for limited funds. It is true that a severe competition makes fairness of the decision-making process almost compulsory. Ever since Estonia regained its independence in 1991, most research funding applications had to be written in English, which allowed use of foreign experts who are more impartial than local experts almost by definition. In addition, writing all applications in English was an invaluable practice for writing scientifically sound articles to say nothing about internationally competitive and successful grant applications themselves. Considering how small Estonia is, using independent reviewers and evaluators from abroad proved to be the only way for avoiding potential conflicts of interests or simply academic nepotism. Another example of good governance was the fact that scientific assessment and decision-making was given to panels consisting of top-level researchers who were mandated to make sovereign decisions that have been rarely reversed by non-scientific authorities. It seems likely that a relative success of Estonian basic science, which was documented above, is due to the fact, partly at least, that scientific assessment and decision-making has preserved its autonomy.

Panels consisted of the best active scientists decided what question is important to study and proposals were selected based on their scientific merits, not what science bureaucrats typically think about importance for particular institutions and Estonian economy and society in general.

It is perhaps only a small exaggeration to say that Lennart Meri (1929-2006), member of the Estonian Academy of Sciences, foreign minister, and president of

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[6] http://en.wikipedia.org/wiki/Democracy_Index

[7] http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdec100

Estonia, helped to put Estonia back on the map of Europe. Sometimes he did it in an extravagant way. When he died in 2006, obituaries still remembered his dramatic arriving back from abroad to find that, despite repeated complaints, the national airport's lavatories were still in a state of squalor, he summoned a press conference in the urinals to lambast the authorities.[8] He is also remembered by his appeals for Estonia to invent Estonia's own "*Nokia*." Since then, it became a national sport to advance the best candidates for our own "*Nokia*." In fact, there are several very good contenders including, of course, *Skype*. However, my own preference inclines towards an extraordinary success of Estonian science, which comes perhaps closest to the heart of this appeal.

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[8] http://www.economist.com/node/5655082