TRAMES, 2018, **22**(**72/67**), 4, 329–344

A PUZZLE OF ESTONIAN SCIENCE: HOW TO EXPLAIN UNEXPECTED RISE OF THE SCIENTIFIC IMPACT

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Abstract. Only sufficient economic wealth can produce science with the highest quality. However, there is room for many intervening factors, which can moderate the process of how money invested into research transforms into a bibliometrically measurable outcome. In this paper, based on the latest update of the Essential Science Indicators (ESI), covering the period 2007–2017, we analyze the progress of Estonian science against the background less successful neighbors, Latvia and Lithuania, in the pursuit of scientific excellence. Estonia improved the impact of scientific papers by eleven positions occupying the 17th position in the world-ranking list of countries/territories, sandwiched between France and Israel who both have approximately two times larger DGP per capita to say nothing about 68 and 12 Nobel Prize winners respectively. By the percentage of papers reaching the top-cited category, Estonia occupies the 7th position of the most successful nations. The fact that Estonian papers are cited 30% more frequently than papers recorded by ESI in general is a puzzle because Estonia is spending only about 0.8% of its GDP on the R&D with a dropping tendency during the last three years. Factors that could moderate transformation of the input money into scientific output are discussed.

Keywords: bibliometric, Essential Science Indicators, Estonian science, scientific excellence, impact of scientific papers

DOI: https://doi.org/10.3176/tr.2018.4.01

1. Introduction

A quality of a scientific publication of any country can be predicted, partly at least, from the GDP per capita but also from the percentage of money that was spent on R&D by this country (Allik 2013a, King 2004, Vinkler 2018). Hence, only very rich nations spending a considerable amount of the produced wealth on R&D afford to produce high-quality scientific papers, which have an impact on science. It was also noticed that open countries whose scientists collaborate with their foreign colleagues are likely to produce scientific output of higher quality (European Commission 2015, Moed 2005, Wagner and Jonkers 2017). Although wealth and money are important factors, countries differ considerably in terms of the efficiency of turning financial input into bibliometrically measurable output (King 2004, Leydesdorff and Wagner 2009, Vinkler 2008). This indicates that not all R&D money is necessarily turned into the high quality scientific output; some of it has been lost in translation. It was observed that countries differ in their ability to transform scientific research into immediate economic return (Vinkler, 2008). Besides money, achieving scientific excellence also requires reasonable science policies, research ethos, and even a culture that supports discovery of new ideas (Jurajda Kozubek, Munich, and Skoda 2017, Moed 2005, Ntuli, Inglesi-Lotz, Chang, and Pouris 2015, van Leeuwen and Moed 2012, van Leeuwen, Visser, Moed, Nederhof, and van Raan 2003).

In the study of factors that could determine scientific excellence, the progress of science in the three Baltic states – Estonia, Latvia, and Lithuania – may be particularly informative (Allik 2003, Kristapsons, Martinson, and Dagyte 2003). By a coincidence, all three countries published only approximately 300 papers each year in journals covered by the *Web of Science* (WoS; or its predecessor, *Clarivate Analytics*) around the moment when the Soviet Union collapsed in 1991 (Allik 2003). Only fifteen or so years later, Lithuania's scientists published about 1,300 papers in the peer-reviewed journals against only about 400 papers that were authored by Latvian researchers in 2007 (Allik 2008; Figure 1). Although the three Baltic countries are often confused, the progress in their science output, both in quantity and quality, has diverged remarkably during the years after regaining independence in 1991. In spite of very similar historical, political, and economic experiences, the progress of science measured on the basis of their bibliometric indicators have been dramatically different (Allik 2011, 2015). To a certain extent, it looks like a natural experiment where three different subjects experienced different treatments with a purpose to observe how it could affect their scientific progress.

In this paper we intend to provide an overview of the Estonian science, using Latvia and Lithuania as a benchmark, based on the latest release (March 15, 2018) of the Essential Science Indicators (ESI; *Clarivate Analytics*) covering 11 years long period from 2007 until 2017. As we hope to demonstrate, the progress of Estonian science, especially during the last decade, has been spectacularly fast. This progress of turning financial input into bibliometrically measurable output can be even called miraculous, because according to the Statistics Estonia, investments to R&D have diminished in the past three last years, despite the embarrassing fact that it is only 0.8% of Estonia's GDP (https://www.stat.ee/news-release-2017-128). We are not expecting to solve this puzzle – turning diminishing financial input into increasing bibliometric output – completely. Instead we hope to provide some additional knowledge how to avoid mistakes in nurturing such a delicate process as scientific excellence.

2. Method

Data were collected from the latest ESI release (updated on March 15, 2018) covering 11 years long period from January 1, 2007 until December 31, 2017. All journals, except universal such as Nature, Science and the Proceedings of the National Academy of Sciences (PANAS), are divided into 21 scientific areas in addition to Multidisciplinary containing papers, which are difficult to assign to any of these areas. When ESI was designed, it was decided to exclude humanities from the list of scientific areas. Thus, ESI data cannot tell anything specific about the state in the humanities for any country or institution.

ESI followed more than 12 million articles in more than 12,000 journals that were published during 11-year observation period and indexed in the WoS. Inclusion in ESI is dependent upon meeting certain citation thresholds. Only the most highly cited individuals, institutions, journals, countries and papers are included in ESI. Researchers, institutions, and highly cited papers must exceed 1% top-citation threshold to be included in ESI. For instance, to be included as a highly cited researcher in any of 22 areas, the total number of citations to a person's output must be in the top 1% when compared to all other researchers in that particular area, who have published papers in this area during the last 11 years. Thresholds for areas are remarkably different. For example, a computer scientist enters ESI collecting at least 322 citations to papers published during the last 11 years while the threshold for a physicist is as high as 7,999 citations. Understandably, countries/territories and journals need to be among the top 50% in order to enter ESI.

Because ESI includes countries/territories producing perhaps only a small number of papers during the 11-year observation period, we excluded from the further analysis all countries/territories publishing fewer than 4,000 papers. For example, over 3,000 papers were published by Senegal, Panama, Malawi, Uzbekistan, Zimbabwe, Macedonia, Sudan, and Burkina-Faso. It could be also mentioned that Bermuda, Seychelles, and Vatican published each fewer than 300 papers included in ESI over 11 years.

3. Results

Table 1 presents a list of countries who entered ESI and published more than 4,000 documents in the period 2007–2017. The listed countries are ranked according to the mean citations per paper (the 5th column Cites/Paper). The 6th column (Top Paper %) show the percentage of papers which reached the top 1% rank in their citations. The next, the 7th column (HSDI Rank) demonstrates country ranking on the High Quality Science Index, which was proposed to combine average citation rate with the percentage of papers reaching the top 1% (Allik 2013a). To compute HQSI both indicators, the mean citation rate and the

Table1. List of countries who published more than 4,000 ESI papers during the last 11 years, in the period 2007–2017

Rank	Countries/Regions	Web of Science Documents	Cites	Cites/ Paper	Top Papers (%)	HQSI Rank	Change in the Rank since 2007
1	ICELAND	9,775	227,554	23.3	3.05	1	5
2	SWITZERLAND	281,839	5,974,440	21.2	2.70	2	–1
3	SCOTLAND	149,732	3,050,642	20.4	2.61	3	2
4	NETHERLANDS	382,711	7,734,062	20.2	2.45	4	0
5	DENMARK	161,671	3,141,880	19.4	2.49	5	–2
6	ENGLAND	976,296	18,091,235	18.5	2.16	9	2
7	USA	4,018,935	73,894,592	18.4	1.85	15	–5
8	BELGIUM	210,940	3,843,680	18.2	2.21	10	4
9	WALES	51,446	936,240	18.2	2.22	8	9
10	SWEDEN	255,231	4,578,903	17.9	2.00	14	–3
11	SINGAPORE	117,749	2,080,794	17.7	2.46	6	31
12	IRELAND	78,858	1,381,373	17.5	2.17	13	9
13	GERMANY	1,063,985	18,088,194	17.0	1.72	21	0
14	CANADA	659,943	11,134,985	16.9	1.85	18	–3
15	NORTHERN IRELAND	25,197	424,684	16.9	1.78	20	7
16	AUSTRIA	145,599	2,451,730	16.8	2.05	16	–1
17	FINLAND	124,726	2,099,606	16.8	1.84	19	–8
18	NORWAY	121,843	1,987,122	16.3	1.99	17	–2
19	FRANCE	744,687	12,117,539	16.3	1.62	26	–2
20	**ESTONIA**	**16,818**	**273,488**	**16.3**	**2.41**	**12**	**11**
21	ISRAEL	141,052	2,247,131	15.9	1.65	27	–7
22	REPUBLIC OF GEORGIA	5,637	88,227	15.7	2.54	11	50
23	AUSTRALIA	540,607	8,417,798	15.6	1.93	23	–4
24	PERU	9,186	141,639	15.4	2.80	7	5
25	ITALY	642,089	9,864,393	15.4	1.49	32	–5
26	HONG KONG	124,997	1,870,561	15.0	1.93	24	–16
27	NEW ZEALAND	89,996	1,345,522	15.0	1.75	28	–4
28	KENYA	14,895	222,062	14.9	2.05	22	0
29	UGANDA	8,565	125,887	14.7	1.56	33	–5
30	SPAIN	554,312	7,991,814	14.4	1.45	35	–3
31	COSTA RICA	5,333	76,815	14.4	1.56	34	–5
32	GREECE	116,369	1,627,653	14.0	1.47	38	8
33	TANZANIA	7,983	110,706	13.9	1.48	39	3
34	PHILIPPINES	11,123	149,008	13.4	2.16	25	1
35	PORTUGAL	125,877	1,665,554	13.2	1.32	41	2
36	LUXEMBOURG	8,439	110,511	13.1	1.87	30	n.a.
37	HUNGARY	69,002	893,493	13.0	1.40	40	–5
38	URUGUAY	8,684	111,700	12.9	1.21	44	–8
39	JAPAN	854,526	10,751,287	12.6	0.85	55	–14
40	CYPRUS	9,899	124,414	12.6	1.96	31	8

To be continued

Rank	Countries/Regions	Web of Science Documents	Cites	Cites/ Paper	Top Papers (%)	HQSI Rank	Change in the Rank since 2007
41	ARMENIA	7,391	90,356	12.2	1.79	36	6
42	SRI LANKA	6,652	78,509	11.8	2.09	29	18
43	CZECH REPUBLIC	115,152	1,316,297	11.4	1.19	48	1
44	SOUTH AFRICA	108,477	1,235,866	11.4	1.48	43	–5
45	ARGENTINA	88,002	988,965	11.2	0.96	57	–7
46	CHILE	68,167	759,513	11.1	1.17	49	–13
47	GHANA	7,438	82,232	11.1	1.40	45	9
48	SLOVENIA	39,276	433,690	11.0	1.15	51	5
49	TAIWAN	277,054	2,949,603	10.7	0.69	70	8
50	THAILAND	68,382	724,041	10.6	0.93	59	1
51	SOUTH KOREA	519,213	5,419,516	10.4	0.85	63	8
52	LEBANON	11,052	115,357	10.4	1.47	47	11
53	INDONESIA	15,999	166,435	10.4	1.25	52	–10
54	NEPAL	5,066	51,812	10.2	1.30	50	n.a.
55	BULGARIA	25,356	253,415	10.0	1.02	60	7
56	ECUADOR	6,486	63,910	9.9	1.59	46	n.a.
57	CHINA MAINLAND	2,168,070	21,231,438	9.8	1.05	61	15
58	COLOMBIA	35,519	346,482	9.8	1.33	54	–12
59	LATVIA	6,478	62,508	9.7	1.31	56	–13
60	SAUDI ARABIA	86,543	816,025	9.4	2.25	37	19
61	SLOVAKIA	34,783	327,297	9.4	0.87	73	0
62	VENEZUELA	11,948	112,289	9.4	0.87	72	–7
63	CROATIA	36,711	342,701	9.3	0.94	67	5
64	MEXICO	125,334	1,166,844	9.3	0.87	74	–15
65	BANGLADESH	14,928	138,281	9.3	1.20	58	1
66	QATAR	10,797	97,882	9.1	1.95	42	n.a.
67	CUBA	8,791	79,208	9.0	0.73	79	0
68	CAMEROON	7,373	65,874	8.9	0.88	75	–14
69	OMAN	5,912	52,452	8.9	1.17	62	15
70	POLAND	249,900	2,204,107	8.8	0.83	78	–18
71	UNITED ARAB EMIRATES	16,699	147,343	8.8	1.08	64	10
72	INDIA	554,273	4,839,616	8.7	0.61	84	–1
73	ETHIOPIA	9,419	81,245	8.6	1.06	66	–8
74	BELARUS	11,849	101,338	8.6	1.05	69	11
75	BRAZIL	407,396	3,420,751	8.4	0.64	85	–17
76	VIETNAM	22,629	187,197	8.3	1.11	68	–26
77	MOROCCO	17,460	141,446	8.1	0.75	80	0
78	AZERBAIJAN	4,955	39,663	8.0	1.21	65	16
79	MALAYSIA	87,529	697,892	8.0	1.12	71	–3
80	LITHUANIA	22,435	178,357	8.0	1.00	77	–16
81	KUWAIT	7,749	60,473	7.8	0.80	81	–6
82	EGYPT	82,585	639,236	7.7	0.64	87	–4
83	JORDAN	13,048	100,485	7.7	0.81	82	7
84	SERBIA	48,720	361,052	7.4	0.86	83	–15

To be continued

Rank	Countries/Regions	Web of Science Documents	Cites	Cites/ Paper	Top Papers (%)	HQSI Rank	Change in the Rank since 2007
85	IRAN	250,418	1,825,070	7.3	0.68	88	2
86	PAKISTAN	67,815	490,947	7.2	1.14	76	–3
87	TURKEY	270,114	1,953,060	7.2	0.54	91	–7
88	ROMANIA	76,027	539,922	7.1	0.81	86	–15
89	TUNISIA	33,944	236,083	7.0	0.43	96	–1
90	NIGERIA	23,821	163,055	6.9	0.73	89	1
91	UKRAINE	52,492	352,886	6.7	0.59	93	–5
92	RUSSIA	332,508	2,150,853	6.5	0.51	95	–18
93	ALGERIA	23,791	148,391	6.2	0.69	92	–4
94	MACAU	4,693	27,961	6.0	1.98	53	n.a.
95	BOSNIA & HERZEGOVINA	4,475	26,101	5.8	0.87	90	n.a.
96	IRAQ	7,351	38,394	5.2	0.84	94	n.a
97	KAZAKHSTAN	5,718	27,394	4.8	0.61	97	–5

percentage of top papers, were transformed into normalized scores after which their mean value was found. The last column show changes in the ranking position compared to a similar ranking list for the period 1997–2007 (Allik 2008; Table 1). Several countries (Luxembourg, Nepal, Ecuador, Qatar, Macau, Bosnia and Herzegovina, and Iraq) were missing from the previous list and we cannot compute the change in ranking for them.

Small countries such as Iceland, Switzerland, and Scotland were able to produce science of the highest impact. Together with the Netherlands and Denmark they produced papers with the highest mean citation rate from which the highest percentage reached the top of citations. If we compare rankings, 1997–2007 (Allik 2008; Table 1) with the current one, then three countries, i.e. the Republic of Georgia, Singapore, and Saudi Arabia have improved their position most by increasing 50, 31, and 19 positions respectively. Three countries who dropped most in their ranking were Vietnam (–26), Poland (–18), and Russia (–18). Estonia improved 11 positions in the ranking while Latvia and Lithuania dropped 13 and 16 positions respectively in the ranking during the last 10 years.

There were worries that Americans produce higher quality science than the EU countries, with a gap between them widening (Albarrán, Crespo, Ortuño, and Ruiz-Castillo 2010, European Commission 2015, Leydesdorff, Wagner, and Bornmann 2014). Inspecting the table above, there is no foundation for these fears. USA not only lost 5 rank positions compared with the previous ranking 10 years ago, but its HQSI rank (15) is 8 positions behind the overall ranking (7) based on the mean citations. The negative gap can be used as a Mediocrity Index pointing to countries, which produce unexpectedly small number of highly influential papers compared with the total number of papers indexed in ESI (Allik 2013a). As an example, experts noticed already several years ago that Scandinavian countries, including Sweden, may have fallen into the comfort zone trap producing an unexpectedly small number of highly cited papers (Karlsson and Persson 2012). If we compare rankings on the mean citation rate and the percentage of highly cited papers, we see that unlike other Scandinavian countries, Sweden and Finland are producing fewer highly cited papers than it could be expected on the basis of the impact of their papers in general. This may indicate that their researchers have become complaisant with regularly good papers and do not aim to produce scientific breakthroughs.

Based on the HQSI ranking, Estonia has currently the 12th position, which is even of a higher ranking that Sweden (14), USA (15), and Finland (19). Latvia occupies the 56th and Lithuania the 77th position. Russia has the 95th position, which is only three positions away from the very bottom.

Next, we demonstrate how the mean citation rate of papers authored by Estonian scientists has changed during the last eleven years. Figure 1 shows the percentage of the citing rate relative to the ESI average. In 2006, Estonian papers were cited approximately 20% less than papers in ESI on average. By the end of 2017, papers written by Estonian scholars were cited 30% more times than papers in ESI on average. The impact of Estonian papers increased approximately 8% faster than the impact of all ESI papers have increased on average during the last five years. If it had been a growth of economic indicators it would have been a sensation.

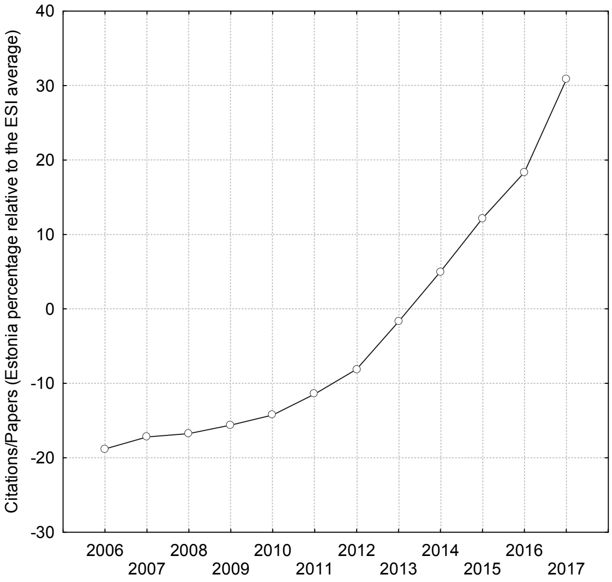

Figure 1. Average rate of citing Estonian papers relative the ESI average rate.

By the number of citations per paper, Estonia shares approximately the same position as France and Israel, which are much wealthier countries compared to Estonia. For comparison, France had in 2017 GDP per capita $38,578 and Israel 37,778. Estonia's GDP per capita in 2017 was about $17,853, which is approximately 50% of GDP in these two countries. Nevertheless, Estonian authors were able to publish papers, which were cited as frequently as papers that were written by the French and Israeli scientists. Please note that Estonia has never won a Nobel Prize compared to 68 Nobel Prize winners in France and 12 in Israel. Like Finland, Estonia has a relatively high national IQ (Pullmann, Allik, & Lynn, 2004; see also http://www.oecd.org/estonia/pisa-2015-estonia.htm), but one of the lowest number of Nobel prizes (Dutton, Nijenhuis, & Roivainen, 2014). It is also useful to remember that France and Israel spend respectively 2.3% and 4.3% of their GDP on R&D. It is even embarrassing to say that Estonia's R&D expenditures are falling the third year in a row, below 0.8% of the GDP (Estonian Research Council, 2017, p. 12; Figure 1.1).

It is unlikely that small countries have equal strengths in all areas into which science is in ESI divided. Table 2 provides ESI bibliometric statistics in each of ESI research areas for Estonia, Latvia, and Lithuania. Estonia passed 50% citation threshold in all 22, Lithuania in 21 areas, and Latvia in 17 research fields. Another success story, the Republic of Georgia passed the ESI thresholds only in 11 research areas. The strength of a country can be measured by the impact of papers measured relative to the ESI world average in this field. For example, in 10 research fields papers authored by Estonian scientists have a higher impact than papers on average in this field (these fields are marked with red). Latvian scientists publish papers with above average impact in two fields: Clinical Medicine and Molecular Biology & Genetics. Lithuania performed above ESI average in three fields: Immunology, Molecular Biology & Genetics, and Plant & Animal Science.

The observations we can make are very similar to those about science in the three Baltic States after the first decade of independence (Allik 2003). Lithuania published the largest number of papers (22,435) exceeding Estonia (16,818) and particularly Latvia (6,478) by more than three times. However, in terms of the paper's quality, which can be measured by the number of times they have been cited, Latvia lags more than 20% behind of the ESI world average. It seems that Lithuania failed to improve the quality of its scientific publications because their citation rate is 36% below ESI world's average citation rate. Thus, out of the three Baltic countries only Estonia was able to increase not only the volume of its publications but also their mean impact (Allik 2013a).

The mean citation rate – cites per paper – tells only a part of the story about a country's science. There were many proposals how to supplement the mean citation rate with additional indicators, which could improve the quality of bibliometric indicators. For example, researchers were concerned how much self-citation could distort the mean citation rate (Aksnes 2003, Jaffe 2011, Thijs and Glanzel 2006). In addition to individual self-citation, there may also be a country-

Table 2. ESI bibliometric indicators characterizing Estonia, Latvia, and Lithuania during the period 2007–2007

	Research Fields	Estonia					Latvia					Lithuania			
		Pap	Cites	C/P	C/P (%)	TopP	Pap	Cites	C/P	C/P (%)	TopP	Pap	Cites	C/P	C/P (%)
1	AGRICULTURAL SCIENCES	379	3,143	8.29	–6.2	5	177	1,378	7.79	–11.9	*3*	883	4,160	4.71	–46.7
2	BIOLOGY & BIOCHEMISTRY	757	15,463	20.43	18.6	13	215	2,209	10.27	–40.4	2	759	8,664	11.42	–33.7
3	CHEMISTRY	1,479	18,801	12.71	–13.6	10	872	5,757	6.6	–55.1	1	2,057	16,303	7.93	–46.1
4	CLINICAL MEDICINE	1,581	42,973	27.18	107.2	83	735	16,451	22.38	70.6	38	2,731	28,824	10.55	–19.6
5	COMPUTER SCIENCE	211	890	4.22	–34.2	0	75	391	5.21	–18.7	0	583	2,575	4.42	–31.0
6	ECONOMICS & BUSINESS	295	1,571	5.33	–36.5	1	124	612	4.94	–41.1	1	1,315	7,899	6.01	–28.4
7	ENGINEERING	732	4,328	5.91	–20.8	5	584	1,821	3.12	–58.2	1	3,487	13,294	3.81	–48.9
8	ENVIRONMENT/ECOLOGY	1,321	26,948	20.40	54.3	42	246	3,190	12.97	–1.9	5	981	9,263	9.44	–28.6
9	GEOSCIENCES	1,219	12,725	10.44	–16.9	11						392	3,281	8.37	–33.4
10	IMMUNOLOGY	271	4,808	17.74	–9.2	3						194	5,648	29.11	49.0
11	MATERIALS SCIENCE	707	6,458	9.13	–24.7	4	671	4,273	6.37	–47.5	2	1,602	7,747	4.84	–60.1
12	MATHEMATICS	330	1,331	4.03	–9.2	1						930	2,362	2.54	–42.8
13	MICROBIOLOGY	257	4,442	17.28	10.5	5	84	1,240	14.76	–5.6	1	251	3,666	14.61	–6.6
14	MOLEC. BIOLOGY & GENETICS	759	37,094	48.87	96.6	46	149	8,039	53.95	117.0	5	253	9,641	38.11	53.3
15	MULTIDISCIPLINARY	52	686	13.19	–10.8	2									
16	NEUROSCIENCE & BEHAVIOR	473	9,324	19.71	6.4	7	62	866	13.97	–24.6	0	259	2,972	11.47	–38.1
17	PHARMACOL. & TOXICOLOGY	280	4,800	17.14	30.8	8	145	1,111	7.66	–41.5	1	239	2,051	8.58	–34.5
18	PHYSICS	1,849	34,036	18.41	59.7	64	1,139	6,783	5.96	–48.3	12	2,946	36,069	12.24	6.2
19	PLANT & ANIMAL SCIENCE	1,675	25,635	15.30	60.7	63	440	3,300	7.5	–21.2	6	1,210	5,390	4.45	–53.3
20	PSYCHIATRY/PSYCHOLOGY	470	6,398	13.61	7.7	11	44	459	10.43	–17.5	1	188	2,057	10.94	–13.4
21	SOCIAL SCIENCES, GENERAL	1,451	7,345	5.06	–27.2	17	262	1,472	5.62	–19.1	5	943	4,252	4.51	–35.1
22	SPACE SCIENCE	270	4,289	15.89	–13.2	4						227	2,159	9.51	–48.1
0	ALL FIELDS	16,818	273,488	16.26	30.8	405	6,478	62,508	9.65	–22.4	85	22,435	178,357	7.95	–36.0

Notes: Pap = WoS papers included in ESI; Cites = total number of cites; C/P = Citations per paper; C/P (%) = Citations per paper expressed as percentage relative to the ESI world average; TopP = the number of papers reached the top 1% citation rate.

level self-citation bias: the degree to which authors from one country cite works carried out by the researchers of their own country relative to the work that was performed outside of that country (Allik 2013b, Jaffe 2011). In addition to the percentage of highly cited papers, the other end of citation frequencies – the percentage of not cited papers – is a sensitive indicator of the scientific quality (Leydesdorff and Wagner 2009, Okubo 1997). Of course, the number of researchers per each country who have reached the top 1% cites could be an additional indicator of the quality of research in any country. Unfortunately, the ESI's search engine does not allow sorting researchers according to their affiliations. We tested potential Estonian researchers one by one and were able to identify 66 researchers with Estonian affiliation (see Appendix 1).

Luckily, *Clarivate Analytics* composes another, even shorter list of about 3,500 highly cited researchers who have reached the top of about 160 most cited researchers in each out of 21 research fields (Clarivate Analytics, 2017; https://clarivate.com/hcr/researchers-list/archived-lists/). In 2017-year's list, Estonia was represented by seven highly cited researchers: Martin Zobel (Environment/Ecology), Tõnu Esko (Molecular Biology & Genetics), Andres Metspalu (Ibid.), Markus Perola (Ibid.), Urmas Kõljalg (Plant & Animal Science), Ülo Niinemets (Ibid.), and Leho Tedersoo (Ibid.). For a reference, nobody from Latvian or Lithuanian researches were included into the list of highly cited researchers, which is perhaps not very surprising considering other bibliometric indicators. Although Russia outperforms Estonia approximately 20 times in the number of published papers, only three Russian researchers have reached the list of highly cited researchers.

4. Discussion

Even after 25 years that have passed from the collapse of the Soviet Union, most post-communist countries are still lagging behind their EU counterparts in the quality of science they produce (Jurajda et al. 2017, Kozak, Bornmann, and Leydesdorff 2015, Must 2006, Pajic 2015, Vinkler 2008). If there is one post-communist country that has managed to escape the curse of the past, it is Estonia occupying the highest position in rankings among all post-communist countries (Allik 2003, 2008, 2011, 2015, 2017). Although the Republic of Georgia is only two positions behind, this was achieved by supporting science only in few limited areas having practically no publications in others. The former flagship of the post-communist science Hungary is on the 37th position falling 5 compared with the situation ten years ago. Some observers were able to foresee this decline (Izsvák, Ivics, and Mátés 2006).

Usually, the lack of money is blamed for the lagging behind of the rest of Europe. In transitional economies, however, it is very difficult to convince policy-makers to allocate more money for science because there is no convincing evidence that investment into R&D will have immediate return in the form of economic growth (Hatemi-J, Ajmi, El Montasser, Inglesi-Lotz, and Gupta 2016, Solarin and Yen 2016, Yasgul and Guris 2016). Some countries show a causal relationship from the output of research to real GDP, but some other countries do not (Hatemi-J et al., 2016). Although economic and scientific wealth, as we said above, are related in general (King, 2004), there are many factors that could intervene to alter straightforward relationship. A good example is Estonia together with the Republic of Georgia who are two exceptions violating a relatively uncomplicated relationship between economic wealth and the impact of scientific papers written by researchers in a given country. Luxembourg is a good example of the opposite deviation because $105,914 of the GDP per capita of Luxembourg in 2017 expects higher position than the 36th in Table 1 (King 2004; Table 1 and Figure 2).

Because the gap between Estonia’s economic and scientific performances was so obvious, we proposed that there must be a considerable amount of 'hidden money' (Allik 2003, 2008). Indeed, the unrealistically low cost of scientific articles suggests that a considerable amount of 'hidden money' must be involved, not reflected in the official expenditures. One possibility is collaboration with partners from more affluent countries. Typically, these collaborative projects are chiefly financed by wealthy Western partners and domestic contribution is primarily a qualified but still cheap labor (Allik 2003, 2008). However, it was clear that the 'hidden money', if there was any, was not enough to fill the gap between recorded expenses and disproportionately high scientific output.

The next obvious candidate to explain differences in the counties’ economic and scientific performance was the efficiency of the R&D system to transform financial input into bibliometrically-measured output. For instance, differences between Estonia, Latvia, and Lithuania in their scientific productivity and quality, which were virtually absent in the early 1990s, can be explained with different approaches and practices of their R&D systems (Kristapsons et al. 2003, Martinson 2015). There are several plausible reasons that alone or in combination with others could explain stagnation in Latvian and inflation in Lithuanian science. For example, one obvious mistake in Latvian science was the elimination of permanent science financing replacing it with a temporary grant system only (Allik 2003). Lithuania, on the other hand, created its own cottage industry of scientific journals instead of competing with the rest of the word for publishing in the leading international journals. Although damaging, one of the main mistakes that Latvia and Lithuania made was not building an impartial R&D system, with the only goal of promoting scientific excellence.

As it was already mentioned, among factors that are behind the recent success of Estonian science is a relatively strong competition for limited funds (Allik 2015). Ever since Estonia regained its independence in 1991, most research funding applications had to be written in English, which allowed using foreign experts as impartial judges. An inevitable consequence of the project-based funding is to make the fairness of the decision-making process almost compulsory. 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. For the transparency of the decision process, all scientific assessment and decision-making in Estonia 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. Panels consisting of the best active scientists decided what question was important to study and proposals were selected based on their scientific merits, not what science bureaucrats typically think about the importance for particular institutions and Estonian economy and society in general. It is not surprising that bureaucrats, who are responsible for science, became worried about too much autonomy and self-governance that scientists had in Estonia. Consequently, the amount of competitive and project-based funding was decreased in favor of more stable funding schemes where decisions can be made by the administrators of universities and other research institutions (Allik 2015).

Estonian politicians became very excited if foreign observers claimed, for example, that Estonia had become the digital leader of Europe (Gaskell, 2017)[1]. Nevertheless, Estonia became the only country whose expenditures on the R&D have decreased in the third year in running. Local politicians even invented a story why the digital tiger did not need to invest more money into research. It was said that public did not understand the need for science and this is why it was not wise to discuss this question in the context of the forthcoming general elections. Officials declared that if Estonian scientists wanted more money for their research they needed to provide evidences that their research helped to increase productivity of Estonian economy. Only after Kristjan Vassil, the Vice Rector for Research, University of Tartu, published a paper in the largest newspaper, the tone of politicians became slightly more apologetic (Vassil 2018).

Summarizing, the economic and scientific wealth of nations are intimately related to each other (Allik 2013a, King 2004). Only very few rich countries can afford mediocre science because they have faith in their neighbors. However, as Estonia and its two neighbors, Latvia and Lithuania, demonstrate a successful science is inevitable because of the economic growth and prosperity. Many factors could intervene in the process of converting economic wealth into bibliometrically measurable scientific output. The mission of small countries is to be a trial case from which we can learn recipes for the growth of scientific wealth and, more important, how to avoid mistakes.

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[1] https://www.forbes.com/sites/adigaskell/2017/06/23/how-estonia-became-the-digital-leaders-of-europe/#50cd890256da

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References

Aksnes, D. W. (2003) "A macro study of self-citation". *Scientometrics* 56, 2, 235–246. doi:10.1023/a:1021919228368

Albarrán, P., J. A. Crespo, I. Ortuño, and J. Ruiz-Castillo (2010) "A comparison of the scientific performance of the U.S. and the European union at the turn of the 21st century". *Scientometrics* 85, 1, 329–344. doi:10.1007/s11192-010-0223-7

Allik, J. (2003) "The quality of science in Estonia, Latvia, and Lithuania after the first decade of independence". *Trames* 7, 1, 40–52.

Allik, J. (2008) "Quality of Estonian science estimated through bibliometric indicators (1997-2007)". *Proceedings of the Estonian Academy of Sciences* 57, 255–264. doi:10.3176/tr.2013.3.01

Allik, J. (2011) "Estonian science estimated through bibliometric indicators". In J. Engelbrecht, ed. *Research in Estonia: present and future*, 456-469. Tallinn: Estonian Academy of Sciences.

Allik, J. (2013a) "Factors affecting bibliometric indicators of scientific quality". *Trames* 17, 3, 199–214. doi:10.3176/tr.2013.3.01

Allik, J. (2013b) "Personality psychology in the first decade of the new millennium: a bibliometric portrait". *European Journal of Personality* 27, 1, 5–14. doi:10.1002/per.1843

Allik, J. (2015) "Progress in Estonian science". *Proceedings of the Estonian Academy of Sciences* 64, 2, 125–126.

Allik, J. (2017) "Scientific publications: Estonia rises to the top". In K. Raudvere, ed. *Estonian Research 2016,* 27–32. Tartu: Estonian Research Council.

Clarivate Analytics (2017) *Introducing 2017's highly cited researchers.* Philadelphia: Clarivate Analytics.

Dutton, E., J. t. Nijenhuis, and E. Roivainen (2014) "Solving the puzzle of why Finns have the highest IQ, but one of the lowest number of Nobel prizes in Europe". *Intelligence* 46, 192–202. doi:10.1016/j.intell.2014.06.006

Estonian Research Council (2017) *Estonian Research 2016* (http://www.etag.ee/wp-content/uploads/2015/12/TA_teaduskogumik_ENG_veeb.pdf). Tartu: Estonian Research Council.

European Commission (2015) *Analysis of bibliometric indicators for European policies 2010–2013.* Brussels: Publications Office of the European Union.

Gaskell, A. (2017) "How Estonia became the digital leader of Europe". *Forbes*, June 23, 2017.

Hatemi-J, A., A. N. Ajmi, G. El Montasser, R. Inglesi-Lotz, and R. Gupta (2016) "Research output and economic growth in G7 countries: new evidence from asymmetric panel causality testing". Applied Economics 48, 24, 2301–2308. doi:10.1080/00036846.2015.1117052

Izsvák, Z., Z. Ivics, and L.Mátés, (2006) "Hungary's 'reforms' are threatening basic science". *Nature* 443, 394. doi:10.1038/443394a

Jaffe, K. (2011) "Do countries with lower self-citation rates produce higher impact papers? Or, does humility pay?". *Interciencia* 36, 9, 694–698.

Jurajda, S., S. Kozubek, D. Munich, and S. Skoda (2017) "Scientific publication performance in post-communist countries: still lagging far behind". *Scientometrics* 112, 1, 315–328. doi:10.1007/s11192-017-2389-8

Karlsson, S. and O. Persson (2012) *The Swedish production of highly cited papers.* Stockholm: Vetenskapsrådet.

King, D. A. (2004) "The scientific impact of nations". *Nature* 430, 6997, 311–316. doi:10.1038/430311a

Kozak, M., L. Bornmann, and L. Leydesdorff (2015) "How have the Eastern European countries of the former Warsaw Pact developed since 1990? A bibliometric study". *Scientometrics* 102, 2, 1101–1117. doi:10.1007/s11192-014-1439-8

Kristapsons, J., H. Martinson, and I. Dagyte (2003) *Baltic R&D systems in transitions: experiences and future prospects*. Riga: Zinatne.

Leydesdorff, L. and C. Wagner (2009) "Macro-level indicators of the relations between research funding and research output". *Journal of Informetrics* 3, 4, 353–362. doi:10.1016/j.joi.2009.05.005

Leydesdorff, L., C. S. Wagner, and L. Bornmann (2014) "The European Union, China, and the United States in the top-1% and top-10% layers of most-frequently cited publications: competition and collaborations". *Journal of Informetrics* 8, 3, 606-617. doi:10.1016/j.joi.2014.05.002

Martinson, H. (2015) *Isolatsioonist akadeemilisse kapitalismi: Eesti Teadusfond 1989–2011*. [From isolation to academic capitalism: Estonian Science Foundation 1898–2011.] Tallinn: Eesti Teadusagentuur.

Moed, H. F. (2005) *Citation analysis in research evaluation*. Dordrecht: Springer.

Must, Ü. (2006) "'New' countries in Europe – research, development and innovation strategies vs bibliometric data". *Scientometrics* 66, 2, 241–248. doi:10.1007/s11192-006-0016-1

Ntuli, H., R. Inglesi-Lotz, T. Y. Chang, and A. Pouris (2015) "Does research output cause economic growth or vice versa? Evidence from 34 OECD countries". *Journal of the Association for Information Science and Technology* 66, 8, 1709–1716. doi:10.1002/asi.23285

Okubo, Y. (1997) *Bibliometric indicators and analysis of research systems: methods and examples*. Paris: OECD Publishing.

Pajic, D. (2015) "Globalization of the social sciences in Eastern Europe: genuine breakthrough or a slippery slope of the research evaluation practice?". *Scientometrics* 102, 3, 2131–2150. doi:10.1007/s11192-014-1510-5

Pullmann, H., J. Allik, and R. Lynn (2004) "The growth of IQ among Estonian schoolchildren from ages 7 to 19". *Journal of Biosocial Science* 36, 6, 735–740. doi:10.1017/s0021932003006503

Solarin, S. A. and Y. Y. Yen (2016) "A global analysis of the impact of research output on economic growth". *Scientometrics* 108, 2, 855–874. doi:10.1007/s11192-016-2002-6

Thijs, B. and W. Glanzel (2006) "The influence of author self-citations on bibliometric meso-indicators. The case of European universities". *Scientometrics* 66, 1, 71–80. doi:10.1007/s11192-006-0006-3

van Leeuwen, T. N. and H. F. Moed (2012) "Funding decisions, peer review, and scientific excellence in physical sciences, chemistry, and geosciences". *Research Evaluation* 21, 3, 189–198. doi:10.1093/reseval/rvs009

van Leeuwen, T. N., M. S. Visser, H. F. Moed, T. J. Nederhof, and A. F. J. van Raan (2003) "Holy Grail of science policy: exploring and combining bibliometric tools in search of scientific excellence". *Scientometrics* 57, 2, 257–280. doi:10.1023/a:1024141819302

Vassil, K. (2018) "Eesti teaduse nutune külg: aparatuuri ja betooni meil on, kuid sente lugev valitsus ajab noorteadlased vägisi välismaale". [A tearful side of Estonian science: we have equpment and concrete but stingy government forces young scientist to go abroad.] *Postimees*, March 4, 2018.

Vinkler, P. (2008) "Correlation between the structure of scientific research, scientometric indicators and GDP in EU and non-EU countries". *Scientometrics* 74, 2, 237–254. doi:10.1007/s11192-008-0215-z

Vinkler, P. (2018) "Structure of the scientific research and science policy". *Scientometrics* 114, 2, 737–756. doi:10.1007/s11192-017-2568-7

Wagner, C. S. and K. Jonkers (2017) "Open countries have strong science". *Nature* 550, 7674, 32–33. doi:10.1038/550032a

Yasgul, Y. S. and B. Guris (2016) "Causality between research output in the field of biotechnology and economic growth in Turkey". *Quality & Quantity* 50, 4, 1715–1726. doi:10.1007/s11135-015-0230-0

APPENDIX 1

The list of Estonian researchers who reached 1% top citation rate in one or several research fields

	Researcher	Institution	Papers	Cites	Top Papers	Fields	HCR2017
1	Abarenkov, K	UT	35	2,667	11	Env/Ecol, Pla&AniSci	
2	Alavere, H	UT	8	2,873	4	MolBio&Gen	
3	Allik, J	UT	104	2,286	4	Psy	
4	Bahram, M	UT	108	3,067	11	Env/Ecol, Pla&AniSci	
5	Blinova, I	NICPB	22	1,293	4	Env/Ecol	
6	Brosche, M	UT	50	1,788	6	Pla&AniSci	
7	Choubey, V	UT	20	3,391	2	MolBio&Gen	
8	Davison, J	UT	149	4,098	8	Pla&AniSci	
9	Dubourguier, HC	EULS	15	2,060	4	Env/Ecol, Pharm&Tox	
10	Dumas, M	UT	98	1,066	1	Compu	
11	Esko, T	UT	193	17,554	42	MolBio&Gen	Yes
12	Giammanco, A	NICPB	716	21,746	48	Phys	
13	Heinlaan, M	NICPB	15	1,261	4	Env/Ecol	
14	Helm, A	UT	49	1,475	2	Env/Ecol	
15	Ivask, A	NICPB	45	2,592	7	Env/Ecol, Pharm&Tox	
16	Junninen, H	UT	103	4,912	17	Geo	
17	Kaasik, A	UT	57	3,547	2	MolBio&Gen	
18	Kadastik, M	NICPB	671	22,007	48	Phys	
19	Kahru, A	NICPB	69	3,877	9	Env/Ecol, Pharm&Tox	
20	Kasemets, K	NICPB	32	1,867	6	Env/Ecol, Pharm&Tox	
21	Kivisild, T	UT	85	3,834	3	MolBio&Gen	
22	Kohout, P	UT	41	1,207	3	Env/Ecol	
23	Kõljalg, U	UT	52	5,196	13	Pla&AniSci, Env/Ecol	Yes
24	Kollist, H	UT	33	1,460	6	Pla&AniSci	
25	Kutser, T	UT	39	1,314	2	Env/Ecol	
26	Kõressaar, T	UT	7	2,477	2	Biol&Biochem	
27	Laan, Maris	UT	121	4,110	6	MolBio&Gen	
28	Langel, Ü	UT	147	3,647	2	Pharm&Tox, Biol	
29	Leinsalu, M	NIHD	52	6,245	12	ClinMed, SocSci	
30	Leito, I	UT	125	2,205	0	Chem	
31	Liira, J	UT	76	2,495	3	Env/Ecol	
32	Mägi, R	UT	116	10,904	26	MolBio&Gen	
33	Mander, Ü	UT	89	2,066	4	Env/Ecol	
34	Merits, A	UT	83	1,369	0	Microb	
35	Metspalu, A	UT	282	19,436	46	MolBio&Gen	Yes
36	Metspalu, M	UT	53	3,137	4	MolBio&Gen	Yes
37	Mihailov, E	UT	73	5,755	18	MolBio&Gen	
38	Milani, L	UT	161	7,026	14	MolBio&Gen	
39	Moora, M	UT	64	3,126	11	Env/Ecol, Pla&AniSci	

To be continued

	Researcher	Institution	Papers	Cites	Top Papers	Fields	HCR2017
40	Morris, A P	UT	223	23,268	29	MolBio&Gen	
41	Müntel, M	NICPB	315	15,631	18	Phys	
42	Näätänen, R	UT	71	3,250	3	Neurosci&Behav	
43	Niinemets, Ü	EULS	181	7,564	22	Pla&AniSci	Yes
44	Öpik, M	UT	51	1,788	6	Pla&AniSci	
45	Org, E	UT	30	3,912	9	MolBio&Gen	
46	Parmasto, E	EULS	5	980	1	Pla&AniSci	
47	Pärtel, M	UT	78	2,887	8	Env/Ecol	
48	Parts, L	UT	36	7,376	5	MolBio&Gen	
49	Perola, M	UT	218	19,496	39	MolBio&Gen, ClinMed	Yes
50	Punab, M	UT	122	3,597	5	ClinMed	
51	Põldmaa, K	UT	22	1,102	3	Env/Ecol	
52	Raidal, M	NICPB/UT	731	23,728	54	Phys	
53	Realo, Anu	UT	73	1,986	5	Psy	
54	Rebane, L	NICPB	432	18,928	31	Phys	
55	Remm, M	UT	54	3,424	3	Biol&Biochem	
56	Snieder, H	UT	202	9,028	19	MolBio&Gen	
57	Tammesoo, M-L	UT	14	3,313	8	MolBio&Gen	
58	Tammeveski, K	UT	99	2,631	5	Chem	
59	Tedersoo, L	UT	86	5,264	18	Pla&AniSci, Env/Ecol	Yes
60	Tiko, A	NICPB	572	16,960	39	Phys	
61	Värnik, A	ESMHSI/ TLU	55	1,308	4	SocSci	
62	Veelken, C	NICPB	657	20,280	44	Phys	
63	Viigimaa, M	NEMCF/ TUT	53	11,024	12	ClinMed	
64	Villems, R	UT	73	3,972	3	MolBio&Gen	
65	Vilo, J	UT	49	1,857	6	Biol&Biochem	
66	Zobel, M	UT	119	5,694	16	Env/Ecol, Pla&AniSci	Yes

Notes: UT = University of Tartu; TUT TalTech?? = Tallinn University of Technology; NICPB = National Institute of Chemical Physics and Biophysics; EULS = Estonian University of Life Sciences; NIHD = National Institute for the Health Development; NEMCF = North Estonia Medical Centre Foundation; ESMHSI = Estonian-Swedish Mental Health and Suicidology Institute; Env/Ecol = Environment/Ecology; Biol&Biochem = Biology & Biochemistry; ClinMed = Clinical Medicine; Phys = Physics; Chem = Chemistry; Psy = Psychiatry/Psychology; MolBio&Gen = Molecular Biology & Genetics; PlaAniSci = Plant & Animal Science; Neurosci&Beha = Neuroscience & Behavior; Microb = Microbiology; ParmTox = Pharmacology & Toxicology; Compu = Computer Science; HRC2017 = Highly Cited Researchers 2017. Krista Fischer from University of Tartu is likely to be included but she cannot be separated from similar name variants.