ESTONIAN RESEARCH 2016

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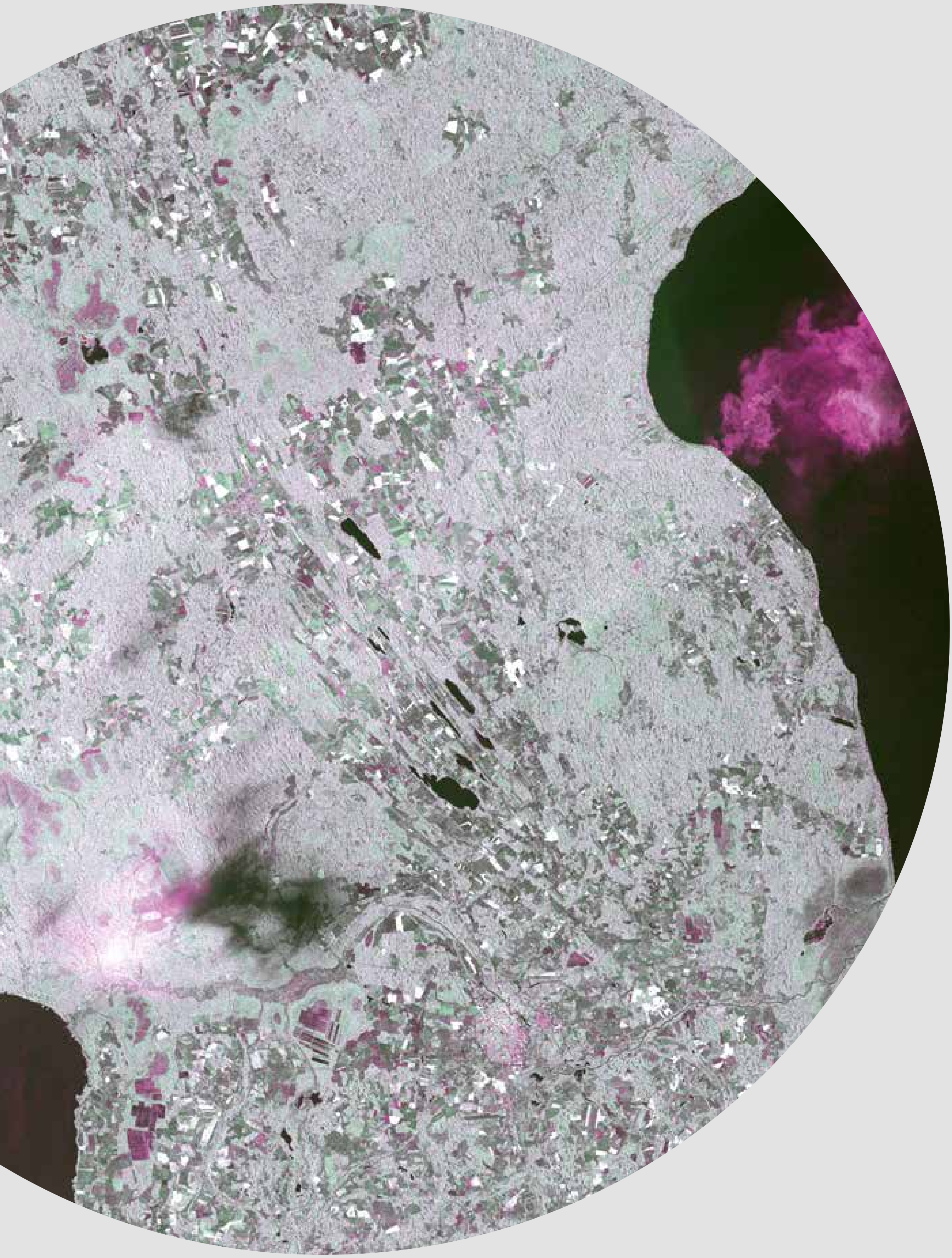


Thunderstorms over Estonia on 12th August 2015.
Copernicus Sentinel-1 synthetic aperture radar image.

Author: European Space Angency, data processing Kaupo Voormantsik (Tartu Observatory), 2015.

https://commons.wikimedia.org/wiki/File:Thunderstorms_over_Estonia_on_a_Copernicus_Sentinel-1_synthetic_aperture_radar_image.jpg

Foreword

Economic and social development on the one hand, and the activities of education and research institutions on the other, are interrelated and co-dependent in every country. Moreover, as a country becomes more prosperous, it becomes more important that its research can be converted into goods and services that benefit business and society. Both the overall quality and the value added of research are critical. And in a world that is changing ever more rapidly and becoming more complex, one must search for and uncover the tools and strategies that enable us to survive as well as grow. Undoubtedly, research plays a key role in this task. It is critical to keep in mind as well that in Estonia, our language and cultural development are directly connected to the performance of our education and research institutions.

From this report, we can see that with respect to many quality indicators, Estonian research is above OECD and EU averages. And it shows that in various areas, we very much need to improve. For example, we need closer relations between research and business, more private sector investment in research, more attention to raising the next generation of scientists, and more certain funding.

We can improve in the rankings to the extent that we meet these challenges. At the same time, gaining higher positions in rankings is not a goal in itself – the goal is to increase the economic and social impacts of our research. This raises the issue of risk management. Investment in research is inherently risky. We cannot predict with certainty which projects will yield results. But failing to invest means that we will not make progress. And so, our investment strategy should balance risks and opportunities.

Reliable statistics that allow for international comparisons are a prerequisite for adequately assessing our situation and developing smart research policy. This statistical overview, with expert commentary, provides a solid foundation for further discussion and decision.

I hope that it is also enjoyable reading!

Maris Lauri
Minister of Education and Research

Ants feeding.

Author: Heiti Paves (Tallinn University of Technology, Faculty of Science, Department of Gene Technology).

Introduction

Andres Koppel
Head of Estonian Research Council

How do we assess the quality of our research and the work of our researchers and how do these assessments comport with international standards? The answers to these and many other related questions can be found in numerous articles, statistical overviews, and databases.

Indeed, there is a great deal of information about Estonian research, development and innovation. Unfortunately, this information is dispersed in various channels and sources. In order to make information about Estonian research, researchers, and the relation between research and business more accessible, we decided to publish this overview.

The overview consists of two interrelated parts. The first part contains facts about Estonian research along with short commentaries. It is divided into four subsections. The first two subsections relate to available resources - ongoing financial support for scientific work, and the human resources that are available to the scientific community. The last two subsections describe the outputs one receives from combining financial and human resources. First is a look at outputs that can be relatively easily measured – publications. This is followed by outputs that are much more difficult to measure – the links between research and the economy. The second part of this overview consists of short articles on current research policy issues. To make the overview more concise for the reader, we have had to limit the material to themes that are currently most pressing in the development of the Estonian research system. The overview is illustrated by photos provided by Estonian researchers.

In order to assess our research system in a broader perspective, which includes expressing pride in our strengths, but more importantly, recognizing our weaknesses and risks, we must look at the development of our system over time and in comparison with over countries.

While the overview is dated "2016", we are only able to include data up to September of that year. And unfortunately, some of the data series end much earlier – for example in 2014 or earlier still. You will find data from OECD reports and databases, from Eurostat reports, from Statistics Estonia, from the Ministry of Education and Research, from the Universities Estonia, from Archimedes Foundation, and from the Estonian Research Council. Data on scientific publications also comes from the ISI Web of Science database of articles.

This overview and the figures that you find here are available on the webpage of the Estonian Research Council[1]. You can also find graphs and tables there that depict this information. Thus, anyone who is interested can use that information for further analysis, or if needed, use the graphics for presentations. An editorial board of three professors oversaw the compilation of this publication. They are Urmas Varblane, Jüri Allik and Tiit Tammaru. Staff from the Estonian Research Council provided terrific assistance in gathering the material, especially, analyst Kadri Raudvere and executive director Karin Jaanson. Many thanks to them and to the authors of the articles for their hard work.

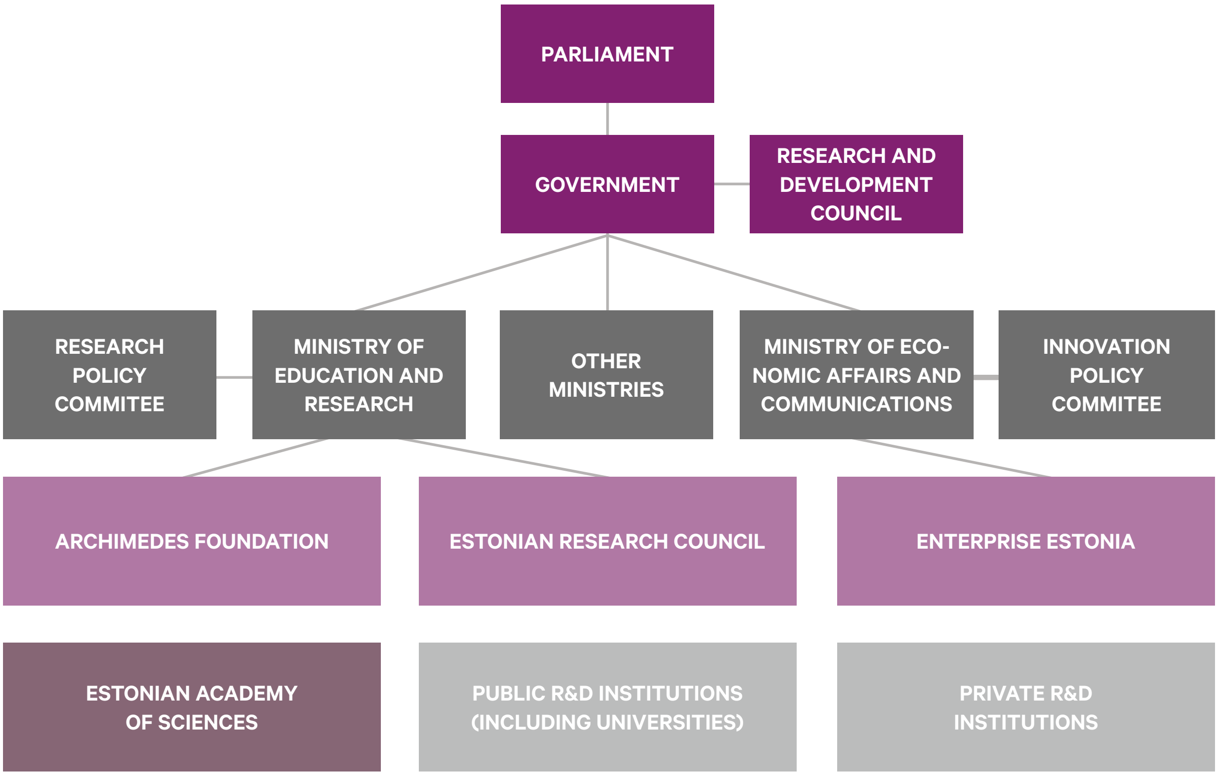
We hope that the data in this overview offers food for thought for researchers, policy makers, and others who are interested in this area. We also hope that the information provided will offer better opportunities for readers to participate in discussions about how Estonian research can contribute more to life in Estonia, and what should be done to promote the more rapid development of science.

The Estonian research system

The legal basis for the organization and functioning of the Estonian research system is the Research and Development Organization Act. Based on this act, parliament approves the overall research strategy, and once per year considers the prime minister's report on the execution of that strategy, as well as the state budget for research. The government develops actual research policy, prepares sectoral development plans and coordinates inter-ministerial cooperation. The Research and Development Council provides technical advice to the government as needed.

- The policymakers are the parliament and the government, who are advised by the Research and Development Council.
- The policies themselves are prepared by and implemented by the ministries. The Ministry of Education and Research is advised by the Research Policy Committee, and the Ministry of Economic Affairs and Communications is advised by the Innovation Policy Committee.
- Funding for organizing and supporting research comes through the Ministry of Education and Research and the Ministry of Economic Affairs and Communication. Under their supervision, the Estonian Research Council funds research and Enterprise Estonia funds innovation.
- Research and development work is carried out by universities and other public and private sector education and research institutions.
- The Estonian Academy of Sciences has a separate legal basis, and as an independent and high level association of researchers, contributes to solving problems related to Estonian research and social and economic development issues.

[1] Estonian Research Council. www.etag.ee.



Estonian research and development organization structure

Source: Estonian Research Council

Estonian research and development institutions

Twenty (20) research and development institutions have successfully passed regular evaluations. Among these are six (6) public universities: the University of Tartu, Tallinn University of Technology, Tallinn University, the Estonian University of Life Sciences, the Estonian Academy of Music and Theatre, and the Estonian Academy of Arts. Estonian researchers are mostly found in universities, where most of the research is done.

The number of research institutions has decreased over the years, as many have become affiliated with universities. And in 2016, negotiations began to merge a number of state or public sector research institutions with universities.

Public research institutions acting under the supervision of the Ministry of Education and Research include the Estonian Literary Museum, the Institute of the Estonian Language, Tartu Observatory and the Estonian Biocentre. Under the Ministry of Social Affairs is the National Institute for Health Development. Under the Ministry of Culture is the Estonian National Museum.

Only one public research institute operates pursuant to a separate and independent legal basis, the National Institute of Chemical Physics and Biophysics. The Under and Tuglas Literature Centre operates under the Estonian Academy of Sciences.

Six private research institutions have successfully passed evaluations: Cybernetica AS, Protobios OÜ, Estonian Business School, Vähiuuringute Tehnoloogia Arenduskeskus AS (Competence Centre for Cancer Research), Tervisetehnoloogiate Arenduskeskus AS (Competence Centre on Health Technologies), OÜ Tervisliku Piima Biotehnoloogiate Arenduskeskus (Bio-Competence Centre of Healthy Diary Products LLC).

Definitions and methodology

Public sector – for the purposes of this overview, this sector includes higher education sector and the government sector.

Private sector – for the purposes of this overview, this sector includes business enterprise sector and the private non-profit sector.

Individual entities within the public and private sectors are understood in accordance with international standards, where:

- business enterprise sector – includes all enterprises, organizations and institutions whose main activity is the production of goods or services (other than higher education), offered for sale at an economically viable price.
- higher education sector – includes universities and other institutions that offer higher education and all institutions under their direct control or associated with universities

(research institutes, clinics, science centers, etc.), regardless of their sources of financing or legal status.

- government sector – includes agencies and offices funded by government or municipalities whose main activities are not the production of goods or services for sale and which do not belong in the higher education sector. The sector includes also private non-profit institutions mainly financed by government.
- private non-profit sector – includes non-profit organizations, societies, funds, and their research units (excluding those primarily financed from government sources, or servicing private enterprises).

The following three sectors are included in the **non-profit sector** in order to distinguish them from the business enterprise sector.[2]

Personal Research Funding (PRF) – Project financing for individuals or working groups at research and development institutions for high level research. Financing is based on a public competition on terms and conditions set by the Estonian Research Council and approved by the Ministry of Education and Research. Applications are evaluated by the Estonan Research Council and funding is provided by the Ministry of Education and Research.

Institutional Research Funding (IRF) – Financing for the activities of high level research and development institutions (related to their research areas), and support to insure instiutional continuity and maintaining, developing and modernizing needed infrastructure. Funds for these purposes are allocated from the budget of the Ministry of Education and Research. Applications are evaluated by the Estonian Research Council.[3]

Baseline Funding – Financing of research and development institutions for the purpose of attaining their strategic development goals. This includes providing co-financing for domestic and international projects, opening new research directions, and investing in infrastructure. Baseline funding is allocated to research and development institutions that have received regular positive evaluations via the budget of the Ministry of Education and Research.[4]

[2] Definitions and Methodology. (2006). Statistics Estonia. – http://pub.stat.ee/px-web.2001/I_Databas/Economy/28Science._Technology._Innovation/04Research_and_development_activities/08RD_in_non_profit_sectors/RD_01.htm (31.10.2016).

[3] Research Funding 2016. Estonian Research Council. – http://www.etag.ee/en/funding/research-funding/ (02.11.2016).

[4] Base funding and centres of excellence. Ministry of Education and Research. –https://www.hm.ee/en/activities/research-and-development/base-funding-and-centres-excellence (02.11.2016).

The spore-forming structures of mold *Aspergillus sp.*

Author: Sulev Kuuse (Institute of Molecular and Cell Biology, University of Tartu), 2007.

Research and development expenditure: an investment in the future

Andres Koppel
Head of Estonian Research Council

Introduction

The share of research and development expenditure (hereafter "R&D expenditure") of gross national product is one of the simplest indicators for comparing the development capacity of countries. The general rule is that the larger the share of R&D expenditure, the more competitive the economy will be and thus, the higher the standard of living of the population over time. Today's R&D expenditures are essentially an investment in the country's future.

It is no surprise, therefore, that most European countries, including Estonia, embrace the strategic objective to increase their R&D expenditures. By the year 2020, it is hoped that the total R&D expenditure in Estonia will increase to 3% of its GDP, with 1% from the public sector and 2% from the private sector.[5]

But if research is to act as the well-oiled engine for the benefit of society and the state, more is needed than just increased financing. It is essential as well, that the system that produces research becomes more efficient, and that all of the links between research and society become more active.

The following overview focuses, however, on just one aspect of the research system - R&D expenditures.

Estonia lags behind other developed countries in R&D expenditures

Estonia's R&D expenditures over the last ten years reflect two general trends (Figure 1.1). First, the level of public sector expenditures (hereinafter, this includes spending by government and higher education sector) has remained relatively stable, although there was a decrease after the recession of 2009, followed by a small net increase. The increase has come mainly from EU Structural Funds. Second, the share of R&D expenditures by the private sector (hereinafter this includes spending by the business sector and the private non-profit sector)[6] has fluctuated considerably from year to year, for example, in the period from 2008 to 2014 varying by a factor of three. The interim increase seen in the years 2011 and 2012 was due to large, one time investments into the R&D in the energy sector. The increase in the share of private R&D expenditure in 2011 to approximately 1.5% of GDP raised the overall share of R&D expenditures to 2.3% of GDP, which placed Estonia in an excellent global position. By 2014, however, the share of private sector spending was just 0.64% and that of the public sector, 0.79% of GDP.

Estonia remains in the lower half among the countries monitored by the OECD for their levels of R&D expenditures as a percentage of GDP (Figure 1.2). Estonia's R&D expenditures are one third of those of countries at the top of the list, such as Korea and Israel and less than one half of Finland, Sweden and Denmark. The main reason for Estonia being left behind is the low level of R&D expenditures by the private sector. From Figure 1.2, in thirty countries, private sector R&D expenditures are larger than those of the public sector. In only seven countries (Estonia, Portugal, Turkey, Poland, Slovakia, Greece, and Romania) are public sector R&D expenditures higher.

We should keep in mind that the share of R&D expenditure as part of GDP reflects the relative effort of society to invest in its research system. In light of the large differences between the actual GDP levels of various countries, the differences in actual R&D expenditures is even more dramatic. As public sector research is one of the most competitive fields in the world, with open labor markets, large differences in levels of research funding become a significant factor in the mobility patterns (and migration) of researchers. How does this impact Estonia? Very simply put, if the Estonian R&D system does not become more attractive – or if it becomes even less attractive – compared to other countries, then we are at risk of losing our talent, and the idea of attracting researchers from other countries to Estonia will remain an unfulfilled dream.

The linkages between research performers and those financing research are complex (Figure 1.3). And R&D expenditure statistics from various sources may be confusing to readers who are not familiar with the nuances of the statistical data. It is important to see who is funding research, and where this work is done and the expenditures incurred. The main financier of R&D in Estonia is the government. Most of the funding provided by the government (90%) goes to research in the public sector, with approximately 10% allocated to the private sector. Likewise, private sector R&D financing tends to stay in the private sector, indeed even more so (94%). Only 6% of private sector R&D financing goes to fund research by universities and research institutes. An in depth analysis of the money flows between sectors in Estonia with comparisons to other countries can be found in the article by Professors Varblane and Ukrainski in this publication.

Of the funds coming to Estonia from abroad (more than half of which come from EU Framework Programmes and less than half from private business contracts), approximately two-thirds go to the public sector and one-third to the private sector.

[5] According to the Estonian Research and Development and Innovation Strategy 2014-2020 'Knowledge-Based Estonia', the R&D funding from the government budget and local government budgets was supposed to increase to 1% of GDP by 2015 and stay at that level. (Estonian Research and Development and Innovation Strategy 2014-2020. „Knowledge-based Estonia". (2014). Ministry of Education and Research. – https://www.hm.ee/sites/default/files/estonian_rdi_strategy_2014-2020.pdf (02.11.2014))

[6] As the private sector also includes the non-profit sector, the respective expenditure ratios do not fully match the business enterprise intramural expenditure on R&D (BERD) often used internationally.

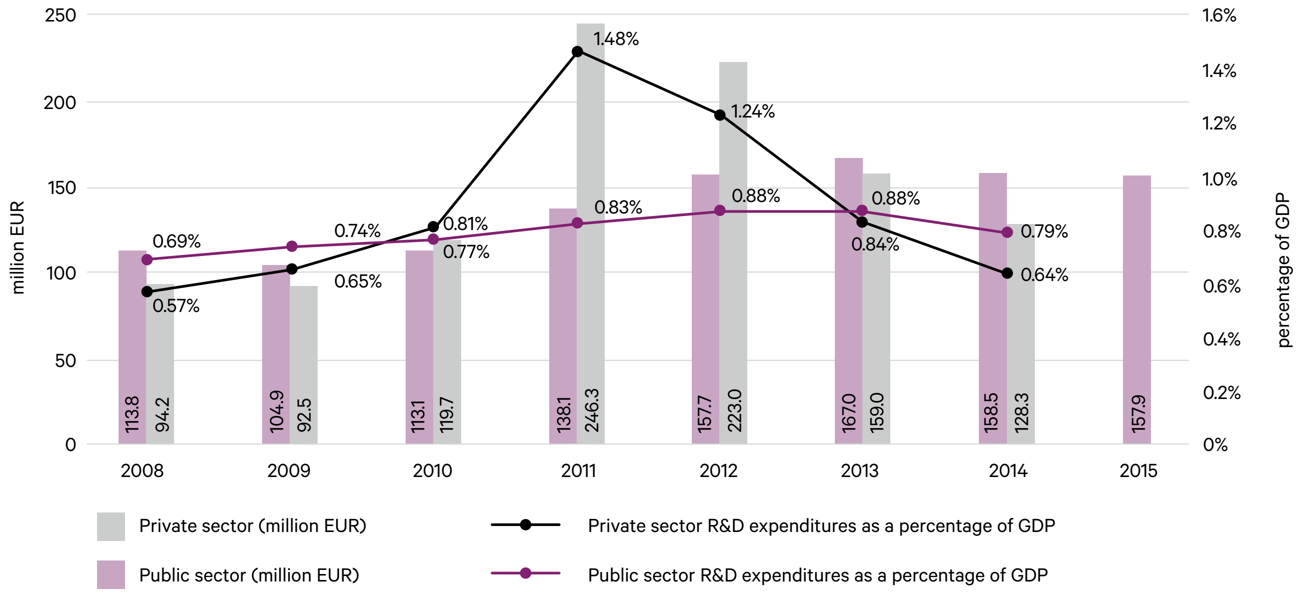


Figure 1.1. Gross domestic expenditure on R&D in Estonia (million EUR and as a percentage of GDP) from 2008 to 2014.

Source: Statistics Estonia[7]; there was no data for 2015 at the time this publication was compiled.

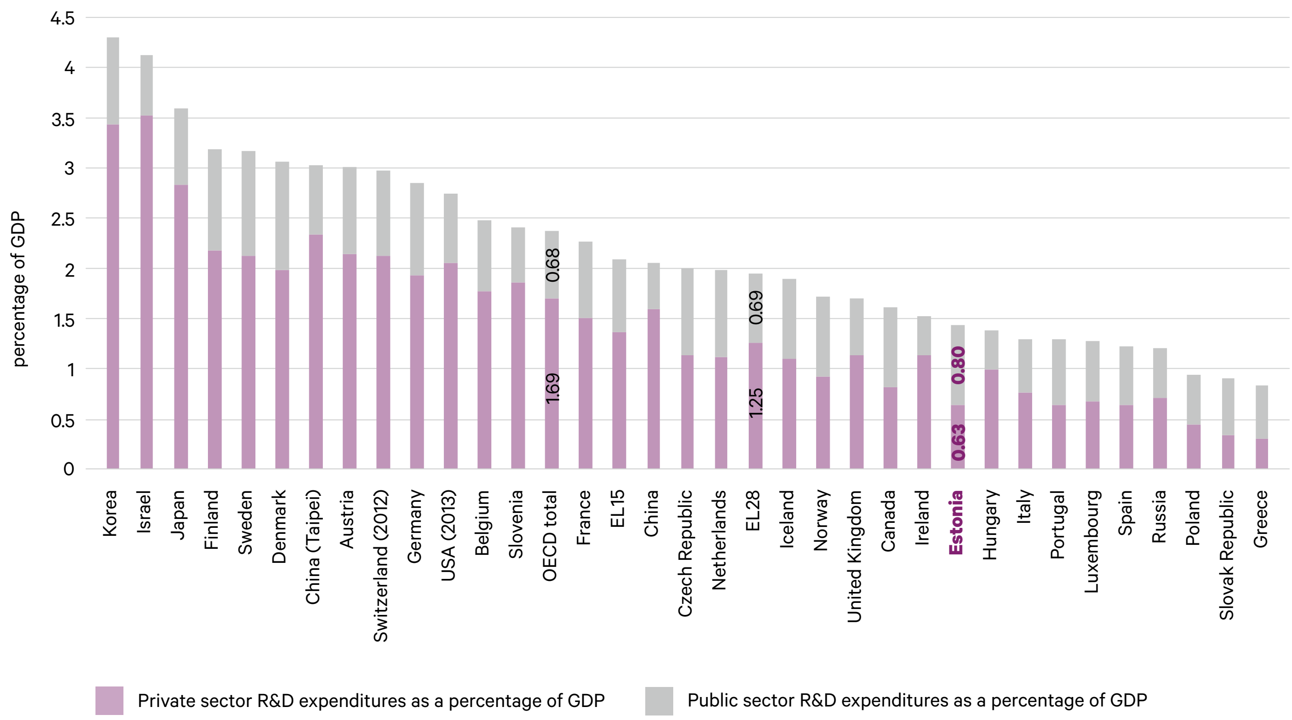


Figure 1.2. Gross domestic expenditure on R&D as a percentage of GDP in 2014.

Source: OECD.[8,9]

[7] Statistics Estonia. www.stat.ee (20.10.2016).

[8] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

[9] Minor divergent on Figures 1.1 and 1.2 (ratios differ 0,01 percentage points in 2014) result from different number of decimal places provided by different data sources (OECD and Statistics Estonia) that after rounding result in slight differences.

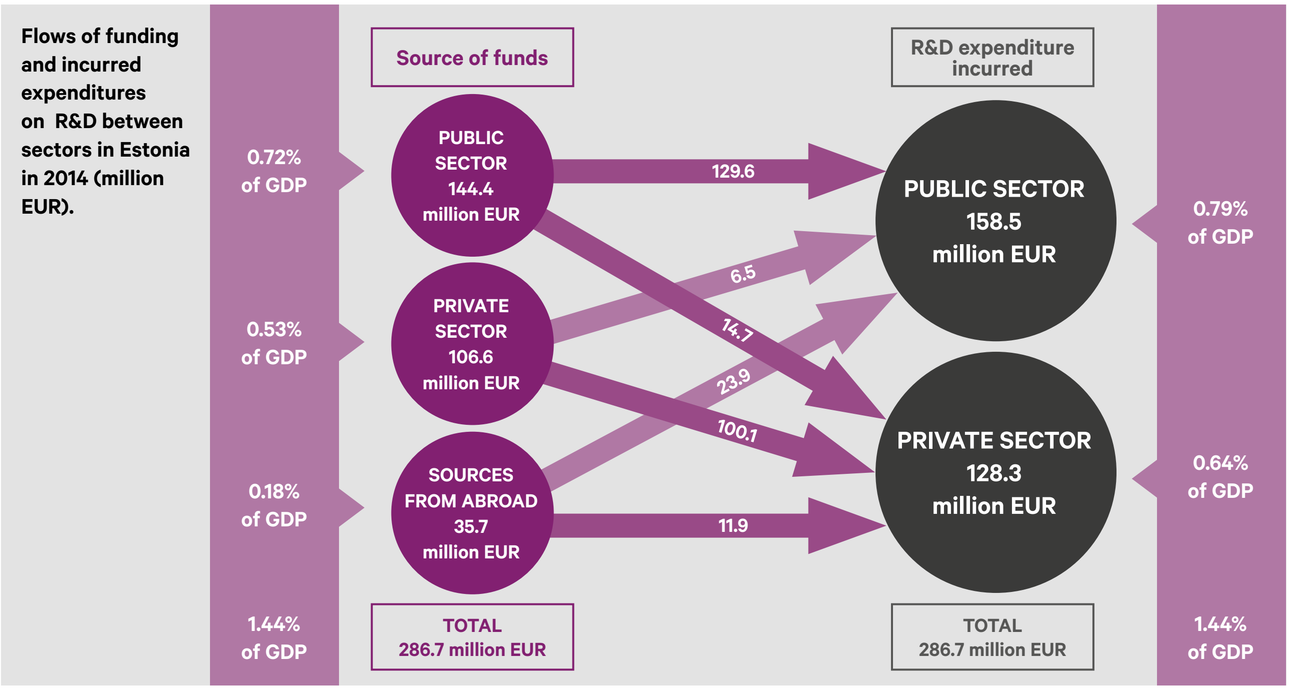


Figure 1.3. Flows of funding and incurred expenditures on R&D between sectors in Estonia in 2014 (million EUR).

Source: Statistics Estonia[10] and OECD[11], calculations by Estonian Research Council.

From 2008 to 2014, the relative share of public and private sector R&D expenditures often changed (Figure 1.4). This was caused by volatility in both private and public sector funding. The availability of EU Structural Funds caused the volatility in public sector funding (for example, investments in large research facilities). Foreign funding is on a growth path. Annual fluctuations in foreign funding are largely caused by the cyclical nature of EU framework funding (see also Figure 1.10).

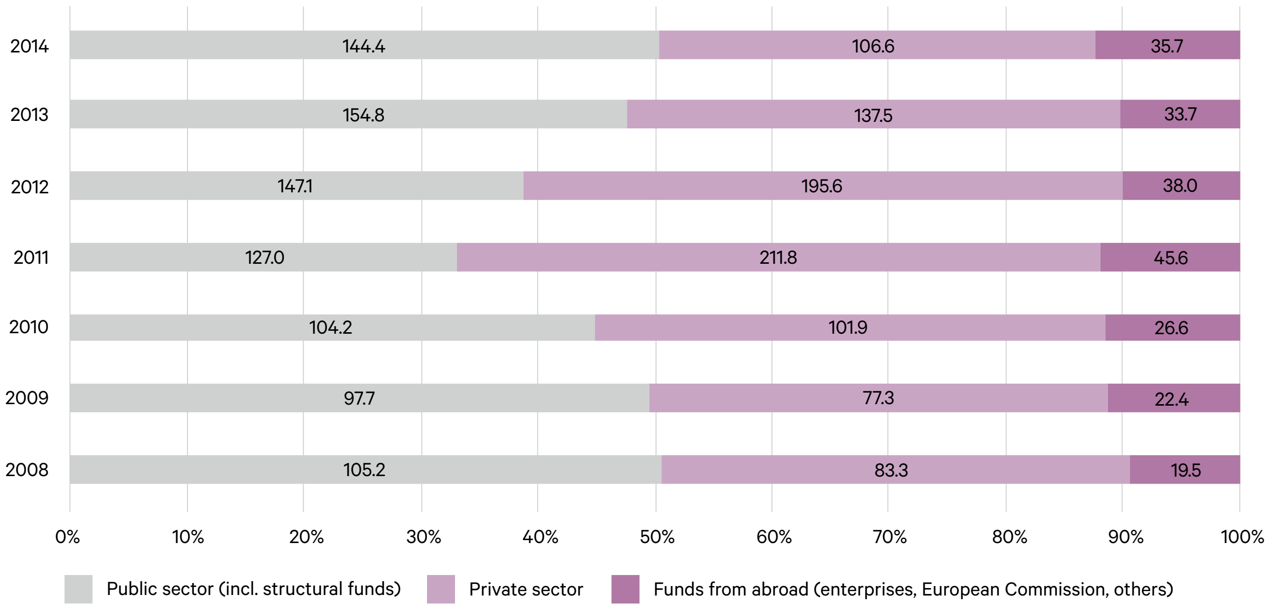


Figure 1.4. Gross domestic expenditure on R&D in Estonia by source of funds from 2008 to 2014. Bars show the proportions (%) of R&D funding sources, and figures refer to respective volume of expenditure (million EUR).

Source: OECD.[12]

[10] Statistics Estonia. www.stat.ee (10.10.2016).

[11] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (07.10.2016).

[12] Reseach and Development Statistics. (2016). OECD. – www.oecd.org/sti/rds (07.06.2016).

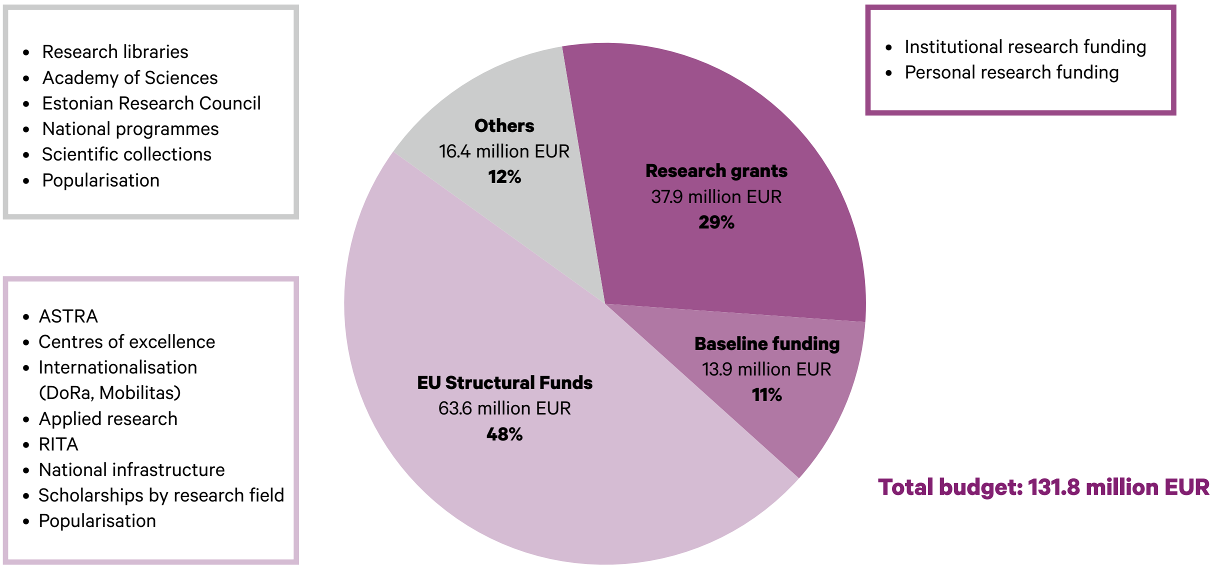


Figure 1.5. The research budget of the Ministry of Education and Research and its main components (million EUR) in 2016.

Source: Government Budget.

Estonian research is highly dependent on EU support

Investment in R&D by the Estonian government is tightly linked to EU Sructural Funds. So, from 2011 to 2015, EU Structural Funds comprised more than half of the research budget of the Ministry of Education and Research[13]. This situation, where a large portion of the research budget depends on temporary funding sources, is very dangerous. In 2016, the percentage has dropped to less than half, 48% (Figure 1.5). This was caused both by a reduced level of R&D funding from EU Structural Funds as well as an increase in the Estonian permanent budget for research, which is a positive development. Estonian Research and Development and Innovation Strategy 2014 - 2020 (hereinafter the R&D Strategy)[14], sets forth that in order to free ourselves of dependence on structural funds, we need to develop an appropriate plan well in advance. In order to reduce this dependency and stabilize the Estonian research system, it is inevitable that we need to increase permanent funding on an ongoing basis.

Changes in financing allocations between research fields are not significant

In general, the pattern of public sector spending on the various fields of research has been rather stable over the years (Figure 1.6). The largest share has gone to the natural sciences, engineering and medicine. A closer inspection reveals that compared to the average increase in expenditures over the six year period (which was 1.4 times) the share of social sciences, medicine, and life sciences has increased slightly. The share of engineering, agricultural sciences and the humanities has somewhat decreased.

The largest part of the Ministry of Education and Research budget for research is composed of research grants and baseline funding for research institutions. These are the main financial instruments the government uses to maintain the broad range of research work.

This started to change in the year 2012 when Estonian Research Foundation grants (hereinafter ERF grants) were transformed into personal research grants (hereinafter PRG) and targeted research grants into institutional research grants (hereinafter IRG). Figure 1.7 provides background about these changes. In 2016, ERF grants and targeted research grants ended almost completely. Figure 1.7 shows the decrease in financing during the recession, stagnation in the following period, and then a slow but steady increase from the year 2013. 2008 levels were not achieved again until 2015. The lion's share of this increase is in baseline funding.

The distribution of research funding among the four ETIS research fields [15] has been very stable throughout years (Figure 1.8). Neither the Estonian Research Foundation nor the Scientific Competence Council or, since 2012, the Evaluation Committee of the Estonian Research Council has considered it necessary to change the proportions of funding between these fields. It would have been especially difficult during the period when funding levels were stagnant.

[13] The share of structural funds is even bigger in the budgets of other ministries.

[14] Estonian Research and Development and Innovation Strategy 2014-2020 „Knowledge-based Estonia“. (2014). Ministry of Education and Research. – https://www.hm.ee/sites/default/files/estonian_rdi_strategy_2014-2020.pdf (02.11.2014).

[15] Estonian research information system fields of research. Estonian Research Portal. – https://www.etis.ee/Portal/Classifiers/Index (02.11.2016).

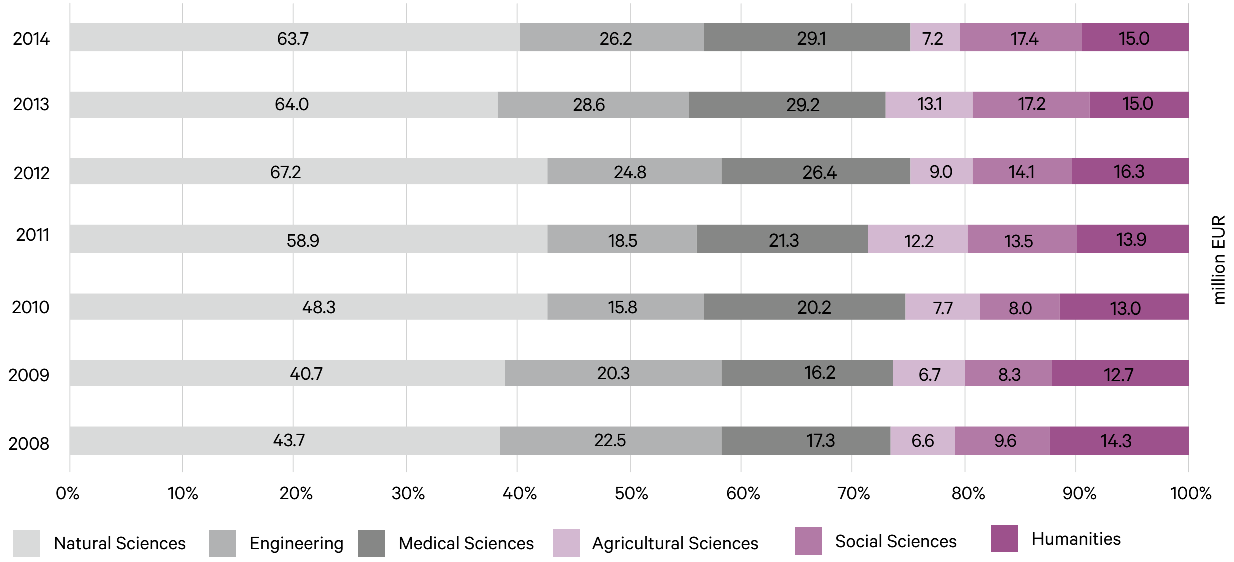


Figure 1.6. Public R&D expenditures by research fields in the period from 2008 to 2014.

Source: Statistics Estonia.[16]

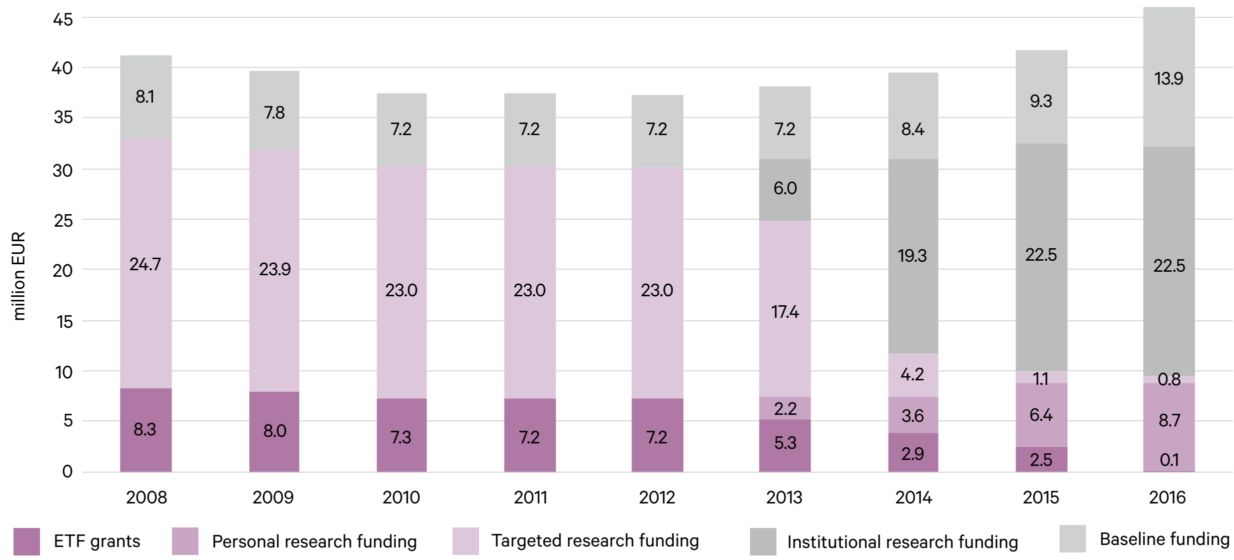


Figure 1.7. Funding of personal and institutional research funding, ERF grants, targeted research funding and baseline funding in the period of 2008 to 2016 (million EUR).

Source: Estonian Research Council.

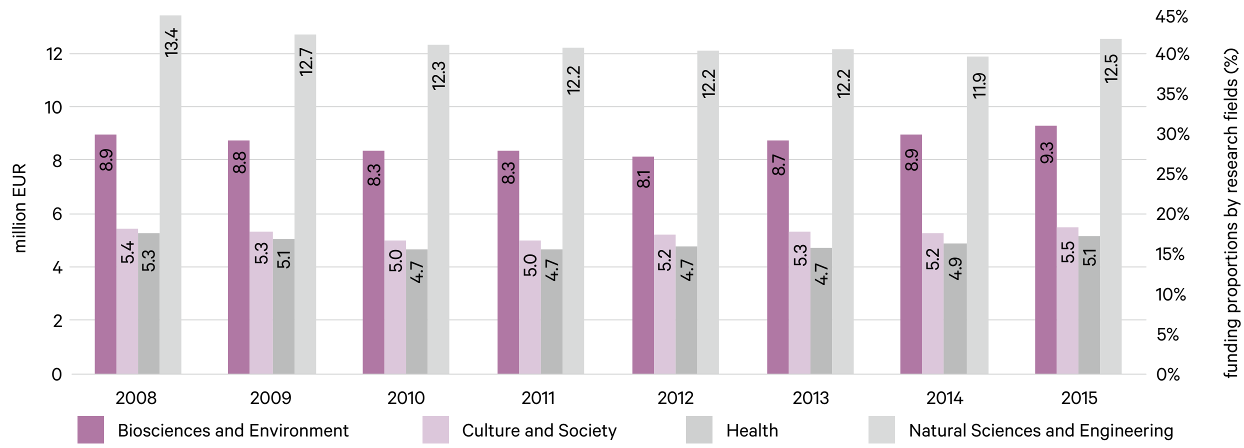


Figure 1.8. Funding of personal and institutional research funding, ERF grants, targeted research funding and baseline funding 2008-2015 (million EUR) and as percentage of proportion (%) among the four ETIS research fields.

Source: Estonian Research Council.

[16] Statistics Estonia. www.stat.ee (23.10.2016).

Competition in applying for research funding is intense

Both personal and institutional research grants are provided on a competitive basis. This competitive approach, using high quality standards to evaluate applications, has been one of the fundamental principles of the R&D system that was adopted after Estonia regained its independence. Applying these principles certainly has been a very important foundation that enabled the leap in quality that Estonian research has achieved (see the article of Prof. Allik in this publication).

The success rate of IRG applications has been almost twice as high as PRG applications. From year to year, the intensity of IRG competition has varied. This has depended on the level of financing available for new topics, which has varied from year to year. Success rate of IRG applications could be considered quite high in comparison with the conventional research grant applications. But in view of the institutional nature of this funding scheme, this competition has been overly intense, resulting in certain research fields receiving no funding and others being severely underfunded.

The competition for personal research grants has been most intense in the fields of culture and society, as well as in the natural sciences and engineering. In these fields, the success rate usually has been below 20%. In the last decade, competition for research funding has intensified all over the world. Even if the competition in many countries is even more intense than in Estonia we can consider the 20% success rate as too low. Such a low rate wastes time, a scarce resource for researchers, makes the application process cumbersome, and wastes money.

Table 1.1. Average success rate in institutional and personal research grants application rounds (by project commencement year).

	Share of funded projects among all applications				
	Biosciences and Environment	Natural Sciences and Engineering	Health	Culture and Society	Total
IRG 2013	50.0%	40.0%	77.8%	26.7%	41.3%
IRG 2014	68.6%	59.1%	64.3%	48.5%	59.5%
IRG 2015	50.0%	39.4%	50.0%	30.4%	40.5%
PRG 2013	23.1%	22.2%	26.7%	18.3%	21.6%
PRG 2014	9.8%	14.0%	21.7%	11.1%	13.1%
PRG 2015	28.0%	21.2%	35.3%	18.8%	23.0%
PRG 2016	27.1%	16.8%	27.3%	13.1%	19.0%

Source: Estonian Research Council.

Table 1.2. Centres of excellence in the period of 2008 to 2022 and funding volumes (million EUR) for the whole funding period.

2008–2015	Total budget (million EUR)	2016–2022	Total budget (million EUR)
Centre of Excellence in Environmental Adaptation	**3.1**	Ecology of global change: natural and managed ecosystems	**4.4**
Mesosystems - Theory and Applications	**2.9**	The Dark Side of the Universe	**4.0**
High-technology Materials for Sustainable Development	**2.9**	Emerging orders in quantum and nanomaterials	**3.9**
Dark Matter in (Astro)particle Physics and Cosmology	**1.5**	Advanced materials and high-technology devices for sustainable energetics, sensorics and nanoelectronics	**4.7**
Centre for Nonlinear Studies	**2.7**	Centre of Excellence for Genomics and Translational Medicine	**5.1**
Frontiers in Biodiversity Research	**4.3**	Center of Excellence in Molecular Cell Engineering	**4.8**
Centre of Excellence in Genomics	**4.8**	Centre of Excellence in Estonian Studies	**4.8**
Translational research for improvement of diagnostics and treatment of neuroimmunological diseases	**5.0**	Zero energy and resource efficient smart buildings and districts	**4.4**
Estonian Excellence in Computer Science - EXCS	**4.2**	Estonian ICT Centre of Excellence in research - EXCITE	**5.1**
Center of Excellence in Chemical Biology	**5.6**		
Centre of Excellence in Cultural Theory	**4.8**		
Centre for Integrated Electronic Systems and Biomedical Engineering	**4.7**		
	46.5		**41.2**

Source: Estonian Research Portal (ETIS).[17]

[17] Estonian Research Portal. www.etis.ee (22.10.2016).

A very important scheme for funding excellence in research is support for centres of excellence, which had support from the second and third stages of EU Structural Funding. Each centre of excellence includes research teams from different research institutions. Centres of excellence create useful opportunities to develop cooperation between research institutions and teams, as well as international cooperation, to support the next generation of researchers, and to popularize research results. The OECD has emphasized the importance of centres of excellence as a tool that countries are using more frequently after the last economic crisis in order to increase productivity and restore economic growth[18].

Estonian research funding is mainly based on competition

Research funding instruments can be divided according to the decision making mechanism used for financing or according to the relationship between funder and user of resources into competition- or non-competition based instruments. But this distinction may be oversimplified and imprecise. Instead, a more accurate way of analyzing the instruments may be division of funding instruments into thee categories based on how free the recipients of funds are to choose research themes and topics. The choice of themes or projects is completely free in the typical grant framework (such as the ERF and the IRG and PRG, from the Estonian Research Council) where the grants are funded on the basis of competition[19]. In programme funding, the funder defines the programmes but the choice of projects may still be free. Competition may remain the basis for receiving a grant. Non-programmatic funding is typically institutional block funding.

Nevertheless, dividing the funding methods into two categories (competitive funding, whose most common form is project funding, and non-competitive funding, whose most common form is institutional block funding) can be useful for generating some general research policy conclusions. Data on the division of research funding mechanisms between these categories for country comparisons is incomplete. Though data is available for the key public sector research institution, universities.

OECD data on the ratio of project-based and institutional block funding shows significant variation by country (Figure 1.9). The share of project funding is the highest (65–71%) in Chile, Korea, New Zealand and Ireland; and it is the lowest in Switzerland, Austria, Netherlands and Denmark, where the permanent funding of institutions is from 25-35%. The two funding methods are almost equally important in Finland, Czech Republic and Norway.

Statistics Estonia has not gathered this type of data. For that reason, the data for Estonia in Figure 1.9 is a compilation of data from the three main instruments the Estonian government uses for funding research. It shows the proportion of grant funding (IRG + PRG) and baseline funding. Baseline funding only started in 2005 and in that year, the ratio of project to baseline funding was 90:10. Ten years later in 2015, the ratio was approximately 80:20. In 2016, when baseline funding increased by 50%, the ratio was 73:27. We might note that most EU Structural Funds support schemes are competition based. Estonian universities receive block funding to provide higher education, and a portion of that is used to fund research. This somewhat reduces the pressure from relying on competitive funding. The small proportion of baseline funding limits the ability of the universities and research institutes to make strategically important choices. It is now universally accepted that the goal for the coming years should be to significantly increase baseline funding to institutions in order to reach a 50:50 ratio.

Estonian research is increasingly successful in EU Framework Programmes

Estonian researchers (and also private sector institutions and enterprises) have increased their participation in EU R&D Framework Programmes over the years. Although the number of successful project applications and the overall amount of funding fluctuate from year to year due to the cyclical nature of the programming, the overall growth trend is significant. So, for example, from 2005, the amounts received from framework programme projects has exceeded the amount provided through Estonian Research Foundation grants, and after that, it exceeded the amount provided through personal research funding. In recent years, the difference is more than two fold (Figure 1.10).

Estonian researchers have proven to be very successful in international competition. If you compare the ratio of financial resources received through Horizon 2020 competitions and GDP, Estonia has been three times more successful than the EU average. If we eliminate the effect of a lower than average GDP, and use per capita H2020 funding, Estonia is still in a good position, exceeding the EU average by one and a half times (Figure 1.11).

There are several factors that explain our success in EU Framework Programmes. The main factors are the high professional level of our researchers, their high level of credibility in the eyes of our foreign partners, readiness to write competitive projects, willingness to work with foreign partners and a well-functioning framework support service. International connections are, in turn, a factor that contributes to a higher level of research quality (see the article of Prof. Allik in this publication). There is an amplification effect: international cooperation is successful if our researchers work at a high professional level, simultaneously the quality of research increases due to this same cooperation.

Although increasing the amount of research funding from international sources is one of research policy objectives in Estonia, a significant increase is most likely not possible. Our involvement in international research cooperation is already quite large. We might improve further if our researchers take more leading roles in international cooperation networks.

[18] OECD (2014), *OECD Science, Technology and Industry Outlook 2014, OECD Publishing. – http://dx.doi.org/10.1787/sti_outlook-2014-en* (22.10.2016).

[19] The effectiveness of national research funding systems. (2014). Dialogic and Empirica on behalf of the European Commission. – http://ri-policy-analysis.eu/studies/the-effectiveness-of-national-research-funding-systems/ (22.10.2016).

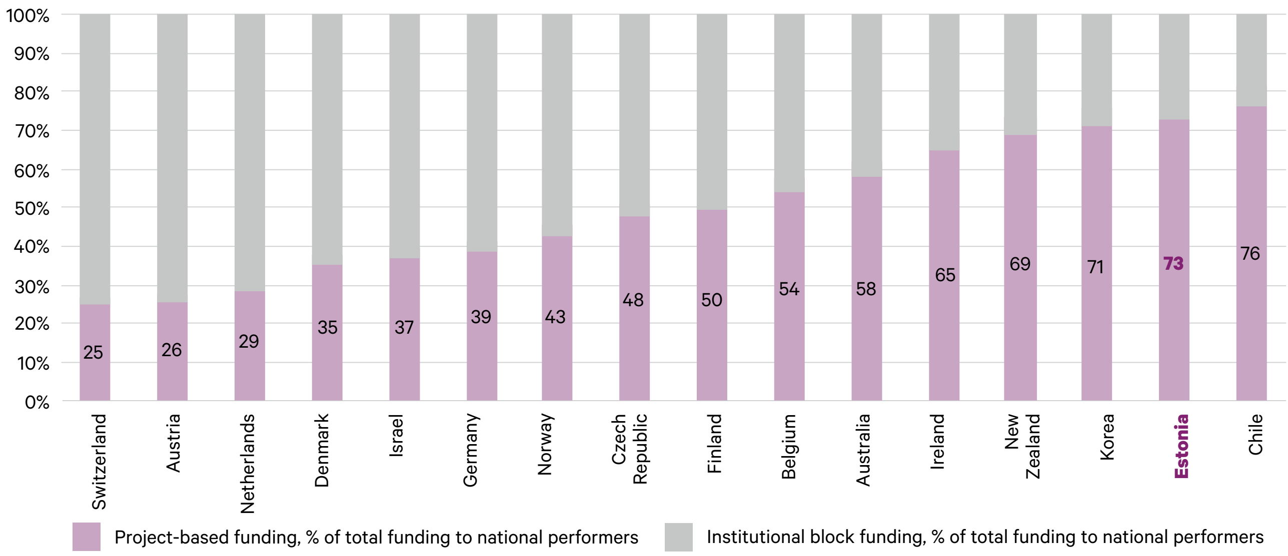


Figure 1.9. The share of project-based funding in total funding in 2011 (or in any other year on which data is available and in 2016 (Estonia).

Source: OECD[20] and Estonian Research Council (Estonia, 2016).

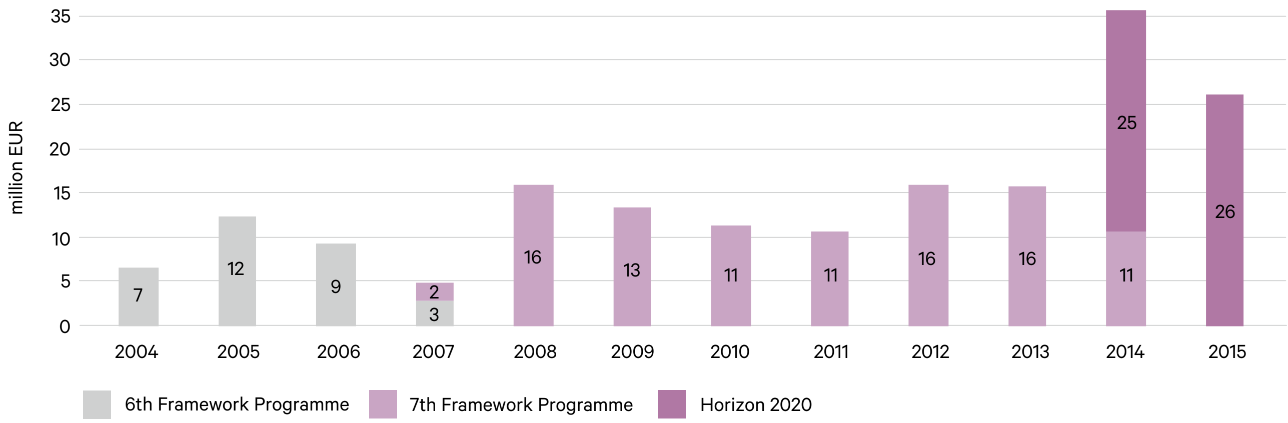


Figure 1.10. Financial contribution from EU Framework Programmes to Estonia 2004-2015 (amounts of signed contracts, million EUR).

Source: Estonian Research Council.

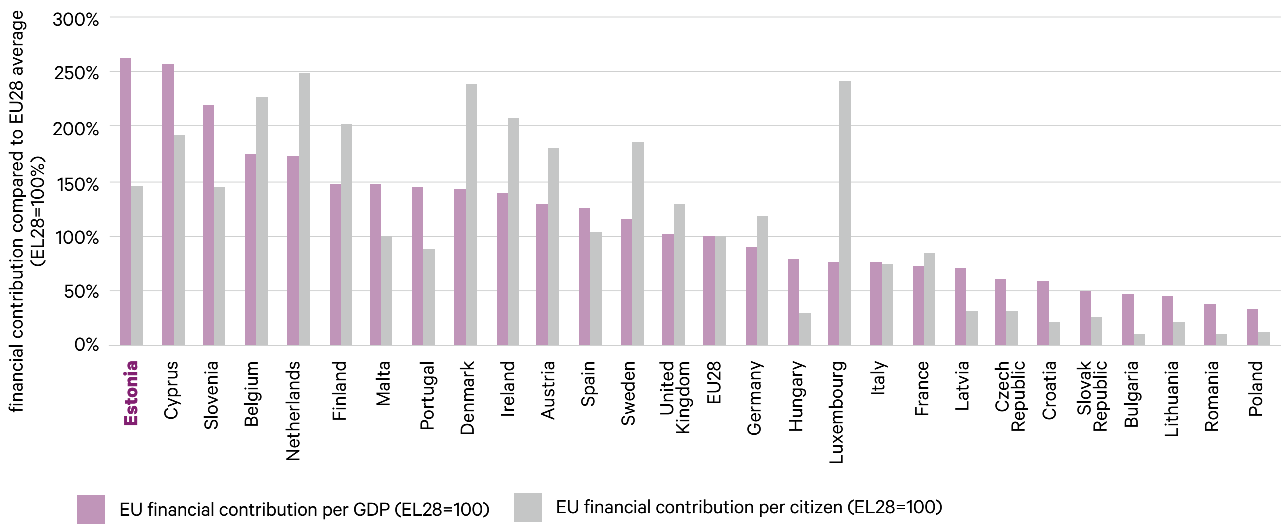


Figure 1.11. EU financial contribution from Horizon 2020 by participating countries per GDP and per citizen in 2016 compared to EU28 average (EU28=100).

Source: Ministry of Education and Research (eCorda database, extraction date 30.09.2016).

[20] OECD (2014), *OECD Science, Technology and Industry Outlook 2014, OECD Publishing. –http://dx.doi.org/10.1787/sti_outlook-2014-en* (22.10.2016).

Doctoral degree holders and researchers in the labour market: Estonia compared with other European countries

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Introduction

One of the most influential country ranking indicators, the Human Development Index, has three components, with education being one of the three. A high level of education is the key to success both for countries and individuals. In general, the higher the level a person's education, the higher his or her income will be. Moreover, the more educated a population, the wealthier society will be as a whole. In other words, the ability of society to help individuals receive ever higher levels of education is a critical driver of development.

Just 50 years ago, higher education was still a privilege for the few, both in Estonia and elsewhere in the world. In 1980, most young people in Estonia received only basic, secondary, or vocational education (Figure 2.1). However, technology has done away with many jobs that require only a basic or secondary level of education and this trend is expected to accelerate over the next 50 years.

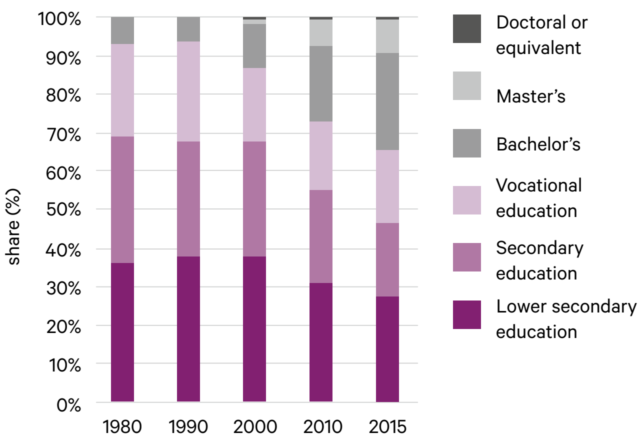


Figure 2.1. Proportions of all persons who completed any level of education according to year of graduation, 1980-2015.
Source: Statistics Estonia.[21]

The last twenty years have brought explosive growth in higher or tertiary education, and receiving higher education has become the norm for younger generations; for example, in OECD countries, 30 to 50% of persons between the ages of 25 to 34 have completed at least the first level of higher education. In Estonia, the figure is 40%, which is very similar to our neighbours, Finland and Latvia.

Now that higher education has become a norm, the next critical question is what changes do we see in tertiary education: how many people stop, for example, with just a bachelors degree, and how many will go forward to obtain a masters and doctoral degree? It is important how many people reach the highest levels of education (i.e. a doctoral degree) and whether the public sector and private businesses are able to offer suitable employment to the growing number of persons with those degrees.

This article focuses on changes within the highest level of education: changes in the numbers of persons holding doctoral degrees, their employment in the public and private sectors, and comparisons between Estonia and other OECD and EU member states. The results indicate that both with respect to students gaining doctoral degrees and researchers participating in the labour market, Estonia is lagging behind, along with other Eastern and Southern European countries. Estonian society and its economy have not been able to generate the same volume of people climbing the education ladder to the highest level as the more successful education systems in western and northern European counties.

There are fewer Estonian workers with doctoral degrees than in successful European countries

According to Statistics Estonia, 29 people defended their doctoral degrees in 1995 and 208 in 2015. Thus, the relative growth in the number of doctoral degree holders has been impressive. and in the period from 1991 to 2015, a total of 3,272 people received doctoral degrees in Estonia. How does this compare with other countries? It turns out, not very well. While the percentage of young people acquiring higher education in Estonia is similar to the OECD average, the percentage of persons with doctoral degrees places Estonia at the lower levels. There are 5 to 10 PhD holders per thousand working age population in OECD countries. In Estonia, the figure is 4, which is very close to Portugal and Italy. Among OECD countries, Switzerland outperforms everyone, with 28 PhD holders per thousand working age population (Figure 2.2). It is also one of the world's richest countries. The linkage between the percentage of persons with doctoral degrees and country wealth is not uniform. Norway is a major exception to the general rule. It is among the wealthiest countries but has only an average percentage of PhD holders. Its wealth, however, is based on its natural resources.

In the OECD, the lion's share of PhD holders work in the public sector. In the private sector, Switzerland leads once again, with one in four PhD holders working in that sector. Data is lacking for many countries, but it can still be said that Estonia – with only 8% of PhD's in the private sector – is closer to eastern and southern European countries than northern and western European countries. For example, in Norway and Finland, one-fifth of PhD holders are employed in the private sector and in Austria and Belgium, the figure is one-fourth. Over the last

[21] Statistics Estonia. www.stat.ee (10.10.2016).

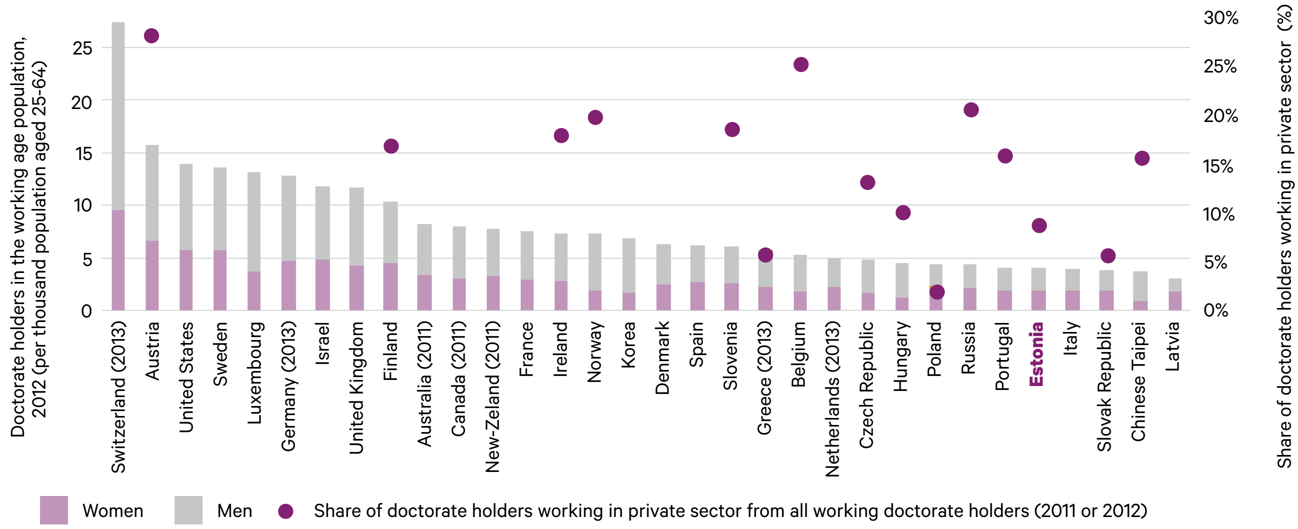


Figure 2.2. Doctorate holders in the working age population (per thousand population aged 25-64, year 2012) and share of doctorate holders working in private sector (2011 or 2012).

Source: OECD.[22,23]

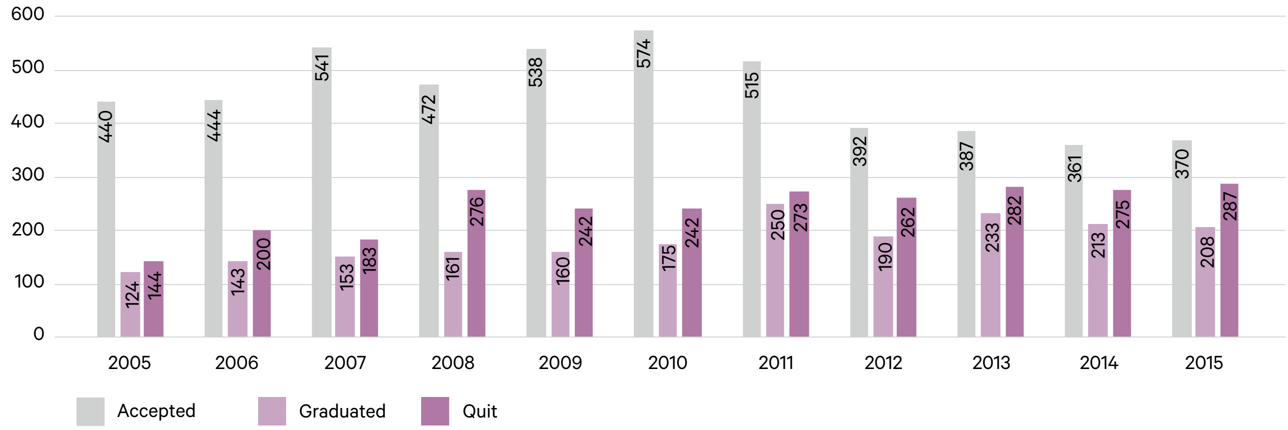


Figure 2.3. Number of students accepted, graduated and quit doctoral studies in Estonia, 2005-2015.

Source: Statistics Estonia.[24]

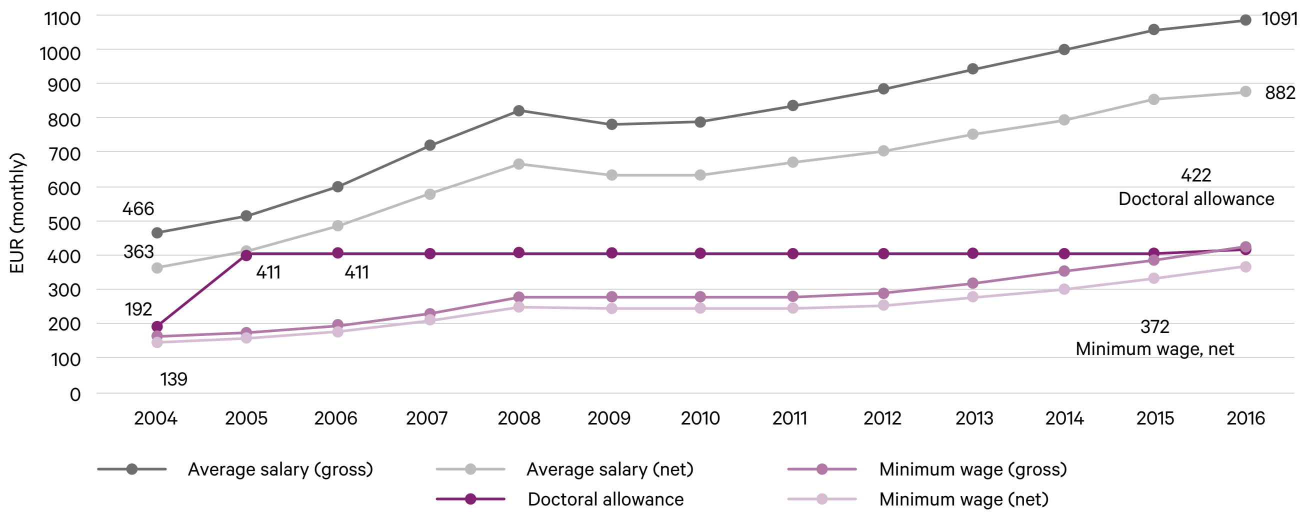


Figure 2.4. The dynamics of Estonian average monthly salary in compared to national allowance for doctoral students, 2004-2016.

Source: Statistics Estonia (salary information on 2016 is based on Q1).[25]

[22] OECD (2015), *OECD Science, Technology and Industry Scoreboard 2015: Innovation for growth and society*, OECD Publishing, Paris. – *http://dx.doi.org/10.1787/sti_scoreboard-2015-en* (14.10.2016).

[23] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

[24] Statististics Estonia. www.stat.ee (20.10.2016).

[25] Statististics Estonia. www.stat.ee (20.10.2016).

decade, there has been no significant growth in private sector employment of PhD holders. In Estonia, both the number of PhD holders in the private sector and the percentage of PhD holders employed in the private sector have decreased. In turn, this means that Estonia shares a problem with many other eastern and southern European countries, namely a low percentage of PhD workers in the workforce overall, as well as a very low employment rate in the private sector.

The small number of PhD holders in Estonia, as compared to the rest of Europe, is due to two factors. First, the economic crisis of 2009 caused a significant reduction in the number of people that were admitted into doctoral studies: in 2005, 440 persons started their doctoral programmes, in 2010, the figure was 574, and in 2015, it was 370 (Figure 2.3). In 2012, there were no longer any non-state funded positions in doctoral programmes. This decreased the number of students admitted to doctoral studies by around one quarter. From that time, the number of doctoral students entering programmes in Estonia has not significantly changed. The number of persons defending their degrees has increased (Figure 2.3), but this reflects that the larger numbers of students admitted during the peak years, were now completing their studies.

The second factor is the low level of efficiency of the programmes: almost half of the doctoral students do not complete their studies. One cause is the small doctoral studies allowance. Doctoral allowances were at their most competitive in 2005, just after they had been raised from €159 to €384, which was then equal to the average net salary in Estonia (Figure 2.4). Thereafter, net salaries increased significantly, reaching €882 per month, while doctoral allowances have remained the same, resulting in a steadily increasing gap between the two. In 2016, the doctoral allowance was raised to €442, which is just 48% of the average net salary. On the positive side, from September 2015, the government has begun paying social security contributions for doctoral allowances, thus increasing the social security of doctoral students, and the government has begun paying health insurance for foreign doctoral students.

According to Statistics Estonia, from 2000 to 2015, the largest number of doctoral degrees – more than one-third of the total number – were awarded to students in the life sciences. Roughly one-fifth were awarded to students in social sciences, humanities and engineering, and one-tenth in health services. There was a significant structural shift from 2000 to 2005, when the number of doctoral defenses decreased in the life sciences and increased in engineering. Since then, there have been no significant shifts between the various sciences. Estonia is above the OECD average, however, with respect to the percentage of persons who have received a doctoral degree in the natural sciences (Figure 2.5).

Estonia is below average compared to OECD and several western and northern European countries with respect to the percentage of people who have received a doctoral degree in health sciences. This is also true of the humanities and social sciences. Based on these figures, one might say that the natural sciences have been more successful in Estonia – and this success should be maintained. At the same time, we should consider why doctoral studies in other areas are below OECD averages. The variation between OECD countries within the average figure is rather large, and there may be differences in the classifications of doctoral themes within the various fields. For example, in Estonia, some doctoral themes are classified under natural science rather than health science.

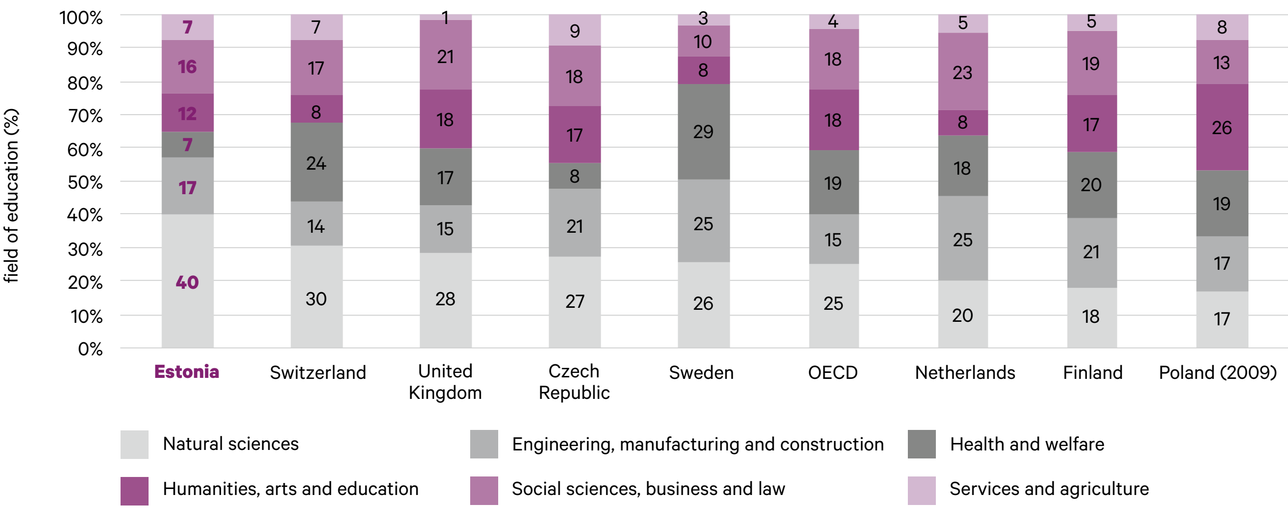


Figure 2.5. Graduates at doctoral level, by field of education, 2012.

Source: OECD.[26]

[26] OECD (2015), *OECD Science, Technology and Industry Scoreboard 2015: Innovation for growth and society*, OECD Publishing, Paris. – *http://dx.doi.org/10.1787/sti_scoreboard-2015-en (10.10.2016).*

Private companies are reluctant to hire researchers

Along with some other European countries, Estonia lags behind with respect to the percentage of persons with doctoral degrees. For that reason, the role of Estonian researchers[27] in the labour market is significantly smaller than in more successful countries of Europe. In 2014, Estonia had 4,323 researchers (scientists and engineers) or 7.1 researchers per thousand total employment, which is below average among the developed industrial countries (OECD) and the EU 28 (7.8) (Figure 2.6). Estonia's difference from the Nordic countries, with whom we would like to compare ourselves, is worth noting. Finland, Denmark and Sweden have respectively 15.3, 14.7 and 14.1 researchers per total employment. The situation is not better in the industrial sector. Estonia has 2.8 researchers per thousand persons employed in industry, which places Estonia below seventh from last among the pool of observed countries. The difference from the OECD and EU 28 average (respectively, 5.1 and 6.3) is even greater. The difference from Nordic countries is four to five fold. This confirms that Estonia has considerable room for improvement in moving towards a knowledge based economy: on the one hand, Estonian researchers are concentrated in the public sector, and on the other hand, there are far fewer to be found in industry than in countries that Estonia would like to resemble.

Looking back over the last fifteen years, we find only small changes in the proportions of researchers employed in the public and private sectors in Estonia. There was a slight jump in the percentage of researchers employed in the private sector after Estonia joined the EU in 2004, but after the global economic crisis began at the start of 2009, there has been a clear decline (Figure 2.7). Similarly, employment of researchers in the public sector has stabilized, i.e. the number and percentage of researchers in the Estonian labour market has not changed in the last five years: there were 4,314 reserchers and engineers in 2009 and 4,323 in 2014. During the same period (2009 to 2014), according to Eurostat data, the number of researchers increased throughout Europe (EU 28) from 1.56 million to 1.76 million. The Estonian research community is getting older: the number of researchers who are 65 or older has clearly increased in the last ten years (Figure 2.8). At the same time, this generation has done well in mentoring: as a result, the research community has also been rejuvenated, with the largest growth in the number of researchers over the last ten years, to be found in the 35 to 44 age group. They too, mainly have found employment in the public sector.

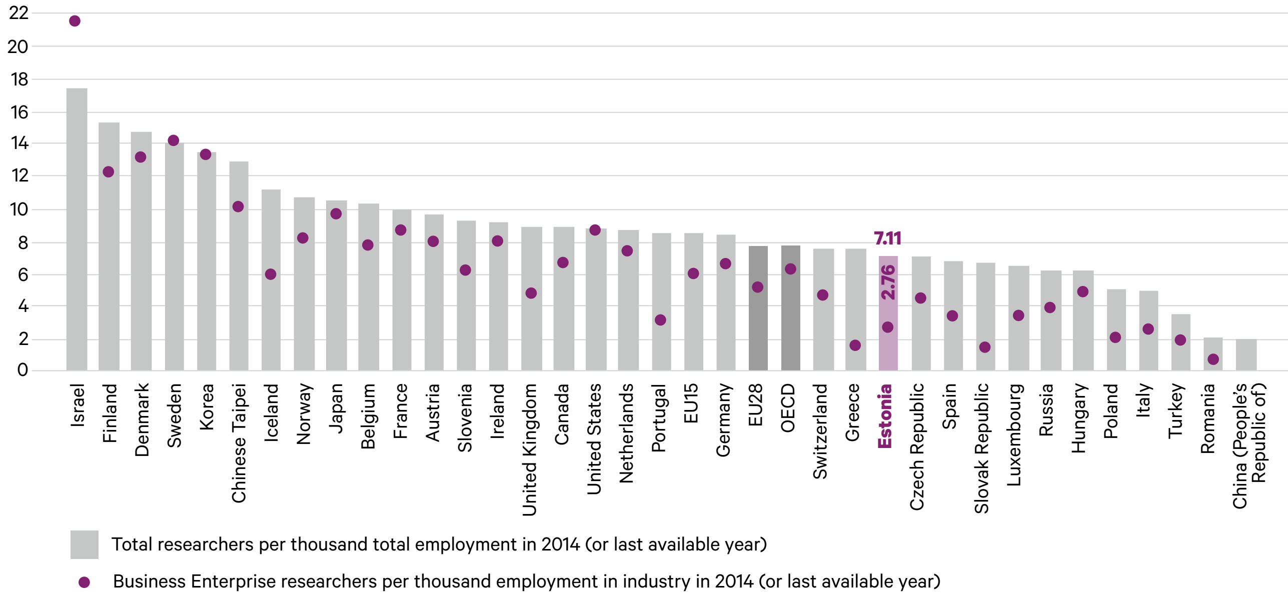


Figure 2.6. Total researchers per thousand total employment and in industry, 2014.

Source: OECD.[28]

The salaries of academic personnel can be analysed on the basis of data for six public universities, who employ a total of 3,252 researchers or three-quarters of all Estonian researchers. The average salary of researchers is €1,551, which is approximately 1.5 times larger than the average salary in Estonia (solid horizontal line in Figure 2.9). Salaries at the lower levels (teachers, assistants, lecturers, and junior researchers, all together 1,253 people) are similar to the Estonian average. On average, 35 leading researchers receive the highest salaries.

[27] Here we define researchers according to definition given in OECD Frascati Manual 2002 (§301, page 93) where **researchers** are professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned. However, the concept of **R&D personnel** is wider covering all persons employed directly on R&D, as well as those providing direct services such as R&D managers, administrators, and clerical staff while persons providing an indirect service, such as canteen and security staff, should be excluded ((§294 and §295, page 92). http://www.oecdilibrary.org/docserver/download/9202081e.pdf?expires=1485250228&id=id&accname=guest&checksum=E13D864271D52ED45E339D696C9B1E98 (10.10.2016).

[28] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

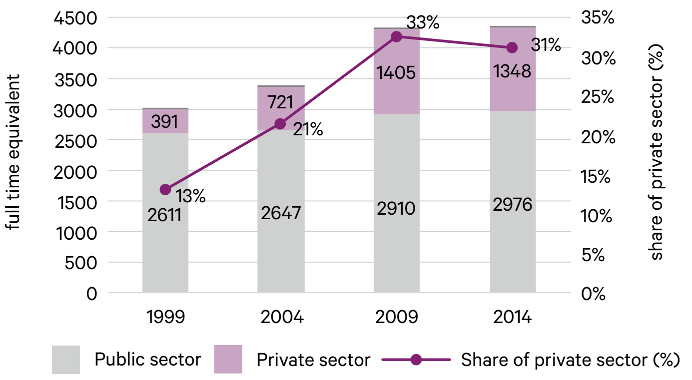


Figure 2.7. Distribution of researchers (scientists and engineers) between the public and private sectors (full-time equivalent).

Source: Statistics Estonia.[29]

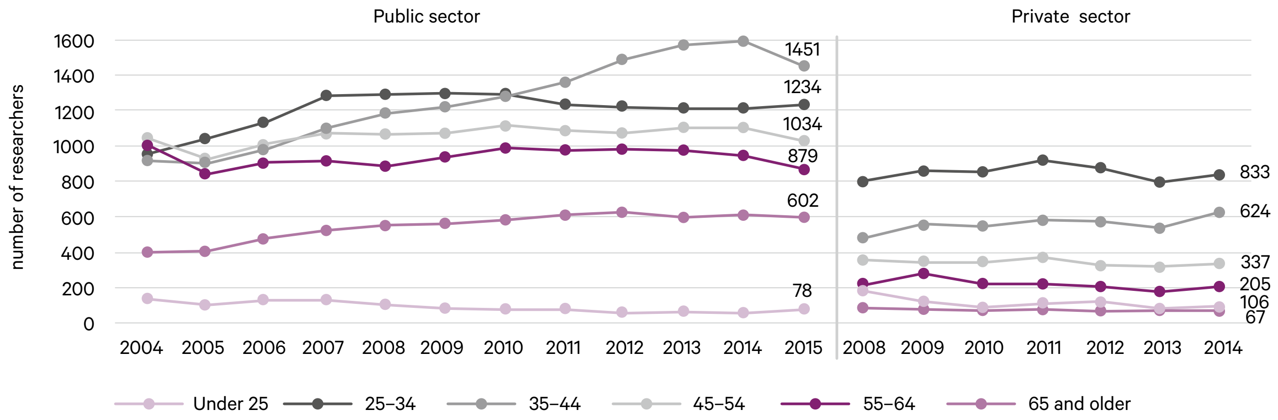


Figure 2.8. Dynamics of age structure of researchers (scientists and engineers) in private and public sectors.

Source: Statistics Estonia.[30]

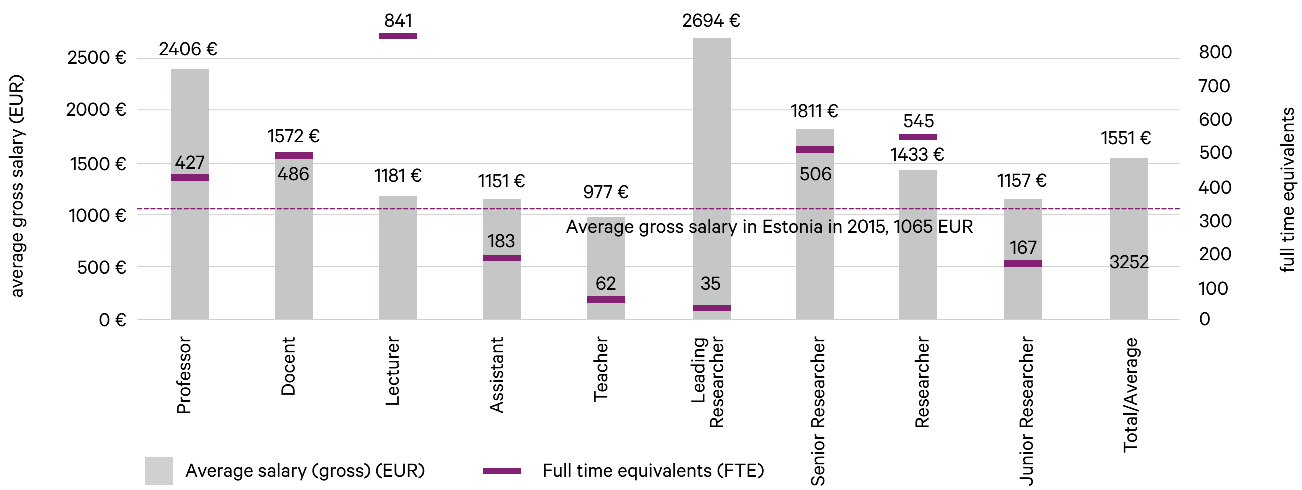


Figure 2.9. Average gross salaries of full-time academic positions and number of full time positions (full time equivalents, FTE-s) in six public universities in 2015.

Source: Universities Estonia.[31]

[29] Statistics Estonia. www.stat.ee (20.10.2016).

[30] Statistics Estonia. www.stat.ee (20.10.2016).

[31] Universities Estonia. www.ern.ee (22.10.2016).

Summary and discussion

From 1991 to 2015, a total of 3,272 people received a doctoral degree in Estonia. While the percentage of young people receiving higher education in Estonia is average among OECD countries, the percentage of PhD holders puts us on the lower tier. In OECD countries, from 5 to 10 working age population per thousand have doctoral degrees. The corresponding number in Estonia is 4. In all OECD countries, the lion's share of PhD holders are employed in the pubic sector, but in more successful countries, the share of PhD holders in business has begun to increase. Thus, Estonian problems are similar to those of other eastern and southern European countries where doctorate holders form a small percentage of the workforce, and a very small proportion in the private sector. In other words, in Europe one can make a broad distinction between the more successful northern and western European countries and less successful eastern and southern European countries based on the proportion of persons with doctoral degrees. Estonia's data places it squarely within the later group.

The small number of persons with doctoral degrees in Estonia compared with Europe can be explained by two factors. First, since the economic crisis in 2009, the number of people admitted to doctoral programmes has significantly fallen. In light of the decreased admission numbers, in the future, the number of doctoral degree holders will not be sufficient to meet the needs of higher education and research or to close the gap between Estonia and the countries of northern and western Europe that have more successful education systems. Moreover, over the next six years (the actual average length of doctoral studies), it is not possible for Estonia to reduce the gap in the number of people with doctoral degrees (because of the length of the doctoral studies cycle), which reduces the competitiveness of Estonia with respect to western and northern European countries.

A second dimension of the problem is the low level of efficiency of the studies: almost half of the doctoral students leave their studies before completion. The reasons for this are very complex, but we should not overlook the fact that doctoral allowances have not increased over the last decade. The second critical reason is the lack of a clear career path for researchers. Universities must become equally attractive to both doctoral students and researchers. This problem is addressed in the current reform scheme for research, where one part is to develop individual career paths and link them with financing instruments. However, one of the preconditions for this reform is increased research funding.

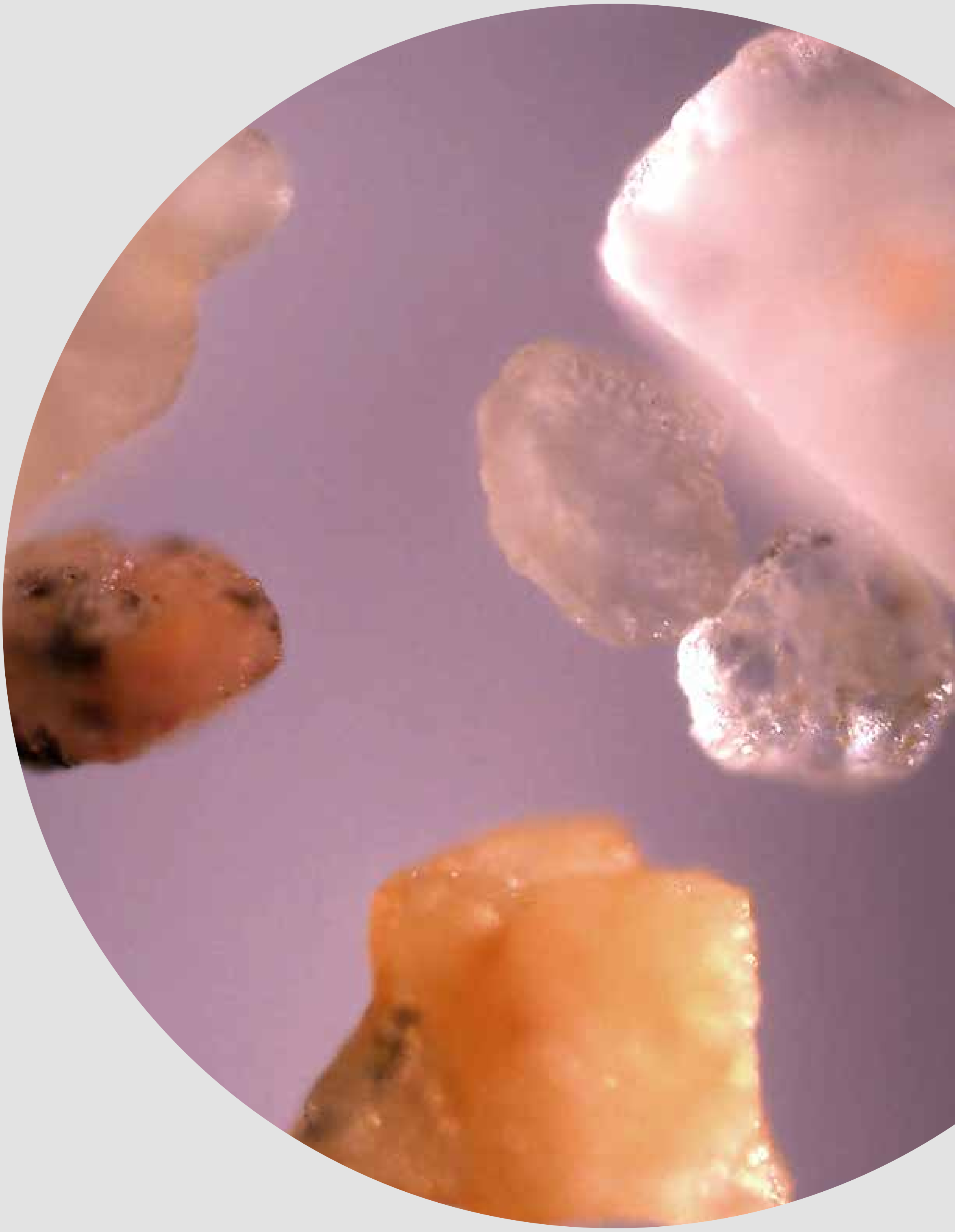
As the percentage of PhD holders in Estonia lags behind European levels, it follows that the role of researchers in the labour market is also significantly smaller than in most successful European countries. On the one hand, the Estonian business community has not increased its demand for researchers. Moreover, over the last five years, Estonia has taken a step back, with a decrease in the number of workers employed in the private sector. On the other hand, for example, holders of doctoral degrees in engineering have found work in both the public and the private sector. For this reason, we need a more detailed analysis whether the small number of PhD holders employed in the private sector overall is because firms are not willing to hire PhD holders (a lack of demand) or because there are just few such persons available (lack of supply).

From this, the key development problems facing Estonia compared to European countries with more successful education systems emerge. First, too few people are reaching the highest level of the education ladder (doctoral level), and the trend is that the number of candidates being admitted into these programmes is decreasing. Second, there is a bottleneck in the programmes, as the percentage of persons not completing them is high. Third, there are fewer PhD holders employed in the private sector than in successful European countries. These are the key problems that should be kept in mind in the political discussions to find solutions that will make Estonia more competitive in this changing world.

Estonia should not lower the requirements for obtaining a doctoral degree just to quickly increase the number of persons holding such degrees. Doctoral studies are and will remain primarily scientific, and the main output is scientific articles (monographs in the humanities). In order to develop independent scientific problem solving capacity during doctoral studies, students' co-authoring at least three scientific articles or compiling a monograph on their own is essential. Certainly, we should consider how to better link the more experimental doctoral study programmes with the needs of the economy. Some steps have already been taken in this direction: industrial doctorate studies, smart specialisation grants, and other similar measures are already helpful in achieving these goals. At the same time, in the arts, along with general doctoral studies, we should develop room for specialisation in areas that benefit creative industries. For that, it is critical to create better conditions and more clear rules for artistic research within doctoral programmes in particular, and more broadly within the scientific community as a whole.

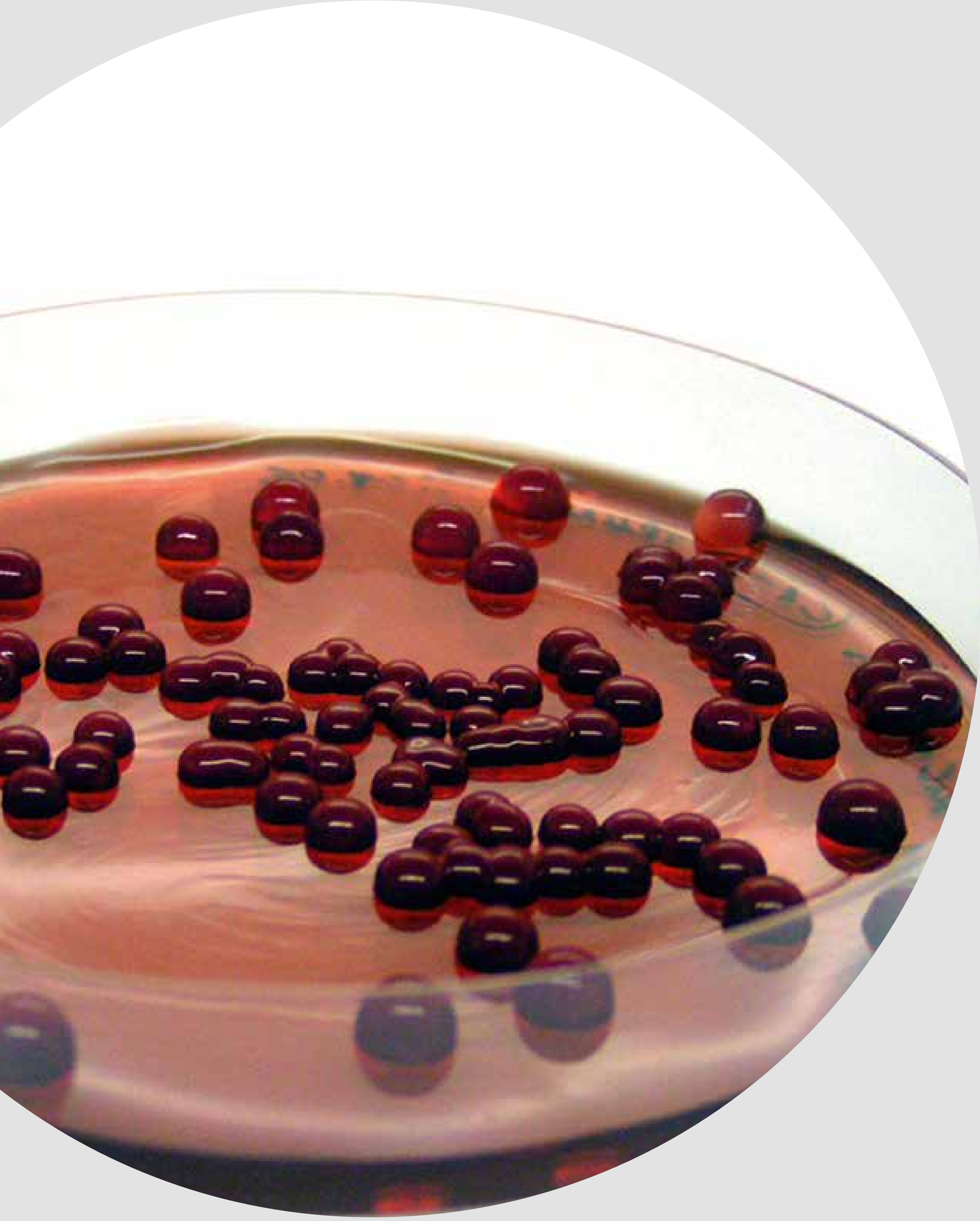
Acknowledgement

Many thanks to Jaak Vilo, Irja Lutsar, Jarek Kurnitski, Marek Tamm and Richard Villems, members of the Evaluation Committee of the Estonian Research Council, for very appropriate and concise comments. The responsibility for the whole article, including any possible mistakes in it, lies with the author.



Structure (Sand from Vainupea).

Author: Triinu Visnapuu (Institute of Molecular and Cell Biology, University of Tartu), 2013.



Bacteria broth.

Authors: Triinu Visnapuu, Kersti Tammus (Institute of Molecular and Cell Biology, University of Tartu), 2007.

Scientific publications: Estonia rises to the top

Jüri Allik
University of Tartu, professor and academic

Introduction

Some people who are not very familiar with research may think that publishing articles and then collecting citations is not the most important aspect of scientific work. But the key feature of science and the thing that distinguishes it from, for example, soothsaying and witchcraft, is that scientific results are made publicly available to everyone who might wish to repeat the experiments in order to confirm or question the results. With mutual verifiability we can discover whether those results are erroneous, and therefore no one has a monopoly on truths that he does not share with others. An entire industry is devoted to bringing research results to the public, and it produces around three million articles each year at a cost that is larger than the annual Estonian government budget.

To better understand the quality of Estonian research, we should study the quantity and quality of articles published by Estonian researchers. Unlike many other forms of human activity, research is very well documented. In 1955, Eugene Garfield, a young, visionary chemist, published his article "Citation Indexes for Science" in the well-respected journal, *Science*. The article's main idea is to use science to assess research articles by mapping citations to those articles.[32] This idea later grew into the most influential research index in the world, the Web of Science (WoS), which today already includes more than one billion citations to scientific publications. Elsevier's Scopus is a competing database to WoS. Mainly with the help of these two databases, we can observe how Estonian research has developed over recent years.

From quantity to quality

In 1991, the year when Estonia regained its independence, Estonian authors published around 300 articles in journals monitored by the predecessor of WoS. This figure includes all articles where at least one of the authors listed an Estonian address. The number of indexed articles published each year since then has greatly increased (for example, in 2015, 2.5 million new publications were recorded in the Core Collection of the WoS, with more than half a million from US authors) and the number of Estonian research articles has increased in a similar fashion. For example, in 2015, there were already 2,698 works in WoS where the authors' addresses mention Estonia. The fact that Estonian researchers have published the same number of articles in one year that used to take nine years, demonstrates great progress. At the same time, it is difficult for Estonia to compete on the basis of the volume of publications with larger countries. For example, Finnish researchers published over 18,000 works in 2015, which is significantly more than Estonians, even looking at the data on a per capita basis.

One indicator of article quality is the number of citations that refer to it. If, for example, an article is not cited over a ten-year period, one might suspect that the results were not interesting, or that there was nothing new that would attract the attention of other researchers. While attracting many citations does not automatically mean that an article is original and interesting, the number of citations to it is one of the most trustworthy measurements of article quality. The Scopus database, for example, measures the quality of a country's research based on the percentage of articles that reach the top 10% in terms of attracting citations. An author may publish an article that attracts few citations. It is still important to publish as many articles as possible that are influential, that is, articles that are frequently cited, and the criteria for measuring that is to reach the top 10% of most cited publications. Figure 3.1 presents a ranking of selected countries based on this percentage. Switzerland, the Netherlands and Denmark are at the top: around one-fifth of all their publications reach the top 10% of the most cited articles. Estonia's percentage is 13.5%, which is slightly better than that of Italy, France and Portugal. Slovenia is average, where approximately 10% of its publications reach the top 10% of most cited articles.

Researchers who measure research quality generally agree that relying on only one indicator is not sufficient. While, the quality of articles is most often measured by the number of citations that it attracts, in some cases, this might mask a tendency towards mediocre research. For example, observers have noted that Swedish researchers publish relatively few top cited articles, which reflects a tendency to publish good but not very original ideas.[33] To address this problem, the author of this article proposed a simple scientific quality index, (High Quality Science Index or HQSI) that gives equal weight to the average number of citations per publication and the percentage of all published articles that reach the top 1% of most cited publications.[34] So that these figures can be more easily understood, the research quality index uses standardized units (standardized normal distribution units, with the mean as zero and standard deviation as 1).

Figure 3.2 shows a country ranking based on a research quality index that combines the average number of citations to article and the share of articles that have reached the top 1% of the most cited publications. Using this indicator, Iceland, Switzerland and Scotland are publishing the best research.

[32] Garfield, E. (1955). Citation Indexes for Science: A New Dimension in Documentation through Association of Ideas. Science, 122(3159), 108–111. http://dx.doi.org/10.1126/science.122.3159.108 (20.10.2016).

[33] Karlsson, S., Persson, O. (2012). The Swedish production of highly cited papers. Stockholm: Vetenskapsrådet.

[34] Allik, J. (2013). Factors affecting bibliometric indicators of scientific quality. Trames: Journal of the Humanities and Social Sciences, 17(3), 199–214. – http://dx.doi.org/10.3176/tr.2013.3 (10.10.2016).

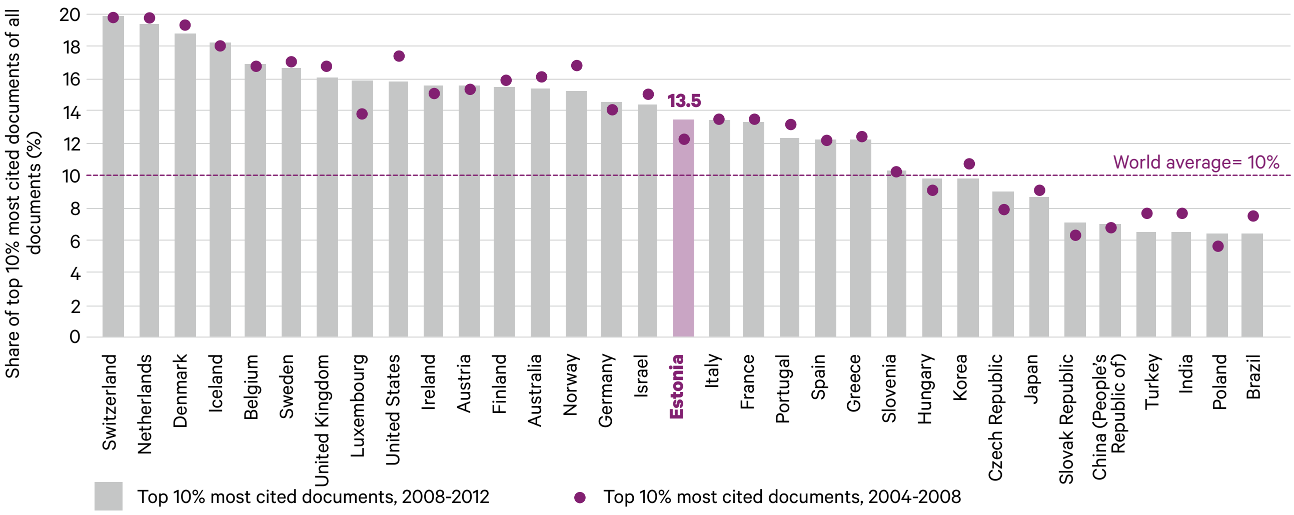


Figure 3.1. The share of publications reaching the top 10% of the most cited articles in the periods from 2008 to 2012 and from 2004 to 2008.

Source: OECD.[35]

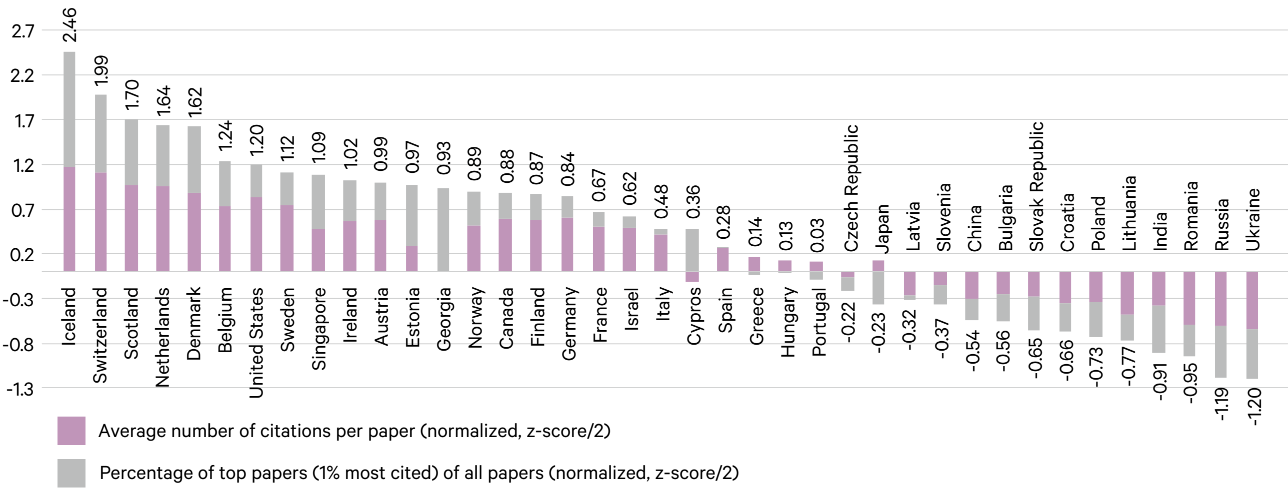


Figure 3.2. High Quality Science Index (HQSI) that reflects the combination of the average number of citations per article and the percentage of articles that have reached the top 1% of the most cited publications in a given age cohort.

Source: *Web of Science, Essential Science Indicators*, method and calculations by the author of this paper.

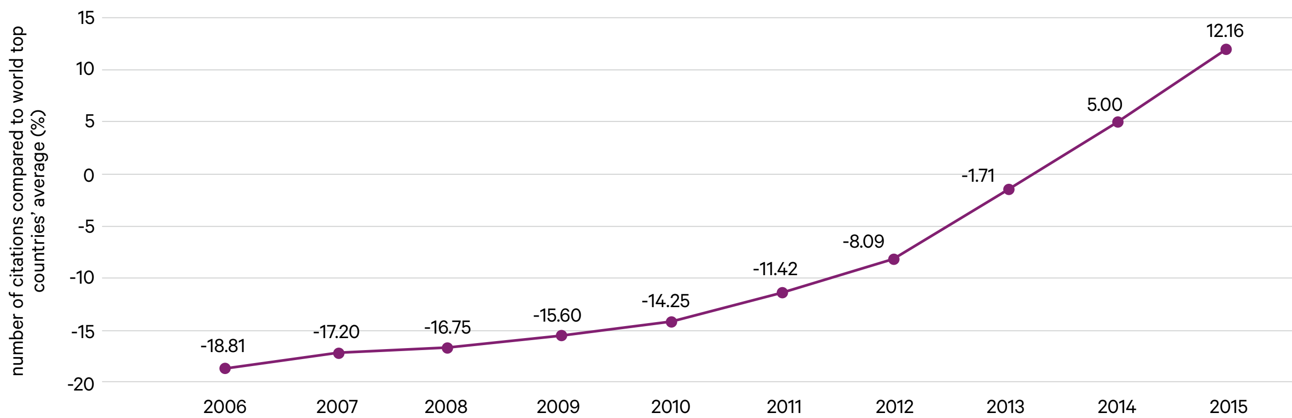


Figure 3.3. The average number of citations per article of Estonian authors collected during 11 year periods from 2006 to 2015 compared to the average of top countries.

Source: *Web of Science, Essential Science Indicators*, calculations by the author of this paper.

[35] *OECD and SCImago Research Group (CSIC) (2016), Compendium of Bibliometric Science IndicatorsOECD, Paris. Accessed from: http://oe.cd/scientometrics* (22.10.2016).

Among the countries that publish a sufficiently large number of articles (at least 4,000 articles over an eleven year period), Estonia occupies 13th place, which is very high. Estonia is ahead, for example, of Norway, Canada, Finland and Germany. Figure 3.2 also shows countries on the bottom of the list: Romania, Russia and Ukraine. Thus, we can see that countries have very different capacities to produce high quality research. Other authors take note of almost every article published from Iceland, Switzerland and Scotland and they cite them so often that there is a high probability that these articles will reach the list of top cited articles. Many countries, however, do not come out as well in terms of producing research. Even if they produce a large quantity of articles, the articles are not cited enough to become classics.

As the WoS and Scopus databases are very large, making concise and meaningful conclusions about them is not always an easy task. To solve this problem, WoS built a specialized search engine called the Essential Science Indicators (ESI). ESI is updated every two months and covers all publications that have appeared over the last decade, adding two months until 12 months are reached. Different categories have different thresholds for inclusion in ESI. For example, in some research areas, all countries are ranked in terms of their authors' total number of references, and in essential research categories only the top half, that is, only the top 50% of the countries are included. ESI classifies all research into 22 fields. Unfortunately, this list does not include the arts and humanities, because the creators of ESI found that the publishing and citation practices in this field differ from all the rest. Nevertheless, excluding the arts and humanities, ESI provides a trustworthy overview of the most important research performed in each country. And looking at ESI over a longer time frame[36,37] allows one to see changes in the quality of science over time.

Figure 3.3 shows the changes in the average number of citations to Estonian articles over the last decade, that is, since 2006. The years listed are the last of prior eleven year periods. The data shows that publications of Estonian authors that exceeded the quality threshold in 2006, were cited 18% less than those from leading countries. By 2014, for the first time, Estonian publications became as influential as those from leading countries in research, and even exceeded their average by 5%. In 2015, Estonian authors were cited 12% more than in the leading group of countries on average. This is one of the fastest and largest increases in the influence of research articles from a given country in the world over the last ten years.

Which area of Estonian research gave us this significant increase in impact? Table 3.1 shows the changes in impact in various fields over the last decade. They are ranked based their impact in 2015. For example, articles by Estonian authors on clinical medicine were cited 51% more overall than the average in this field. In addition to clinical medicine, six more fields exceed the leading group average: environment/ecology, plant and animal science, molecular biology and genetics, physics, pharmacology and toxicology and psychiatry/psychology, *i.e.* publications by Estonian authors in these fields have been cited more frequently than the average of the field in the period from 2005 to 2015. Five more fields – biology/biochemistry, neuroscience and behaviour science, microbiology, computer science and agricultural sciences – are about equal to those of the leading group of countries. By way of contrast, the data for Estonian materials science is interesting. It was the most successful field in Estonia in eleven years preceding 2006. Its decrease in impact may not be due to a dramatic deterioration in the quality of the articles. For example, it may be that their focus shifted and researchers who worked there are now publishing in journals that are classified under physics.

The last column of Table 3.1 shows changes in impact during the last decade from 2006 to 2015. Clinical medicine has increased in influence the most, but the increases in psychiatry/psychology and computer science also have been impressive. Some fields, for example, engineering and the social sciences, have been rather stable. One should not take the last line – multi-disciplinary research – very seriously. It is a kind of "grab bag" that includes articles published in universal scientific journals like *Nature, Science***,** etc., and the algorithm failed to classify them under any specific field.

Filling all of the cells of Table 3.1 since 2008 by a single country (ignoring the last row) is not the norm. Reaching the top 50% of countries in all 22 fields of research is an accomplishment that only strong research countries can accomplish. It would seem that one of the most salient features of Estonian research is that we are competitive in all fields of our research. This is good news for our universities. Modern university education that is not based on world-class research is not sustainable.

As ESI does not do justice to the arts and humanities, their success needs to be assessed separately based on WoS. Arts and humanities can be defined by the following list of fields: history, literature, music, philosophy, religion, theatre, linguistics, art, archaeology, classics, dance, film & radio & television, history of science, cultural studies, along with a few additional smaller areas. We compared Estonian articles in these fields with those of Finland and Lithuania in the period from 2005 to 2015. Figure 3.4 shows the percentage of arts and humanities among all WoS publications in Estonia, Lithuania and Finland.

The share of arts and humanities articles among all publications increases from 2005 to 2010. This may be due primarily to the fact that WoS started to index a larger number of arts and humanities journals. The percentage of arts and humanities articles among all publications is the largest in Estonia (6.3%). Next comes Lithuania (4.6%) and Finland (2.8%) is last. Thus,

[36] Allik, J. (2003). The quality of science in Estonia, Latvia, and Lithuania after the first decade of independence. Trames: Journal of the Humanities and Social Sciences, 7 ((57/52)), pp. 40–52.

[37] Allik, J. (2013). Factors affecting bibliometric indicators of scientific quality. Trames: Journal of the Humanities and Social Sciences, 17(3), pp. 199–214. http://dx.doi.org/10.3176/tr.2013.3.01 (10.10.2016).

Estonian arts and humanities authors contribute more to WoS publications than their Lithuanian or Finnish colleagues. As one can see, the articles of Estonian, Lithuanian and Finnish arts and humanities authors are cited less and less each year. This is expected, because the amount of time for citing publications from 2005 extends to ten years, while the amount of time for citing articles from 2015 is just one year. The comparison shows that the publications of Finnish arts and humanities authors were cited 1.6 times on average, those of Estonians 0.9 times and Lithuanians, 0.5 times. Thus, Finnish arts and humanities authors have been writing slightly more influential articles than Estonians, who in turn have been more influential than Lithuanian authors. The figure also indicates that the influence gap between Estonian and Finnish articles is getting smaller.

To summarise, Estonian arts and humanities researchers have done a very good job in the last decade and contributed significantly to the success of Estonian research.

Table 3.1. Influence of Estonian research fields compared to the average of the top countries in the period from 2006 to 2015.

Field	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Change 2006-2015
Clinical Medicine	-27.3	-19.7	-13.7	-9.4	-3.5	3.0	14.3	18.8	35.5	51.1	78.4
Molecular Biology & Genetics	-22.4	-9.9	-2.5	1.0	7.6	9.1	6.7	18.1	23.9	40.0	62.4
Physics	-27.0	-28.8	-33.2	-32.5	-28.2	-21.7	-15.9	0.5	16.8	29.3	56.2
Psychiatry/Psychology	-44.2	-38.7	-36.3	-31.2	-30.2	-23.5	-14.8	-7.0	2.6	5.4	49.7
Plant & Animal Science	-0.5	0.0	3.1	7.7	14.2	23.7	25.5	32.4	39.4	45.8	46.3
Computer Science	-49.6	-54.4	-51.4	-35.4	-35.2	-31.6	-31.8	-20.9	-14.8	-3.8	45.8
Environment/Ecology	7.0	10.5	6.4	11.5	9.8	14.7	19.8	34.1	40.5	47.0	40.0
Immunology	-46.4	-46.8	-43.8	-38.9	-43.5	-37.2	-21.7	-25.1	-19.9	-14.8	31.6
Economics ja Business			-70.1	-74.1	-69.0	-62.2	-57.6	-50.7	-43.9	-42.0	28.1
Microbiology	-29.5	-26.2	-28.9	-26.0	-32.2	-28.1	-17.8	-12.6	-3.4	-3.3	26.3
Geosciences	-46.5	-41.0	-37.2	-32.9	-30.0	-22.6	-23.9	-21.6	-21.0	-20.7	25.9
Neuroscience & Behavior	-27.8	-27.7	-34.4	-39.8	-39.3	-36.0	-31.3	-21.2	-12.4	-2.8	25.0
Biology & Biochemistry	-22.0	-22.0	-18.2	-19.9	-21.6	-18.6	-16.7	-19.9	-13.7	-2.1	19.9
Agricultural Sciences	-26.9	-23.8	-22.1	-23.2	-14.2	-18.9	-12.7	-16.7	-15.7	-7.0	19.9
Pharmacology & Toxicology	6.4	1.1	-10.0	-26.7	-26.1	-23.7	-14.0	-6.0	5.5	16.2	9.8
Mathematics	-16.6	-29.0	-30.9	-30.8	-33.6	-39.8	-43.7	-26.2	-16.5	-12.3	4.3
Social Sciences general	-33.4	-30.3	-37.5	-43.5	-46.7	-45.8	-53.0	-36.0	-35.0	-34.4	-0.9
Engineering	-17.2	-17.8	-16.8	-15.6	-12.4	-14.3	-25.4	-19.9	-18.0	-21.9	-4.7
Space Science	-19.1	-31.2	-44.2	-47.9	-47.6	-53.0	-49.6	-37.0	-32.4	-24.3	-5.2
Chemistry	-2.1	-6.3	-5.5	-8.3	-8.8	-14.5	-14.0	-13.6	-13.1	-14.4	-12.2
Materials Science	60.3	43.5	40.6	23.3	9.5	-6.4	-18.9	-20.3	-26.0	-28.2	-88.6
Multidisciplinary	71.3	82.4	79.9		-54.5	-43.7	-73.7	-28.4	-36.9	-52.0	-123.3
All Fields	**-18.8**	**-17.2**	**-16.8**	**-15.6**	**-14.2**	**-11.4**	**-8.1**	**-1.7**	**5.0**	**12.2**	**31.0**

Source: *Web of Science, Essential Science Indicators*, calculations by the author of this paper.

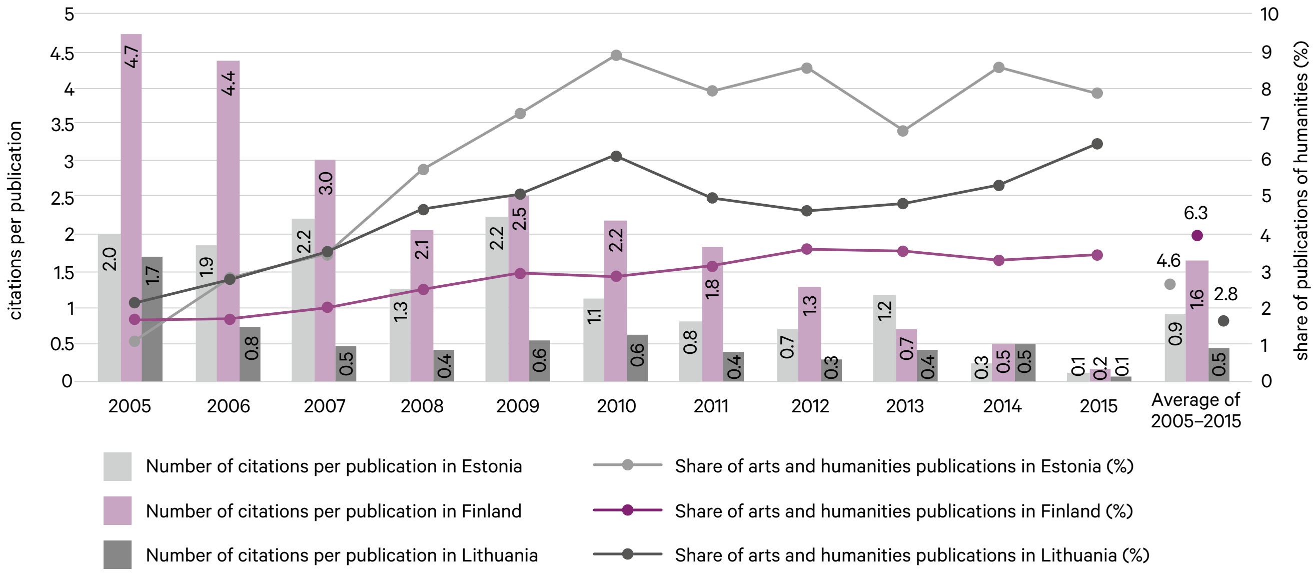


Figure 3.4. Share of arts and humanities publications of all WoS publications and the citation average in Estonia, Lithuania and Finland as of 8 June 2016.

Source: *Web of Science, Essential Science Indicators*, calculations by the author of this paper.

How can the success of Estonian research be explained?

Figure 3.3 is the best confirmation of the spectacular success story of Estonian research. Over the last ten years, its impact has increased very quickly, placing it now at the forefront, among the leading group of countries. There is no reason to believe that this is just a natural and inevitable path that accompanies the overall economic and political development of a country. For example, the Russian Federation – whose former research system, the Soviet Union, just a quarter of a century ago, included Estonia – is, among the high output countries for articles produced, at the pinnacle of influence. In 1991, the contributions of Estonia, Latvia and Lithuania to international research literature were rather similar. Each published around 300 articles in journals indexed by the predecessor of WoS[38]. Within the last 11 years (2005–2015), journals indexed by WoS published 14,386 articles by Estonian authors. Latvia, however, published just 5,423 and Lithuania 19,642 articles in the same time period. Also, the average number of citations diverged significantly. The average number of citations to Lithuanian, Latvian and Estonian articles is 6.9, 8.7 and 13.3, respectively. Although Lithuanian researchers published over 5,000 articles more than their Estonian colleagues, Estonian articles were cited 191,108 times and Lithuanian ones only 135,487, *i.e.* the difference is more than 55,000 in favour of Estonia. Consequently, the development of research in volume and quality has been very different in Estonia, Latvia and Lithuania in the last two decades, despite their rather similar starting positions in 1991.

It is not quite clear what has caused the sharp increase in impact over the last couple of years[39]. If we look at research grants - the main support for writing articles - not much has changed in Estonia since 2008. (Figure 1.7) Or taking into account that doctoral students are the main driving force of research, one might assume that their working conditions have improved. Figure 2.4 (Tammaru, 2016), however, shows that the doctoral allowance was raised in order to equal to the average salary in Estonia in 2005. Since then, the amount has remained unchanged and the minimum salary level has caught up with it. The salary increase of our researchers has definitely not inspired them to write better articles and publish these in good international journals that are often cited, either.

One possible explanation might be that Estonian researchers have more frequently cooperated with top researchers in other countries. The number of international publications Estonian researchers have co-authored has always been relatively large. Figure 3.5 shows the internationalisation of science in various countries in 2008 and 2012. Estonia belongs in the same group as the Netherlands, Norway and Finland, who are leading research countries. However, there is no significant change in the period from 2008 to 2012. High-quality research requires international cooperation, but obviously, this is not what caused the fast improvement in Estonian research in the last few years.

[38] Allik, J. (2003). The quality of science in Estonia, Latvia, and Lithuania after the first decade of independence. Trames: Journal of the Humanities and Social Sciences, 7 ((57/52)), pp. 40–52.

[39] Allik, J. (2015). Progress in Estonian science. Proceedings of the Estonian Academy of Sciences, 64(2), pp. 125–126.

Certainly, one reason for the success of Estonian research is investment in research infrastructure, made possible primarily by EU Structural Funds. Nevertheless, modern research infrastructure — buildings, equipment etc. — alone do not produce original ideas that colleagues all over the world want to cite.

The fast improvement in Estonian research quality, as depicted in Figure 3.3, probably does not have a single explanation. Thus, in addition to the research-environment contributing to good research, Estonian researchers themselves have made the right choices and done the right things that have helped them reach the top. We might call this "research culture". This culture seems to be characterised by the lack of the 'just another paper' mentality. Articles are published because they have original ideas that offer solutions to important problems, thus catching the attention of colleagues around the world. One part of this culture seems to be avoidance of 'convenience' research and publications. Certainly, one could advance one's career with convenient publications that appear in local journals, for example, but that have rather modest impact on international research. Convenience research also deals with local problems rather than those on the cutting edge of international research. In summary, Estonian success based on its research culture is characteristic of the world's best research countries.

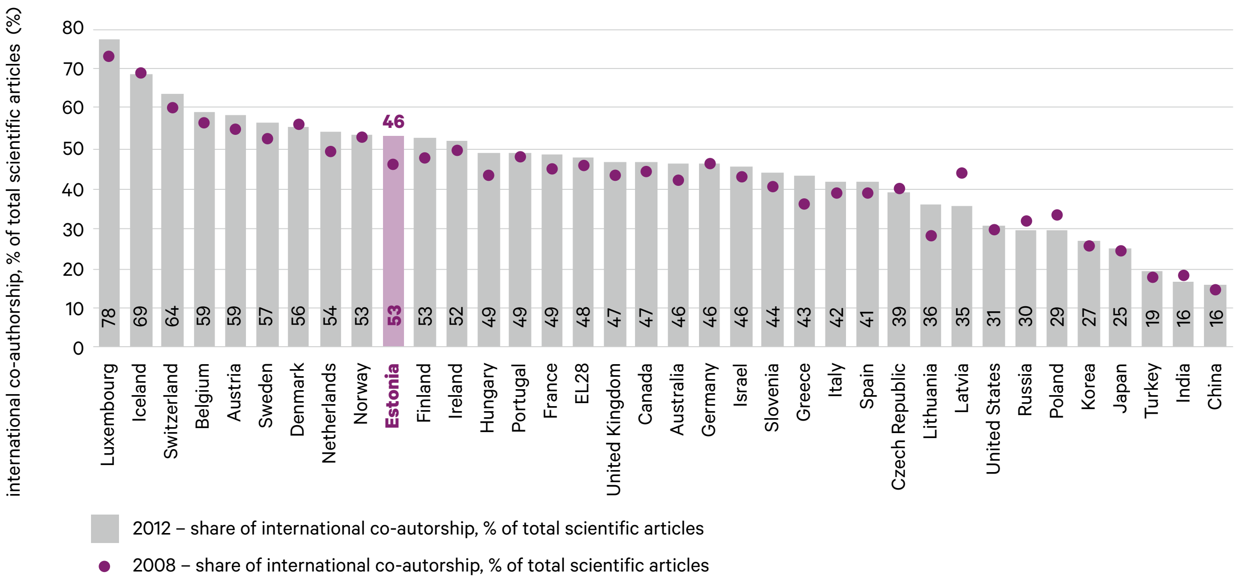


Figure 3.5. International co-authorship, per cent of total scientific articles in 2008 and 2012.

Source: OECD.[40]

[40] OECD (2014), *OECD Science, Technology and Industry Outlook 2014*, OECD *Publishing. –http://dx.doi.org/10.1787/sti_outlook-2014-en* (22.10.2016).

Research, development and productivity compared internationally

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Introduction

Economic growth in Estonia has been very modest lately and is expected to be just 1.3% in 2016. There is more and more talk about economic development slowing down and Estonia failing to break out of the middle income trap. Indeed, the average income level of Estonia has been between 74% and 76% of the EU average over the last five years, and the gap is not getting smaller (see Table 4.1). However, this is not unique to Estonia. As seen in Table 4.1, the income level of many countries is growing more slowly or even regressing compared to average growth. For example, the income level of Finland has fallen from 120% to 108% of the EU average between 2008 and 2015.

The contribution from different sources of economic growth is changing. Opportunities for increased contribution from several production factors, in particular the labour force, is limited. In upcoming years, the working age population of Estonia is going to decrease by five to six thousand people per year. Such a situation urgently demands more productive use of the existing labour force and capital. The main source of value creation and profit is no longer physical labour or manual skills, but intellectual skills and knowledge. 'The most fundamental resource in the modern economy is knowledge, and, accordingly, the most important process is learning'[41]. According to the OECD, a knowledge-based economy is 'directly based on the production, distribution and use of knowledge and information'.[42]

A condition of breaking out of the middle income trap is more knowledge input throughout the Estonian economy, thus producing more innovation everywhere in society. This argument is supported by global experience. But only very few countries have managed to establish themselves in the so called 'big league' over the last several decades. Among them are several Asian countries such as Singapore, Taiwan and South Korea, where their rise largely has been the result of contributions from research and development (hereafter 'R&D'). These countries have built a well-functioning national innovation system that focuses on the creation, dissemination and application of knowledge. One indicator that reflects this trend is the level of R&D investment. The generally accepted definition of R&D includes basic research, whose goal is to create new knowledge without any specific focus on application; applied research, with its more practical goal, and testing and development, with the specific goal of developing new products or processes.

This article provides an overview of the dynamics of Estonian R&D expenditure and the knowledge intensity of our economy compared internationally. It also describes the options proposed in Estonia for using knowledge to enhance

Table 4.1. GDP compared to the EU28 average in the period from 2004 to 2015, EU28 = 100.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Czech Republic	79	80	81	83	81	83	81	83	82	83	84	85
Denmark	125	123	123	121	123	122	126	125	126	125	125	124
Germany	117	117	117	117	118	116	121	124	124	124	126	125
Estonia	55	59	64	68	68	62	63	69	74	75	76	74
Ireland	144	145	146	146	132	129	130	132	131	131	134	145
Latvia	47	51	55	60	60	52	52	56	60	62	64	64
Lithuania	50	53	56	60	63	56	60	65	70	73	75	74
Poland	49	50	50	53	54	59	62	64	66	67	68	69
Slovak Republic	56	59	62	67	71	71	73	73	74	76	77	77
Finland	117	115	114	117	120	116	115	116	115	113	110	108
Sweden	129	123	125	127	126	122	125	126	127	124	123	123

Source: Eurostat.[43]

[41] Lundvall, B.-A. (1992). National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. London: Pinter.

[42] OECD. (1996). The Knowledge Based Economy. Paris: OECD Publishing. – https://www.oecd.org/sti/sci-tech/1913021.pdf (19.10.2016).

[43] Eurostat. http://ec.europa.eu/eurostat/data/database (14.10.2016).

our economic performance. One might say that the knowledge intensity of the Estonian economy is average – this is reflected in the level of performance of our economy, which is well below the EU average.

It should be acknowledged that the Estonian innovation system is not yet efficient enough in its ability to transform R&D expenditure into economic results. To increase knowledge intensity in the Estonian economy, our companies would have to adjust their positions in the international value chain and thus contribute to increased productivity and overall prosperity as well as increase the motivation to partner with research institutions. As our companies compete more intensively in the "big leagues", the more they will need universities, research and researchers. On the other hand, top-level research and highly-motivated researchers are their best partners. So far, the Estonian research funding system and researchers' career orientation have not had a strong focus on cooperation with private enterprises, and changes in this area are crucial to increase the knowledge intensity of our economy.

The link between GDP and R&D investment

The most broad measure of a country's knowledge intensity is the ratio of R&D expenditure to GDP. This includes public and private expenditure on R&D and it indicates how important R&D is to the country. This indicator is often criticised, on the grounds that it measures all expenditure or investments, including those that will not bear fruit. Therefore, we will look at the most general indicator of productivity as well, which is gross domestic product (GDP) per capita measured in comparable prices (Purchasing Power Parity or PPP). Figure 4.1 shows gross domestic expenditure on R&D as a percentage of GDP and GDP per capita measured in thousands of US dollars (PPP). Thus, Figure 4.1 shows the link between R&D expenditure and income levels. Countries with higher GDP per capita usually have higher R&D expenditures as well. This, however, says nothing about the cause and effect relationship, but time series studies have shown in the case of several Asian countries that first, they have increased R&D expenditures and then their GDP has increased as well. That is, R&D expenditure was an investment in economic growth. But this has worked well only with the help of a well-built national innovation system[44].

Figure 4.1 shows Estonia in a rather modest position among the OECD countries with respect to the ratio of gross domestic expenditure on R&D as a percentage of GDP and GDP per capita. Hungary and Portugal are at the same level as Estonia; and the Czech Republic and Slovenia are at slightly higher levels. As a whole, R&D investments of the countries correlate very well with their general productivity level. The US, Denmark, Sweden and Germany stand out as having very high R&D expenditures and high GDP per capita. Japan, Korea and Israel are an interesting group of countries, because their R&D expenditures are relatively higher than GDP per capita. And there are also countries whose GDP per capita is relatively higher than one would expect based on their R&D expenditure. In those cases, the country is usually rich in natural resources (Norway and Canada) or is a base for foreign investors operating in the EU (Ireland). This allows them to gain higher GDP levels without making R&D expenditure.

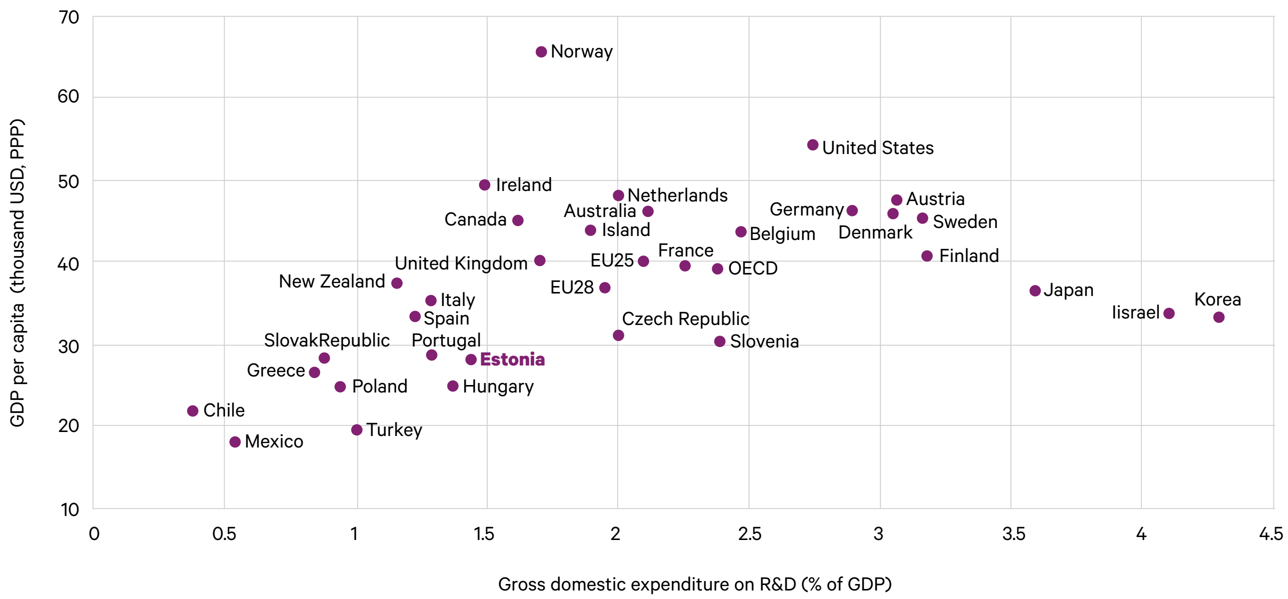

Figure 4.1. Gross domestic expenditure on R&D (% of GDP) and GDP (PPP) per capita in 2014.

Source: OECD.[45]

[45] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (07.10.2016).

[44] Fagerberg, J., Godinho, M. (2007). Innovation and Catching Up. – The Oxford Handbook of Innovation. Oxford: Oxford University Press, pp. 514–542.

Estonia's ability to transform research into productivity is limited

Figure 4.1 indicates that, in general terms, the level of R&D investment and the level of productivity in a given country correlate. The next step is to investigate the link between productivity and the number of researchers employed in businesses that use a significant amount of R&D investment. Naturally, there are great differences among the various fields of economic activity. The limited scope of this article does not allow us to delve into these differences; it only looks at the link between productivity (measured by the value added generated per worker) and the number of business enterprise researchers per thousand persons employed in the industrial sector in OECD countries. This sector of the economy is very important from the aspect of knowledge intensity of the overall economy, because high-tech and knowledge-based industry is a demanding client for many service sectors, thus contributing to the growth of productivity and knowledge intensity of the whole economy. The vertical axis of Figure 4.2 shows productivity per employee and the horizontal axis shows the number of researchers per thousand employed in industry in 2014. The first conclusion that can be made is that once again, the relative share of researchers in the labour force and productivity per employee correlate. This correlation persists over a longer period of time. The second conclusion is that unfortunately, Estonia is in a very weak position among OECD countries both as regards the productivity of industry as well as the ratio of researchers: we are in the same group as Turkey, Portugal and Poland. Our neighbours to the north do much better with respect both to productivity and the percentage of researchers.

Estonian private sector employs few researchers and PhD holders

As a next step, we might describe the situation with respect to the main input of the Estonian knowledge-based economy: its researchers. We ask, what has been the dynamic in the employment of researchers in Estonian industry and the business enterprise sector as a whole? Is their relative share in the labour force increasing? From the perspective of a knowledge-based economy, we also need to investigate what has happened with respect to the number of researchers with a PhD in the business sector. The most important input in a knowledge-based economy is the number of educated people and the quality of their knowledge and skills. The share of highly educated people (45%) puts Estonia in a very good place in international rankings, but the position is more modest if we look at the relative share of researchers in the labour force. Figure 4.3 shows the changes in the total number of researchers per 1000 employees in the overall labour force of Estonia in the period from 2000 to 2014. The figure thus basically reflects the dynamics of the share of researchers among the labour forces of various countries.

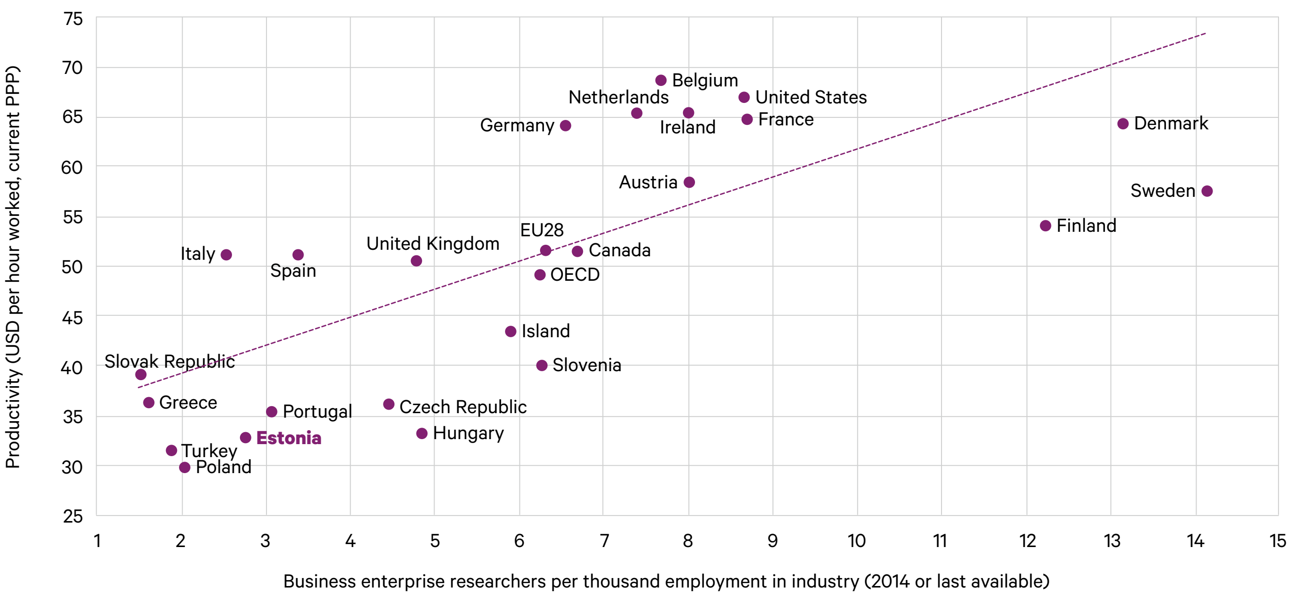

Figure 4.2. Productivity (USD per hour worked, current PPP) v. researchers per thousand employment in industry in 2014 or last available.

Source: OECD.[46]

[46] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (07.10.2016).

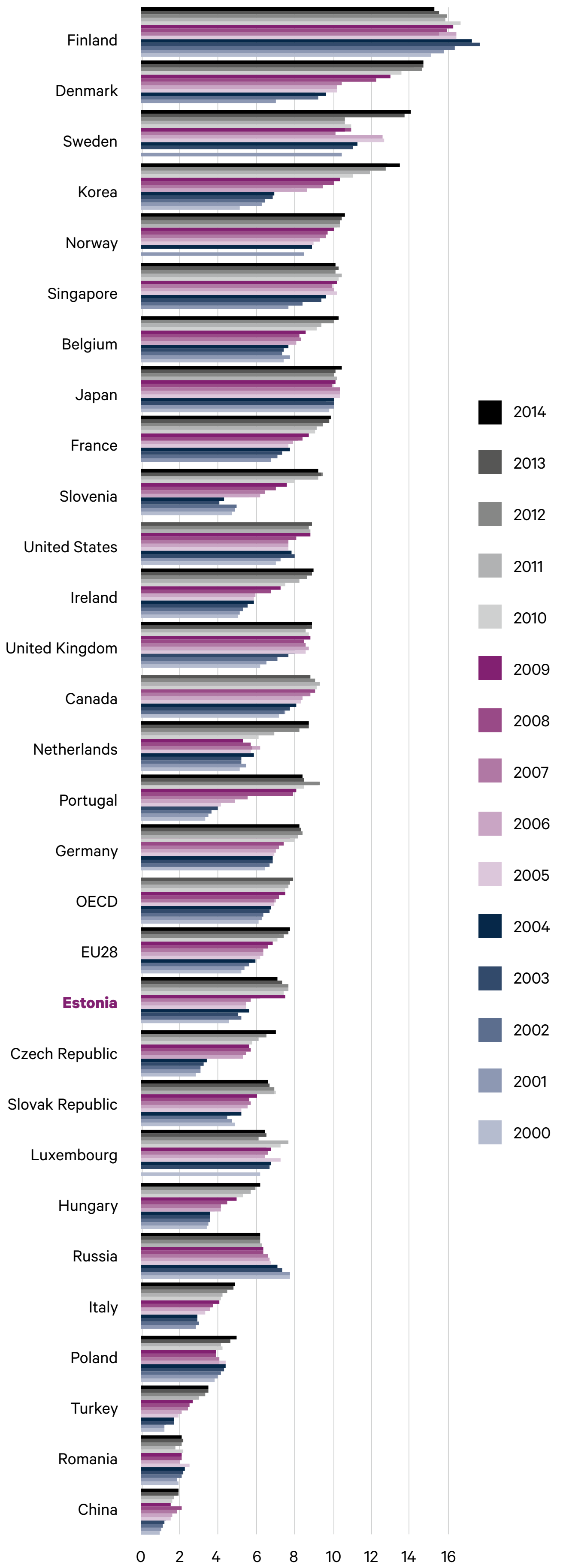

Figure 4.3. Total researchers per thousand total employment in the period from 2000 to 2014. Source: OECD.[47]

From Figure 4.3 we can see that Finland occupies a leading position. They have 15 researchers per 1000 employees. The number of researchers in Estonia increased from 4.5 to more than 7 per 1000 employees and then has stayed at that level. The ratio of researchers in Estonia is thus rather close to the EU and OECD averages. In addition, Finland, Denmark, Korea and Sweden are above average. In contrast, the number of researchers per 1000 employees in South Korea has increased from 5.13 to 13.5 between 2000 and 2014. This is a rapid increase. Denmark has seen a similar growth trend, but the data for Sweden and Finland have fluctuated. The share of researchers is very low in China, Romania and Turkey. In general, the higher the percentage of researchers in the labour force, the better the preconditions for R&D cooperation between companies and universities. To summarise, the dynamics of our indicator have been quite positive. If we look at industry, however, the situation of Estonia is less impressive. Figure 4.4 shows the number of researchers per 1000 employed in industry in Estonia and several other countries at different levels of development in the period from 2000 to 2014. The figure indicates that despite improvement, Estonia's 2.8 researchers per thousand employed in industry is less than one quarter of that of Finland, Sweden and Denmark, as well as less than in Slovenia and the Czech Republic. Of the countries compared, only Poland has a lower indicator.

The country that stands out most is Israel, where the percentage of researchers is extremely high, South Korea also stands out as a good example of a country with a rapid increase in its share of researchers. From the countries chosen for this analysis, Ireland is also interesting, because after a long standstill, foreign investments have finally started to increase the number of their researchers as well. Unfortunately, we still cannot see any increase in the number of researchers in our industry. This raises the question of why we still have such a low percentage of researchers in industry. It is probably due to the role of Estonian companies in the international value chain: their place does not require R&D job creation. Instead, the required knowledge comes from abroad.

Another very important measure of the knowledge intensity of economic sectors is their ability to hire holders of PhD degrees. The next table, Figure 4.5 shows the number of employees in business enterprise sector with PhD's in eight broad fields of economic activity in Estonia, in the period from 1998 to 2014. From 1998 to 2010, the number of PhD holders in the business sector of Estonia increased rapidly from 83 to 292. Unfortunately, in 2011, the number of PhD holders hired in this sector started to decrease, and this trend has not reversed. During the period of rapid economic growth, the number of employees with PhD's increased especially in the field of R&D, *i.e.* mostly in the public research system (see Figure 4.5). At the same time, the number of PhD holders in the manufacturing, business services, telecommunications and software development sectors has increased over the long run, but it has decreased in recent years. The reason is probably that R&D-intensive services and even production have moved out of Estonia.

[47] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (07.10.2016).

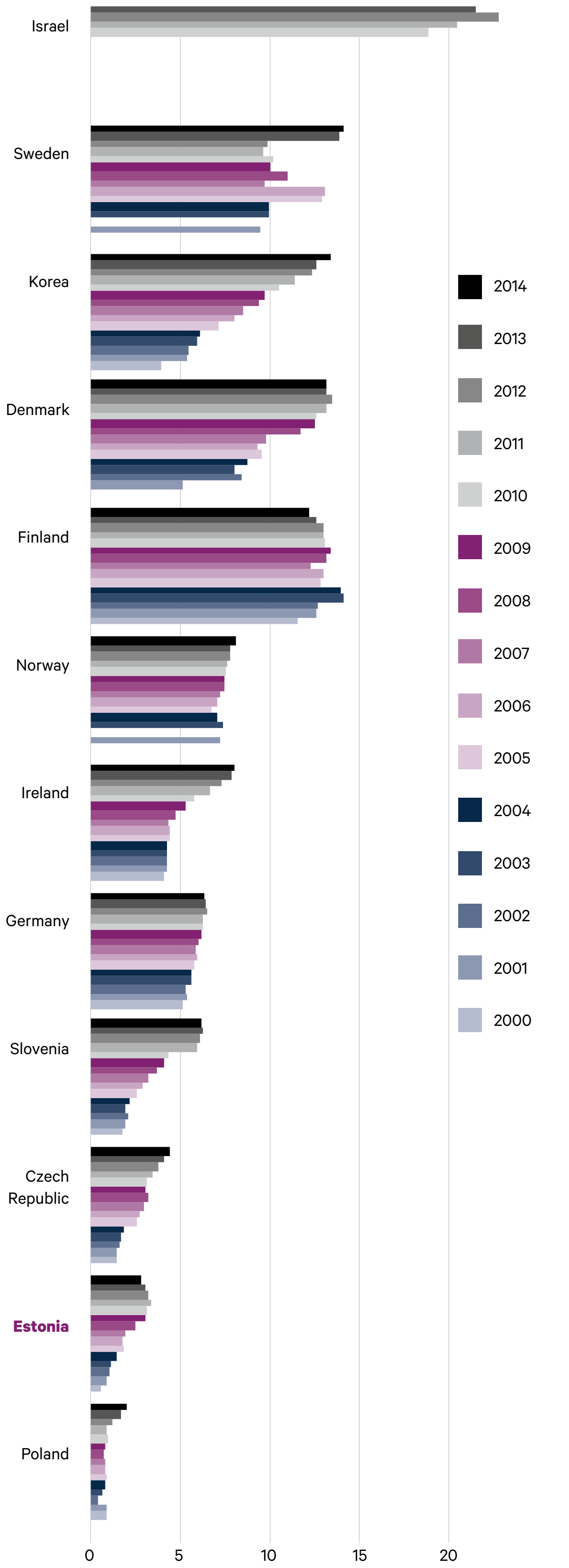

Figure 4.4. Business enterprise researchers per thousand employment in industry in the period from 2004 to 2014.

Source: OECD.[48]

[48] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

The electricity and water supply sectors are positive exceptions: their number of PhD holders has increased from 0 to 8. The total number of PhD holders working outside R&D in Estonia is approximately 75 people. This is directly at odds with the fact that each year, 150 new doctoral students graduate from Estonian universities. The contrast is more sharp considering our strategic objective, which is graduating 300 new PhD holders per year.

Thus, the data from the above figures (showing the low percentage of researchers in industry and very low number of employees with PhD's hired by the business sector), clearly indicate that our economy and society as a whole, are not able to use the input of highly educated specialists. This, in turn, is reflected in the low productivity of our companies, *i.e.* their moderate capacity to create value, as Figure 4.2 indicates. At the same time, productivity is, in the long run, the most important direct factor driving competitiveness and the foundation for economic growth.

In the Estonian business sector, R&D has a very narrow basis

R&D expenditures in the Estonian business sector are very concentrated. Estonia has a total of just 250 companies that have made any investments in R&D. In 2012, 75% of these investments were made by 27 larger companies and 85% by 50 companies[49]. Among these bigger companies are government controlled entities, such as Eesti Energia, Eesti Post (Omniva) and Elering. On the other hand, more than one-third of the companies investing in R&D are micro-enterprises that have fewer than nine employees. There are fewer than ten companies with more than 500 employees investing in R&D. This concentration has increased over the last decade.

Figure 4.6 below shows R&D expenditures of Estonian companies by economic activity; these include both in-house and external R&D expenditure in 2014. The biggest investor is the ICT sector with 32% of all R&D investments, followed by manufacturing with 23%, professional, science and technology sectors with 20%, and the financing and insurance sectors with 10%. The share of professional, science and technology sectors has increased rapidly in the last decade. In view of the future, it will be extremely difficult for Estonian companies to be competitive in a knowledge-based economy if only very few of them engage in R&D. We need to have more such companies and in more diverse fields of activity.

[49] Mürk, I., Kalvet, T. (2015). *Teaduspõhiste ettevõtete roll Eesti T&A- ja innovatsioonisüsteemis. – TIPS uuringu 4.3 lõppraport. Tallinn: TTÜ Ragnar Nurkse innovatsiooni ja valitsemise instituut, lk 49.*

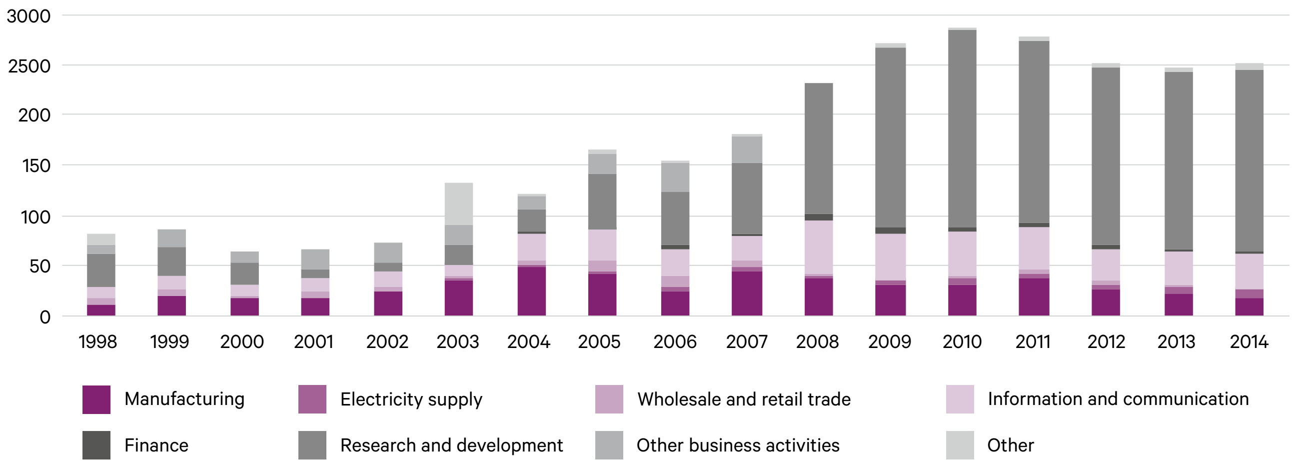

Figure 4.5. Researchers with a PhD in the various parts of the Estonian business sector.

Source: Statistics Estonia.[50]

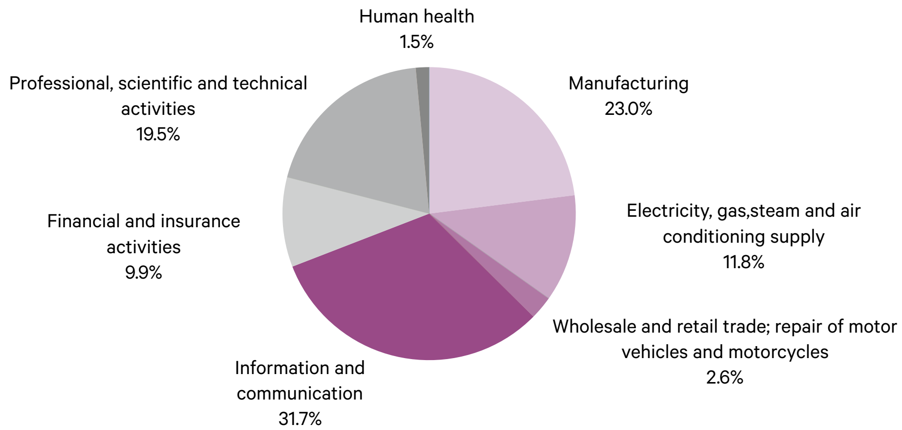

Figure 4.6. Percentages of R&D expenditure of Estonian companies by economic activity (intramural and extramural R&D expenditures summarised) in 2014.

Source: Statistics Estonia.[51]

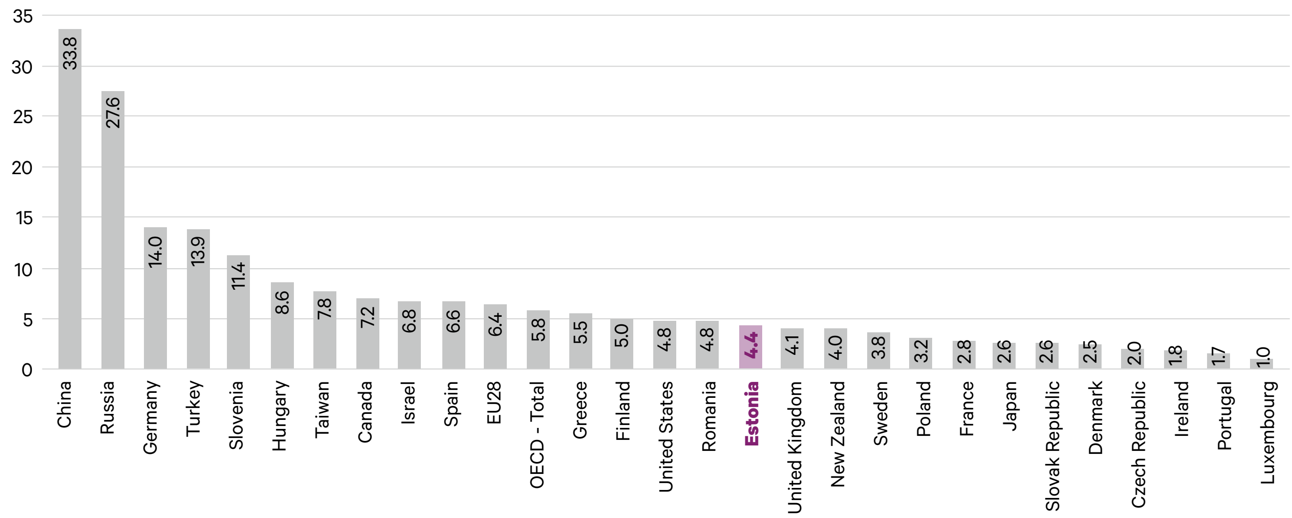

Figure 4.7. Percentage of higher education intramural expenditure on R&D financed by industry in 2013.

Source: OECD.[52]

[50] Statistics Estonia. www.stat.ee (20.10.2016).

[51] Statistics Estonia. www.stat.ee (20.10.2016).

[52] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

R&D cooperation between business enterprises and the research sectors is weak

Previous studies regarding the innovation behaviour of companies have shown that innovative companies use many and diverse sources of knowledge and work with various partners (consumers, suppliers, competitors, universities, etc.). Cooperation of this sort is useful primarily because it widens the resource base and enhances competences. Hence, we can conclude that the innovation capacity of companies improves with a wider knowledge base, where costs and risks are shared with others, which takes place through cooperation with other entities (partners). The more complex the companies' activities become in the international value chain, the more diverse knowledge base they need and the more they turn to universities.

Comparing the contribution of companies in financing the research activities of universities on an international basis, Estonia is only slightly below the OECD average. Figure 4.7 shows OECD data on the percentage of higher education R&D expenditures financed by industry in various countries. Estonia's 4.4% is slightly below the EU and OECD average, *i.e.* 6.4% and 5.9%, respectively.

Surprisingly, the Estonia data for 2013 is close to that of the US and the UK. Private sector financing of research in higher education is extremely high in China and Russia. This is probably the result of their command economies, where the government has an important role in directing the activities of state-owned companies. Germany's 14% is most probably linked to their highly developed industrial capacity that needs new knowledge inputs from universities. The role of the business sector is the most modest in Luxembourg, Portugal and Ireland. In conclusion, it can be said that the Estonian data based on percentages is comparable to that of several important innovating countries. However, the results of innovation studies[53] show that although the share of companies working with universities in innovation has slightly increased, it is very low, and supports the conclusion that R&D cooperation is very concentrated. Figure 4.8 below shows the business enterprises sector R&D financing (million EUR) given to universities and other non-profit research institutions in the period from 1998 to 2015.

A noticeable change in business sector financing appeared in 2007, which is linked to the availability of EU Structural Funds. With co-financing, it became possible for the business sector to commission research from research institutions. During the crisis period, expedited launch of several business measures was important in maintaining the R&D capacity of the business sector[54]. While business sector R&D investments was static from 2008 to 2009, public sector financing in the R&D of businesses slightly increased, and since 2010, R&D expenditures have accelerated especially in the business sector, while public sector expenditure slowed down a bit.

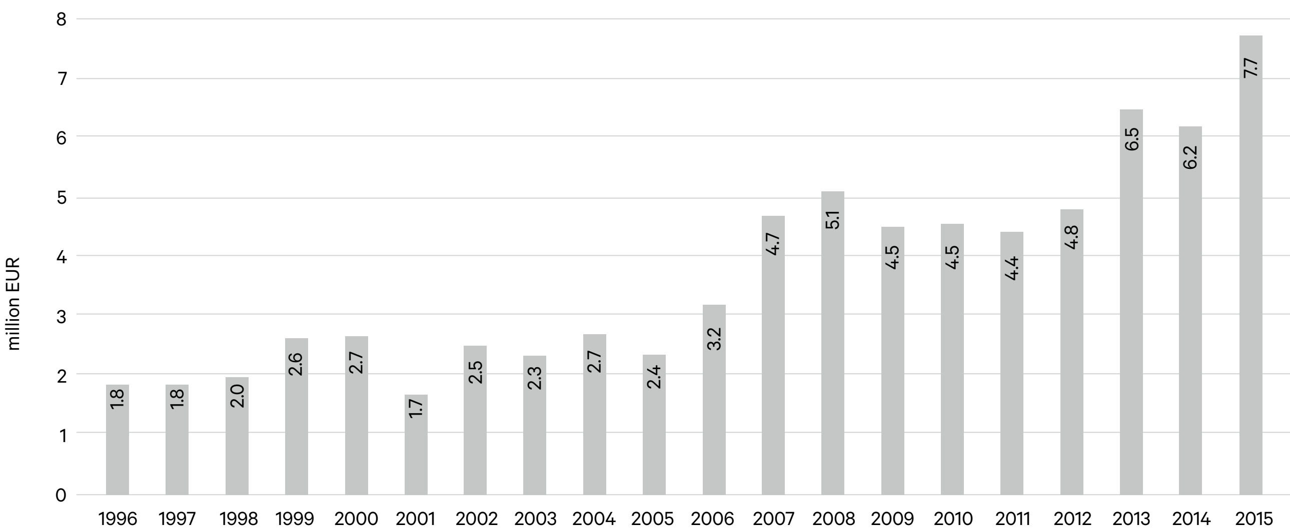

Figure 4.8. R&D expenditure in non-profit sectors financed by the business sector (million EUR).

Source: Statistics Estonia.[55]

[55] Statistics Estonia. www.stat.ee (20.10.2016).

[53] Ukrainski, K., Varblane, U. (2015). *Teadmusmajandus kui Eesti eesmärk: kas läheneme sellele või mitte? – Eesti Inimarengu Aruanne 2014/2015. Tallinn: Eesti Koostöö Kogu, lk 36–46.*

[54] Ukrainski K., Karo, E., Kelli, A., Vallistu, J., Tänav, T., Kirs, M., Lember, V., Kalvet, T. ja U. Varblane. (2015). *Eesti teadus- ja arendustegevuse ning innovatsiooni strateegia 2007–2013 täitmise analüüs.* – Lõpparuanne. Tallinn ja Tartu: Tallinna Tehnikaülikool ja Tartu Ülikool.

Next, with the help of Figure 4.9, let us compare the share of the government in financing business enterprise expenditures on R&D in selected countries. Once again, the variation is rather large, from less than 1% in Switzerland to almost one-fifth in Hungary and 14% in Romania. This might reflect the different development needs of the countries and their business sectors or different policy choices. The figure shows that Estonia, with its 10.2%, occupies a relatively high sixth place, which means that, with the help of the European Union, our government supports business sector R&D quite considerably. This co-financing gives the government a potential innovation policy tool to promote closer cooperation between universities and companies.

While monetary stimulus alone might not be enough to change behavior, financing as a signal from policymakers should not be underestimated. Based on this indicator, Estonia is quite significantly above the EU and OECD averages, *i.e.* 6.7% and 6.6%, respectively. The rather large share of public co-financing presents a challenge for the government to channel these support instruments into the development of society in the best possible way. Setting development priorities under the Estonian smart specialisation concept poses inherent conflicts for policymakers. On the other hand, this rather high Estonian indicator might be seen as the government's attempt to alleviate the negative impact of limited financial resources of companies on the R&D activities of the private sector. In conclusion, we must admit that, except the US, in countries that lead in innovation, the role of the government in companies' R&D financing has been smaller.

The need to increase productivity, drives companies to become more knowledge intensive

Countries compete with each other over capital and labour on an ongoing basis, trying to offer the best conditions in the form of physical and institutional infrastructure. Similarly, companies compete over production inputs. Their success depends on their capacity to sell goods and services and earn profit. The capacity to earn profit depends largely on how efficiently they use their production inputs, *i.e.* on their productivity. This reveals the link between the competitiveness of countries and companies and their levels of productivity. In the long run, productivity is the most important factor that directly affects competitiveness and provides a source of economic growth[56]. It plays this role both on the level of the national economy as well as with individual companies. Stable productivity growth in companies allows them to make more profit, raise real salaries, make additional investments in new technologies and product development, develop new channels for entering foreign markets, etc. These increase the competitiveness of companies in both domestic and foreign markets. A strong business sector, in turn, is the basis for the economic strength of the country. Thus, any increase in productivity directly leads to increased standards of living: people's real income increases, they can buy more goods and services, invest into education, etc.

What is the cause of the low productivity levels of our labour force? This cannot be explained simply by low intensity work of Estonian employees. It is very important to see what kind of work they do, and how complex the products or services they produce, are. The OECD productivity report says that it is not important what kind of products a country makes; instead, it is important what activities the country performs in the production chain[57]. Hence, the position of our companies in the global value chain is extremely important[58].

To ensure and improve the competitiveness of the Estonian economy in the future, we must make huge efforts to make our economy knowledge intensive and offer goods and services that contain much more added value. And any increase in knowledge intensity is closely connected with increased productivity - factors that influence the level of productivity of companies as well as the country as a whole. It is not enough to intensify the level of work at the workplace. The position in the international value chain where a given company operates is very important. Improving productivity is a continuous and complex process that requires continuous learning. Thus, productivity cannot be increased by employing one simple solution; instead, it requires the interaction of many factors and the contribution of both the private sector as well as the government, with its economic policy, which goes further than just political measures based on its RD&I strategy. Many companies in Estonia are small, and their size limits their ability to produce and sell more. Furthermore, they often lack the knowledge of global markets, the technology used by their competitors, and new organisational solutions, all of which could contribute to their ability to sell their products in the global market. Another problem is the low price level of our products, because these are often just semi-finished products that that are sold to partners in Western Europe who then add value to them.

Several studies have shown that within the value chain (from product development to its sales to final consumer) the production phase creates the smallest added value[59]. To improve the situation and increase its productivity, a company has at least three strategic courses of development if it intends to stay in the same value chain (see Figure 4.10).

[56] Krugman, Paul. (1994). Competitiveness: a dangerous obsession. – Foreign affairs, Vol 73, No 2, pp. 28-44.

[57] OECD (2015). The Future of Productivity, OECD Publishing. – https://www.oecd.org/eco/OECD-2015-The-future-of-productivity-book.pdf (24.10.2016).

[58] WTO. (2013). Global Value Chains. in a Changing World, WTO Publications. https://www.wto.org/english/res_e/booksp_e/aid4tradeglobalvalue13_e.pdf (26.10.2016).

[59] Dhanani, S., Scholtès, P. (2002). Thailand's Manufacturing Competitiveness: Promoting Technology, Productivity and Linkages. – UNIDO SME Technical Working Paper Series, No 8.

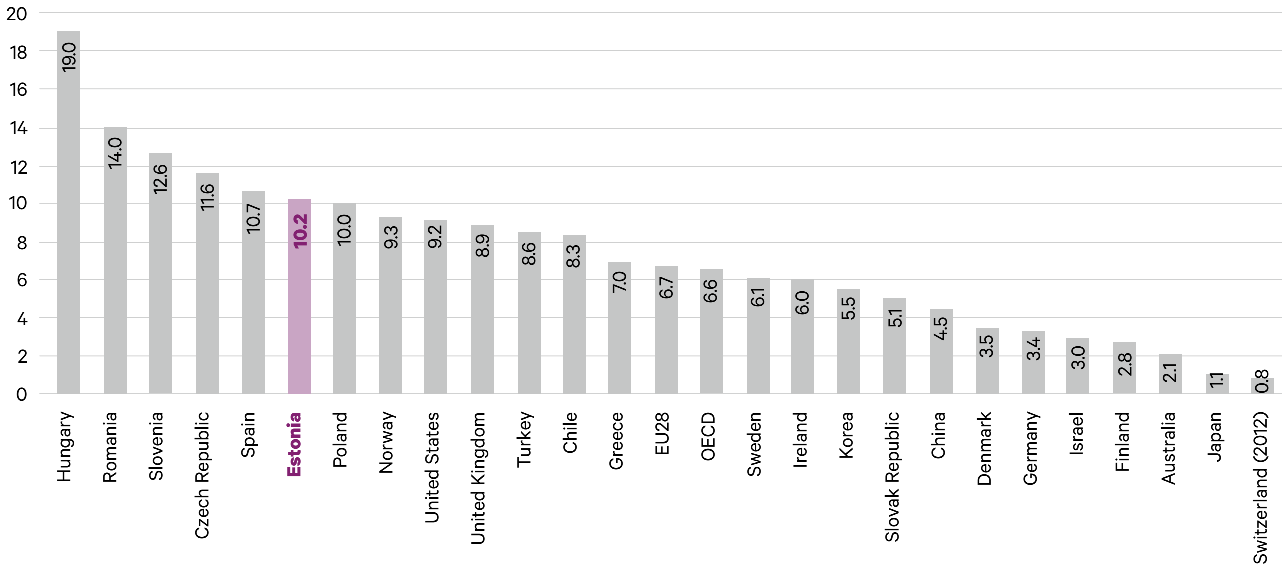

Figure 4.9. Percentage of business enterprise expenditure on R&D financed by government in 2013 (per cent).
Source: OECD.[60]

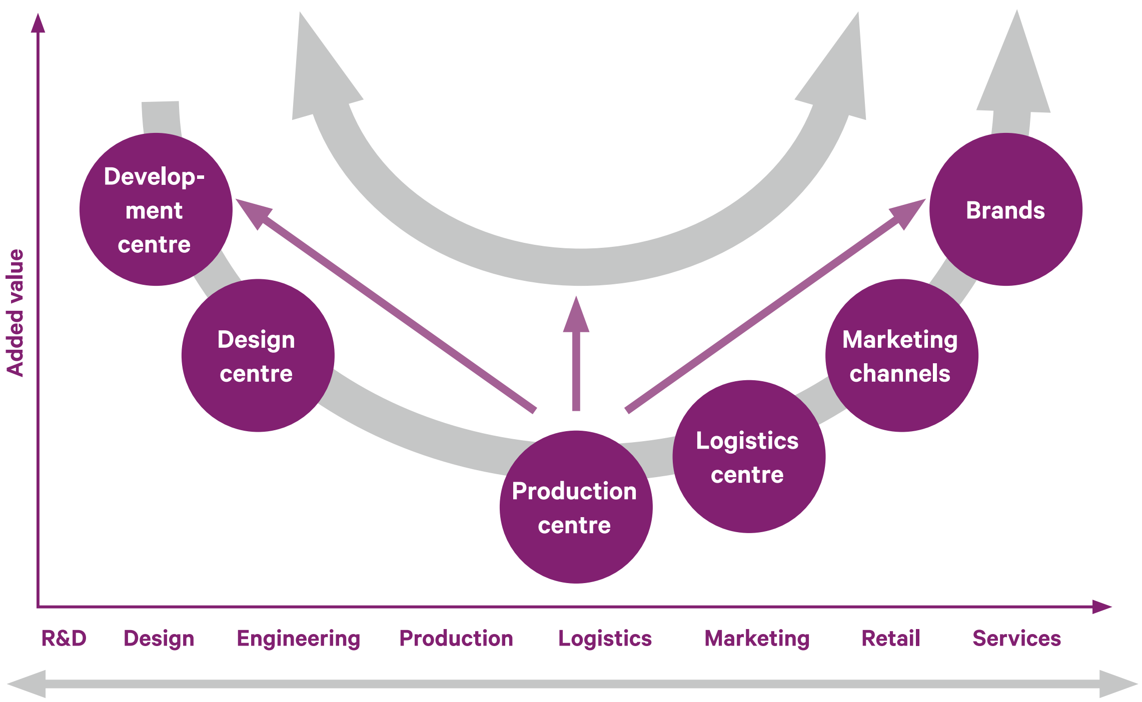

Figure 4.10. Various options for increasing labour productivity by changing the company's place in the international value chain.
Source: Urmas Varblane, Uku Varblane.[61]

[60] Main Science and Technology Indicators Database. (2016). OECD. – www.oecd.org/sti/msti.htm (14.10.2016).

[61] Varblane, U., Varblane, U. (2009). *Tööjõu tootlikkus ja selle muutused Eesti majanduses rahvusvahelises võrdluses. – Eesti majanduse aktuaalsed arengu-probleemid keskpikas perspektiivis. Tartu: Tartu Ülikooli Kirjastus, lk. 134–171.*

The first option is to continue with current production activities, but try to apply various process innovations and improve organisational functioning, thus reducing production costs and increasing added value. In the chart, this would be presented as moving up the value chain to the next line (see Figure 4.10). It might turn out that production becomes profitable again, creating more complex products that can be made with specific skills and knowledge that foreign competitors cannot easily copy.

The second option is for the company to move towards the beginning of the value chain - that means developing a new or upgraded product or service, developing new engineering solutions, and linking these to production. With these in place, it is possible to pay more to employees engaged in production, and the overall value added created by the company increases (the arrow from production to the left in Figure 4.10). The third option is to move from production towards the customer, *i.e.* to merge sales with production until you are selling your own brand. Here it would be sufficent for firms to link suitable and necessary services to the product that is on the market (the arrow from the production to the right in Figure 4.10). In this way too, the added value created by the company is larger and it is possible to pay the employees involved in production more.

In fact, there are definitely fields of activity where it is already necessary to think much more globally, which means deciding to move the least value adding aspects of production to other countries, and taking a role in managing the international value chain. The whole discussion above leads to the conclusion that success is based on the desire, ability and opportunity to learn continuously. To realize any of the above strategies, it is necessary to apply new knowledge, and this should lead companies to develop internally as well as find new sources of knowledge and thus turn to universities and research institutions.

To ensure and improve Estonia's competitiveness in the future, we need to make huge efforts to offer goods and services that contain much more added value. At present, the preconditions for rapid development in Estonia are not just companies making large investments in R&D, but also very skillfully using the technology, management methods and production systems used elsewhere in the world. Innovation must not be viewed narrowly, as just developing new products. Naturally this first requires some explanatory work to be undertaken among company managers at all levels to help them get used to the need for continuous learning. To summarise, the key to productivity growth in Estonia is its people, - their knowledge and skills development. An economy is not a set of physical structures and technologies, it is working people and their knowledge. The development of competences among employees initiates changes that later reflect in the economic indicators of company. **Improved innovation and productivity in the business sector requires a variety of sources of knowledge and more cooperation with research institutions.**

Government options for increasing knowledge intensity in businesses

Although this article describes the increase in the R&D in the Estonian economy and does not delve into RD&I policy making processes, the following are some policy recommendations based on other analyses made recently in Estonia.

One key factor in devising the Estonian RD&I strategy for the period from 2014 to 2020 was the understanding that the implementation of the strategy should - in addition to supporting the development of our research system - also contribute more and in a more direct way to improving the productivity of our companies, and avoid the situation where the share of R&D expenditure in GDP is growing and innovation indicators are improving, but the ability of the economy to add value is increasing very slowly. This requires much more effective cooperation between the private sector and public institutions and universities. Cooperation cannot be forced; instead, there needs to be a motivational and institutional framework for it to evolve. For the most part, the latter yet needs to be created, especially with respect to cooperation between the government and companies.

The first and most critical step is that the Estonian growth strategy focus should be on increasing the knowledge intensity of our economy, so that government's activities will be coordinated in order to unambiguously support this process. The assessment of the RD&I strategy 2007–2013 highlighted various problems with coordinating different policy areas, levels and instruments[62], which problems have not significantly changed. This indicates the limited effectiveness of the strategy (as well as the Ministry of Education and Research, which has the main responsibility for the strategy[63]) in resolving this problem as well as the limits of the so called knowledge sector to solve it on its own initiative.

In using support instruments for business R&D, so far Estonia has followed the principle of supporting the winners, in effect, strengthening the strongest, as well as companies that are active in Tallinn and Harju County[64]. The same applies to the research side - supporting internationally competitive

[62] Ukrainski K., Karo, E., Kelli, A., Vallistu, J., Tänav, T., Kirs, M., Lember, V., Kalvet, T. ja Varblane, U. (2015). *Eesti teadus- ja arendustegevuse ning innovatsiooni strateegia 2007–2013 täitmise analüüs.* – Lõpparuanne. Tallinn ja Tartu: Tallinna Tehnikaülikool ja Tartu Ülikool.

[63] *Teadus- ja arendustegevuse ning innovatsiooni strateegia 2007–2013 „Teadmistepõhine Eesti" rakendusplaan strateegia eesmärkide täitmiseks aastatel 2010–2013. Kinnitatud Vabariigi Valitsuse 29.12.2009 korraldusega nr 587 (RT III 2010, 26, 57)*

[64] Vicente, R., Kitsing, M. (2015). Picking Big Winners and Small Losers: An Evaluation of Estonian Government Grants for Firms! – https://www.researchgate.net/profile/Meelis_Kitsing/publication/277716024_Picking_Big_Winners_and_Small_Losers_An_Evaluation_of_Estonian_Government_Grants_for_Firms/links/5571861b08ae49af4a95ef4f.pdf (24.10.2016).

research groups. However, this has not reduced the specialisation gap between higher education R&D and business R&D[65]. It is important to widen the base of companies engaging in R&D outside of Harju County and to develop R&D financing and management mechanisms that are more suitable for dealing with local socio-economic problems. To increase the number of companies engaging in R&D, the first thing to do is to increase their other competences in order to help them better cope within the open innovation paradigm (*ibid*). This can be done through educational cooperation between universities and companies.

Policymakers and universities alike have viewed the cooperation between companies and universities very narrowly – mostly as conducting applied research. Our companies, the government and universities should consider more cooperation options: development and implementation of curricula, lifelong learning, mobility of students and researchers, management cooperation, etc.[66] Such an approach would widen the circle of potential partners. Our companies, the government and universities should initiate long-term cooperation, experiment with different forms of cooperation and demand high quality in cooperation. For example, Estonian companies could use more researchers' help in getting additional R&D financing from the various development programmes of the EU. Uncoordinated interests are one of the important factors hindering cooperation. Universities should cooperate more, for example, towards developing joint curricula, practice arrangements and internationalisation, to become more useful to companies and become their credible partners. A comparative study of 14 European countries showed that companies that export and have a foreign shareholder tend to choose a foreign university as their partner because domestic universities cannot offer them the knowledge they need. For cooperation with domestic universities government support was needed in all countries. This increased the likelihood of cooperation in 12 out of 14 countries[67].

Conclusion

One might say, with respect to the development of Estonia's research and economic systems, that to ensure and improve the competitiveness of Estonia in the future, we need to make huge efforts to make our economy knowledge intensive and offer goods and services that contain much more added value. It might be said that both the Estonian research and its economy are moving in the right direction in strengthening their competences. The achievement of the goal – a knowledge-based economy – is hindered by the fact that our innovation system is fragmented, as reflected in the context of this article, in the rather weak innovation synergy between research institutions and companies.

Increases in knowledge intensity are closely connected with increased productivity - with factors that influence the level of productivity of companies and the country as a whole. For that reason, it is not sufficient to think in terms of intensifying work at the workplace. The place where a company operates in the international value chain is very important. Improving productivity is a continuous and complex process that requires continuous learning. Thus, productivity cannot be increased by one simple solution; instead, it requires the interaction of many factors and the contribution of both the private sector as well as the government with its economic policy. One important tool is better aligning research and higher education institutions to cooperate with companies and the public sector, because Estonia's research system supports economic innovation less than that of other countries. The government can adjust the research financing system and researchers' career orientation from high-level publishing to more applied research and innovation. We should learn from the reform conducted in the Nordic countries undertaken in 1980's to direct researchers to investigate more about societal needs; during which time the research productivity of these systems did not suffer

Many companies in Estonia, however, are small, and this limits their ability to produce and sell more. Furthermore, they often lack knowledge of global markets, the technology used by their competitors and new organisational solutions, all of which could contribute to their ability to sell their products in the global market. Another problem is the low price level of our products, as they are often just semi-finished products that partners in Western Europe add value to. The meager innovation capacity of Estonian companies and the weak motivation of both of companies and the public sector to cooperate with universities are also problems, as they prevent implementation of the so called "open innovation" method to move up the value chain. Various studies indicate that Estonian companies act very pragmatic: cooperating primarily with those stakeholders whose contribution has an effect that can be measured in money and implemented immediately. Setting an objective of achieving knowledge-based production and attaining that objective is a very long process. One of the most important problems in Estonia is the very narrow base for R&D investment – this has become very clear especially in recent years. As soon as the oil shale-related chemical research was frozen, the knowledge intensity indicators of the Estonian economy fell considerably. With rapidly-growing labour costs, the R&D base has widened in the business sector step-by-step in any event, but to accelerate this process. Attention needs to be focused on the factors affecting knowledge intensity.

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[65] Ukrainski K., Karo, E., Kelli, A., Vallistu, J., Tänav, T., Kirs, M., Lember, V., Kalvet, T. ja Varblane, U. (2015). *Eesti teadus- ja arendustegevuse ning innovatsiooni strateegia 2007–2013 täitmise analüüs.* – Lõpparuanne. Tallinn ja Tartu: Tallinna Tehnikaülikool ja Tartu Ülikool.

[66] Lilles, A., Lukason, O., Roolaht, T., Seppo, M., Varblane, U. (2015). *Ettevõtete ja kõrgkoolide koostöökogemuse seire. – TIPS uuringu 4.1 lõpparaport, Tartu, lk 100.*

[67] Mohnen, P., Rõigas, K., Seppo, M., Varblane, U. (2014). Which firms use universities as cooperation partners? – The comparative view in Europe. University of Tartu Faculty of Economics and Business Administration, Working Paper Series, 93, pp. 1–28.

The stomata of Moses-in-theCradle (*Tradescantia spathacea*). In opening stoma guard cells (swollen). You can see vacuoles and chloroplasts (green).

Authors: Sulev Kuuse (photo) and Evi Padu (prepared the sample) (Institute of Molecular and Cell Biology, University of Tartu), 2007.

Topical issues

Estonian research funding system needs reorganisation

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Starting from the time that we regained our independence, the development of research in Estonia has been significant. One reason for this has been the successful R&D system reform of two decades ago. Its main components were the reorganisation of the research institution network to make it primarily university-centred, the creation of a competition-based research funding system, and the use of international expertise in assessing the quality of research. After the restoration of independence, our objective in those financially poor circumstances was to increase our scientific potential and adopt the principles of a western style research system. We had to support and develop the best parts of our research, at the cost of abandoning the weaker parts. As the economic situation of Estonia improved, new objectives could be targeted: modernising research infrastructure and increasing international cooperation and mobility of researchers. In addition to maintaining its high level and diversity, now research[68] is expected to provide more support to the economic growth of Estonia and to increase the overall welfare of our people.

The current national research funding system is characterised by high proportion of project-based and competitive R&D funding, and considerable dependence on EU Structural Funds. The large share of project-based funding does not allow research institutions to set long-term objectives, or to offer a stable research environment for researchers. The modern buildings and labs constructed with the help of EU Structural Funds have created completely new and internationally attractive research infrastructures, but now we do not have enough funds to use these in full capacity, because the volume of funding from instruments financed from our own tax revenue have stayed more or less the same since 2008. Estonia's low R&D investment level compared to other countries and dominantly project-based funding have not allowed Estonian research institutions to develop a researcher's career model, which among other things would support researchers' cooperation with enterprises and their international mobility, contribute to their self-development (incl. in the business sector) regarding knowledge transfer and innovation, and motivate young people to choose career in science or engineering.

The research funding system that was created about twenty-five years ago and which contributed to our success has, by now, become obsolete, and the incremental changes made to it over time cannot solve the issues that have emerged. What should be changed?

An effective research funding system should support a researchers' career and motivate research institutions to conduct fruitful cooperation with enterprises and government agencies. The system should also support and motivate entrepreneurs to invest in R&D.

A well-functioning funding system should include instruments that each have their specific role and the instruments together form a consistent whole. Research funding that is granted through tough competition is well suited for achieving excellence if it supports researchers at various stages of their career. However, this tough competition does not allow research funding to ensure the stability of the various research fields necessary for society, and does not give research institutions (our biggest research institutions are universities) the tools that they need to implement their strategic plans. Therefore, we need to reorganise the current baseline funding of research institutions into the institutional block funding instrument and increase its volume to equal the volume of research grants for researchers. Similar to higher education activity support that supports providing higher education, the government can establish the conditions for using research block funding. For example, the universities have to ensure the provision of competitive higher education in their areas of responsibility, they must also ensure high-quality research, support research of doctoral students, apply the researcher's career model, increase cooperation with enterprises, etc.

Grants and block funding together should support the core of Estonian research, which should be strong enough to form the intellectual basis for Estonian advancement. However, these two funding instruments would account for less than half of total public sector R&D expenditure, even if the public sector R&D expenditure would increase to 1% of GDP. In addition to grants and block funding, research is also financed by other funding instruments and measures administrated by various ministries. The precondition for achieving the objectives of the Estonian RD&I Strategy is to maximise the synergy between all of these instruments and measures. Thus, we need to think through how the increase in R&D expenditure should support the development of society and the economy through all the existing and possible new funding instruments.

To make preparations for these changes, the Estonian Research Council invited experts of various stakeholders (including the Estonian Academy of Sciences, Ministry of Education

[68] For the purpose of this article, research means research and development as a whole.

and Research, universities, other research institutions and young researchers) to come together in 2016. The cooperation resulted in the new concept for grants and block funding (*'Uurimistoetuste ja baasfinantseerimise uus kontseptsioon teadus- ja arendustegevuse rahastamise süsteemis'*). This document proposed changes to grants and block funding with respect to other R&D funding instruments, so these would ensure a logical, coherent and holistic research funding system.[69]

The new concept of grants and block funding focuses on these two funding instruments as the basic elements of the research funding system. To better link other R&D, technology transfer and innovation funding instruments, joint discussions among the ministries managing these should start as soon as possible, because if the research funding system is reorganised without making any changes to the funding of related activities, it would not be possible to achieve the expected impact of research on the economy.

To further increase in the overall welfare of our country, we have no alternative than to invest in people. The essential precondition for providing high quality higher education is top-level research. Research also offers solutions for problems we are faced with, either in business, or in society in general. Thus, we need to increase R&D investments. In doing so, the guiding role of the government and enterprises should significantly increase. The opportunities of research institutions in performing their tasks should increase together with their responsibilities for the use of research funds.

[69] The concept is accessible on the webpage of the Estonian Research Council at www.etag.ee.

The younger generation and careers in research

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In the upcoming decade, the talented and motivated young people who have started their university studies, up to postdoctoral research, will form the next generation of our researchers. Compared to the previous decade, students have more opportunities to study abroad and participate in international exchange programmes, and these are ever more widely used[70]. Our secondary school graduates and university students are competitive and successfully apply to very strong foreign universities. One should not underestimate the contribution our system of Olympiads, valuation of pupils' research papers and other outlets, including a high-quality secondary education, make in finding and developing scientific talent. It is a pleasure to see that there are many talented and ambitious young people who have the mental potential as well as motivation to become researchers. However, we should keep in mind that the younger generation has not promised, for the sake of homeland ideals, just to eat potato peels as the older generation did. For young people who have grown up in a free Estonia that has enjoyed rapid economic growth, further developing themselves and testing the limits of their abilities are top priorities. Figuratively, to fly as high as their wings can carry them and to change the world.

When moving from lower levels to higher levels of higher education, the image of the researcher changes. During the first level (bachelor's studies), a teacher/researcher is an honourable role model, a person whose knowledge is at the upper limit of human potential. It is an attractive ideal. By the end doctoral studies, this image is replaced by the recognition that a researcher who enters the research system is indeed expected to work at the peak of their abilities[71] and not just bask in already acquired knowledge. Finding a position with larger research team is necessary to continue as a researcher, but these positions are rare. A modern independent researcher who is beginning his or her scientific career is first and foremost a successful administrator, who can write applications and manage several projects at a time, network, obtain equipment, generate ideas, lead a team, perform administrative duties and when working in a university, also teach. This means that most of one's working time is spent on activities and requires competences not acquired or not expressly considered important during doctoral studies. To practice science, if one has any energy left, one has to find

[70] Erasmus+ 2014 Statistics. European Commission. –http://ec.europa.eu/dgs/education_culture/repository/education/library/statistics/2014/estonia_en.pdf (14.10.2016).

[71] Alas, R., Kindsiko, E. (2012).*Teadlase karjäär: Eesti rahvusvahelises taustsüsteemis.* –http://dspace.ut.ee/bitstream/handle/10062/40968/Uuring.6.4_Teadlased_teenistus.pdf?sequence=1 (17.10.2016).

time outside of full-time work, *i.e.* to do that as a hobby. This exceedingly demanding career stage often coincides with having a family. That, in turn, fills one's personal time and increases income expectations.

How does one begin a scientific career? Our top researchers and visionaries have reviewed in-depth the specifics and shortcomings of the current Estonian research system and career model[72,73,74 and references therein]. Unfortunately, gaining entry into the system depends on rather random circumstances. Advancement and exit are similarly random. Furthermore, it seems that expectations for researchers can be very different even within a single research institution. Current academic work demands are not very transparent, with high expectations at every stage while offering only blurry future perspectives. Thus the possibility of burnout is ever present. The growth and development of our research[75,76,77] has, to a large extent, relied upon internal resources that are running out. We have reached a breaking point. The work environment and conditions in the current system are not attractive to those talented young people who have acquired their experience in (an) international team(s) on the frontier of research, who can lead, and for whom we are waiting to come home to modernise and diversify our research landscape and build the future.

Let us return to the situation facing new PhD holders. Statistics show that in recent years, the number of doctoral graduating per year has remained around 200 (Figure 2.6). It should be noted that new PhD holders grow to resemble their academic 'parents'. In the current system, they mostly become researchers. After receiving a PhD, these young people are faced with the fact that only 10%–20% of doctoral graduates are likely to find their place in research. What happens to the rest? Figure 2.5 shows that the number of PhD holders finding work in the private sector is significantly lower than in the public sector, and has been slightly decreasing in recent years. It seems that our economy, in its current form, does not need the PhD holders coming from our universities. The 10 years that these capable young people have invested in their education often turn out to be non-profitable and they have to re-think their career, go abroad or start acquiring new applied knowledge in Estonia, and all this at the very vulnerable time of having a family.

One higher education and research vision for a small country is offered by Gunnar Okk in his infamous report, where he stresses the need to build closer links between research and entrepreneurship[78]. A knowledge-based economy already has been a strategic objective of national importance for many years. Nevertheless, these visions are difficult to bring to life. Perhaps we have been too impatient to see results? Careful observation of the current higher education landscape offers a solution to the problem - entrepreneurial graduates, including PhD holders, are emerging from teams of entrepreneurial professors, who are founding high-tech companies. If we could apply this model more widely, we would have a solution for these 80%–90% of PhD holders who do not continue in research .

On the other hand, Prof. Mart Loog warns us against setting our objectives in research too low, as that leads the system toward mediocrity[79]. His inspiring vision is absolutely necessary for those 10–20% of doctoral graduates who have the mental and leadership potential and motivation to practice cutting edge research. The researchers who enter the system and their abilities will affect the characteristics of the whole system in the upcoming decades. In conclusion it can be said that the sustainable development of research requires a long-term vision and a transparent, open, and motivating[80] career model that allows for development, and that is accompanied with supporting financing.

[72] Niinemets, Ü. (2015). *Teadlase karjäärimudel. Milleks, kellele ja kuidas?* – http://www.sirp.ee/s1-artiklid/c21-teadus/teadlase-karjaarimudel-milleks-kellele-ja-kuidas/ (17.10.2016).

[73] Niinemets, Ü. (2015). *Eesti teadus Euroopa teadusruumis.* – http://www.sirp.ee/s1-artiklid/c21-teadus/eesti-teadus-euroopa-teadusruumis/ (17.10.2016).

[74] Stern, R. (2015). *Teadussüsteemi kriis, teaduse kokkutõmbamine või jätkusuutlikkus?* – http://www.sirp.ee/s1-artiklid/c21-teadus/teadussusteemi-kriis-teaduse-kokkutombamine-voi-jatkusuutlikkus/ (17.10.2016).

[75] Allik, J. (2014). *Eesti teaduse positsioon maailmas.* – http://www.etag.ee/wp-content/uploads/2014/10/Eesti-teaduse-positsioon-maailmas-6-11-2014.pdf (17.10.2016).

[76] Nature Index. Central & East Europe. – Nature, 522, S18–S19 (2015), http://dx.doi.org/10.1038/522S18a (17.10.2016).

[77] Abbott, A., Schiermeier, Q. (2014). After the Berlin Wall: Central Europe up close. – Nature, 515, S22-25, doi: http://dx.doi.org/10.1038/515022a (17.10.2016).

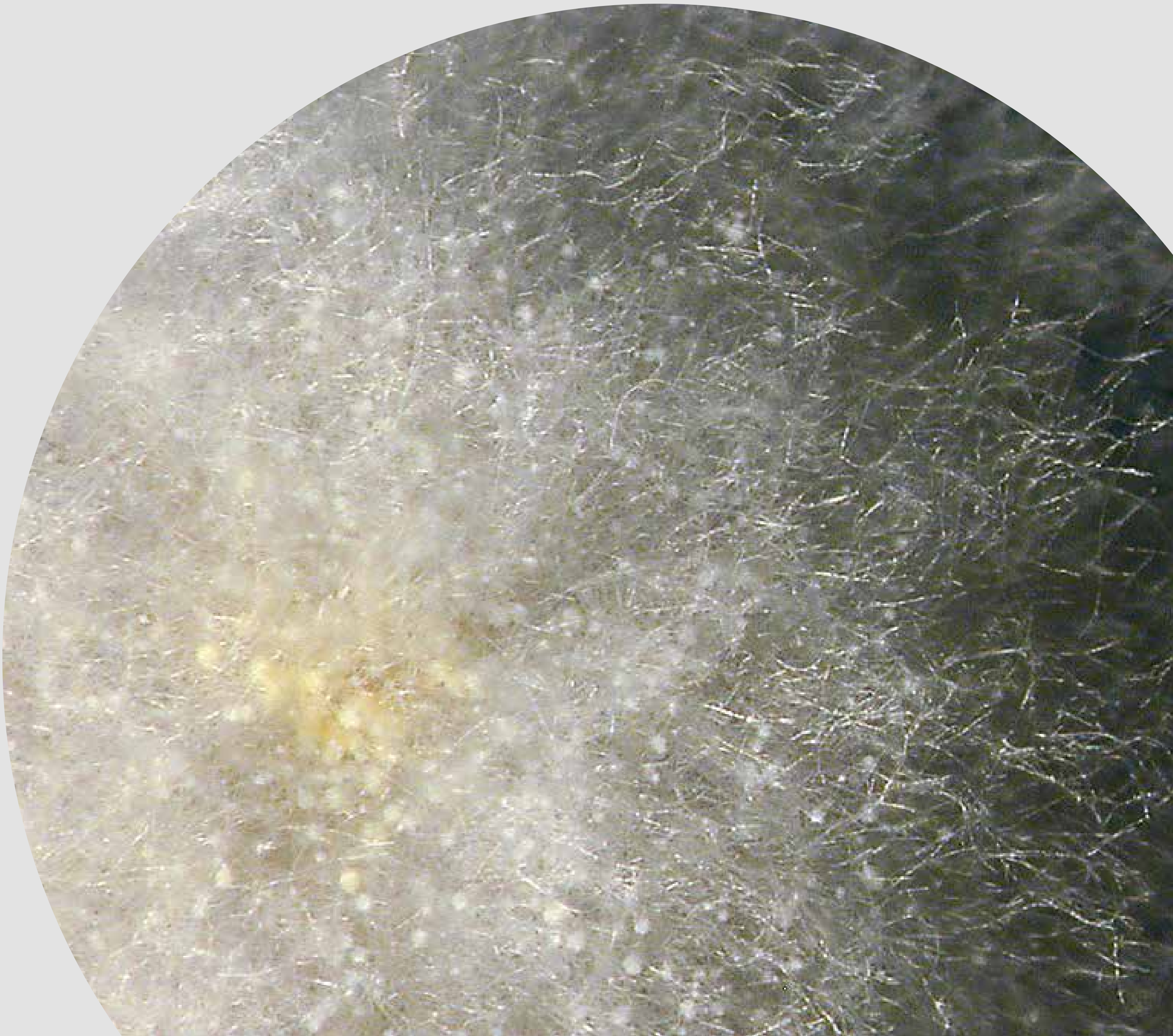
[78] Okk, G. (2015). Report on the network and policies of Estonian universities, research institutions and institutions of professional higher education. https://riigikantselei.ee/sites/default/files/riigikantselei/strateegiaburoo/tan/rdc_gunnar_okk_report_2015.pdf (03.11.2016).

[79] Loog, M. (2015). *Teaduse kadumine ei muudaks midagi, tehkem teadust!* –http://arvamus.postimees.ee/v2/3414463/mart-loog-teaduse-kadumine-ei-muudaks-midagi-tehkem-teadust (19.10.2016).

[80] Reino, A., Jaakson, K., Kase, K., Kivipõld K., Orav, P., Aidla, A., Türk, K., Ahonen, M. (2014). *Eesti teadus -ja arendusasutuste juhtimismustrid. – TIPS uuringu 3.1 lõppraport. Tartu.*

Explosion (mold colony).

Authors: Triinu Visnapuu, Sulev Kuuse (Institute of Molecular and Cell Biology, University of Tartu), 2010.



The importance and impact of research on society

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Tallinn Technical University, visiting professor

Stripped to the essentials, the claim made in this essay is that 'Research creates suitable jobs for everybody in society'. But to reach that conclusion, we to need to step back and gain some perspective.

Basic economic theory sets forth that the level of output in society depends on the resources that are available. This idea was used by Robert Solow to elaborate the first growth model. That model posits that output equals capital multiplied by the input of labour. Solow's model was improved throughout the second half of the 20th century to include innovation and intellectual capital among the various factors of growth. At first it was assumed that the level of development and innovation was determined by external factors, but since the 1980's, and especially on the basis of Paul Römer's work, many economists have begun to support the endogenous growth theory, according to which, the level of development of a country depends on its internal resources. The general understanding by now is that, as the labour force and capital levels are generally slow to change over time, more focus should be put into innovation and development of new technologies in order to boost the economy.

However, it is known that the income distribution in society is subject to the so called "power law". In each society there will generally be large numbers of people with low incomes and only a small number with high incomes. This phenomenon is also known as Pareto distribution: 80% of members of society own 20% of value and conversely, 20% of people earn 80% of the income.

The government as an insurance policy for the average person

Estonia is a small country with an open economy, and each citizen is a carrier of our language and culture. As our population is small, each person has a much larger role in preserving our language and culture than they would in a larger nation. Thus, as we maximise our economic growth, Estonia should also definitely provide enough job opportunities for unskilled labour that ensure decent subsistence for a large part of the population. To ensure the sustainable development of Estonia, the government should act as an insurance policy, where nobody is left without an education, job or basic needs, without regard to their ideas, beliefs and place of origin, as long as the person is a carrier of our culture and language.

But how can we solve the seemingly controversial dilemma of both contributing to innovation, which is necessary for growth according to economic theory, and providing jobs that match a wide variety of skill sets, which are necessary for preserving our culture? The answer turns out to be relatively simple: we need to stimulate cooperation between research and the economy.

Entrepreneurs consider research useful only if the money invested in it somehow improves the prosperity of their companies. In other words, entrepreneurs assess investments into research mainly on the basis of return on investment.

At the same time, researchers are motivated to solve global problems by contributing to the development of knowledge over a very long period of time. The motives of researchers are usually not to capitalise on intellectual property. By bringing together research and entrepreneurship competences within the country, it is possible to create value chains where entrepreneurs are able to capitalise on the results of researchers.

What the are the goals of state funded universities? Should a university be a research institution or a place where the required labour force is trained? In view of the fact that universities must ensure education, qualified labour for enterprises and the preservation of our culture, we can choose neither extreme. For economic development it is necessary to train required specialists and to boost innovation and high level research where these they already have taken root.

How to maximise what entrepreneurship and research have in common?

Most countries in the world, not just Estonia, are too small to have the resources to be active in absolutely every field of research and industry. Thus, in the context of added value, it is important to maximise the common interests of both business enterprise and research. This, however, cannot be achieved by state policies alone; instead, it has to be achieved through free competition. There is enough global experience to confirm that centrally planned economic systems are not viable in the long run. Also, it is doubtful whether artificially created fields of science will provide any new quality in the long run. It is natural for research teams to move in directions where their creations have potential for innovation. They engage in fields where their work is published and cited.

In a globalised world we would fully expect that researchers could offer new ideas to the entire world. Those ideas might not be commercialised by Estonian enterprises, but instead, this might be done by anybody else in the world who is able to pay for the right to do so. Entrepreneurs think the same way: if they can obtain new know-how from abroad, then why not use it? And the more of our production we can sell abroad, the better it is for the Estonian economy.

There is no hidden controversy here. The controversy lies in the fact that in the context of preserving the Estonian language and culture, it is important for local entrepreneurs to create suitable jobs for large numbers of people while being at the top tier globally in their industry. This can be achieved only through an endogenous growth model, where local entrepreneurs commercialise locally created intellectual property.

If Estonian researchers create new intellectual property with Estonian entrepreneurs and through that, Estonian enterprises create new jobs that are suitable to many people, we reach a situation where Estonian researchers create jobs for the Estonian people. Research is needed to create jobs that are suitable for everybody!

Open science

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Chair of Open Science Expert Committee

The central idea of open science is to provide freely accessible digital scientific information, and to optimize its circulation and use by researchers, various other interest groups and society as a whole. Open access to scientific publications and research data are the two major agendas within the open science movement, but in addition, there are open source software, open methodology, open peer review and other similar principles that are beginning to replace earlier practices. Why? Because open science principles foster scientific cooperation, improve efficiency and transparency, as well as increase the visibility and citation of research. Equally important are the increased feedback to society and wider opportunities to use up-to-date scientific information and ideas in education, state agencies, amateur science and other areas where access to a large amount of publications is restricted by paywalls. Many studies indicate that open science contributes to innovation and has considerable economic benefits. The latter is without doubt, one of the most important reasons why the leading countries in science and innovation, such as the US, China, EU, UK, Canada and Japan, are pushing forcefully for more free access to scientific information. The European Union has the ambitious goal of making all publicly funded European scientific articles and their source data publicly accessible on the Internet by 2020. Most member states also have introduced open science policies and many research funding organisations have established open access to results as one of their financing criteria.

The ideology of open science is not new in Estonia. Our main scientific journals have been freely accessible online since their electronic versions first appeared more than 10 years ago, and open access events, led particularly by the University of Tartu Library, have become an annual tradition. The political position of Estonia regarding open science is formulated in the Government's decision which, in response to the European Commission's Communication on access and preservation of scientific information, sets forth, among other things: 'Estonia supports open access to scientific publications and establishing open access as a financing criterion for research funded by the public sector'[81,82]. The Estonian

[81] *Vabariigi Valitsuse otsus. Istungi protokoll (04.10.2012). Eesti seisukohad Euroopa Komisjoni teatise „Teadusinfo paremini kättesaadavaks: rohkem kasu avaliku sektori investeeringutest teadustegevusse" ning Komisjoni soovituse, 17.7.2012 nr C(2012) 4890, teadusinfo kättesaadavuse ja säilitamise kohta.* – (briefly in English: Government's decision made on 04.10.2012 in response to EC advisory letters about the accessability and conservatoin of research data.)

[82] *Seletuskiri Vabariigi Valitsuse protokollilise otsuse „Eesti seisukohad Euroopa Komisjoni teatise „Teadusinfo paremini kättesaadavaks: rohkem kasu avaliku sektori investeeringutest teadustegevusse" ning Komisjoni soovituse, 17.7.2012 nr C(2012) 4890, teadusinfo kättesaadavuse ja säilitamise kohta" juurde. Haridus- ja teadusministeerium.*

Research and Development and Innovation Strategy 2014–2020 'Knowledge-based Estonia'[83] identifies open access as one of the measures for increasing the social and economic benefits of research and development and: 'encourages open access to public-financed research results and research data.' Since 2013, competition-based research funding instruments have included an open access recommendation. The data from the Estonian Research Portal (ETIS) for 2015 indicate that over 40% of publications issued as a result of competition-based research are already open access.

Estonia has also taken some important steps in establishing technical solutions that allow the depositing and publishing of research data. For instance, several objects of the „National Research Infrastructure Roadmap" have been brought to life, notably the 'Natural History Archives and Information Network', the 'Centre of Estonian Language Resources', the 'Estonian Centre of Genomics' and the 'e-Repository'. In addition the DataCite Estonia Consortium was created in 2015, providing DOI identifiers to research data sets, thereby ensuring their higher visibility and usability. These possibilities, however, are only used by a small fraction portion of the research community – depositing and opening up source data is currently not a widespread practice in many fields, and there are no administrative regulations on the accessibility of research data at present.

What further steps will Estonia take in implementing open science principles? The Open Science Expert Committee - which was formed under the Estonian Research Council in 2015 - has looked for the answer to this multifaceted question. The committee's work and further open discussion led, in June 2016, to the publication of Estonian open science policy recommendation. This document sets forth two main strategic objectives for Estonia to achieve by 2020:

(1) publications resulting from public sector funded research should be freely accessible to everybody, no later than one year after their first publication, and at least half of these should be available immediately and in their final form; and

(2) research data gathered with the help of public sector funding should be placed in open repositories where they should be freely accessible to everyone and reusable unless restricted by law.[84]

To achieve these objectives, the committee proposed several principles and specific actions for entities distributing research funding, for R&D institutions and researchers. The feedback from R&D institutions on the policy recommendations showed general support for the principles of open science, but also identified several concerns. The main problems mentioned were the potential extra costs, additional administrative burdens on researchers, and a risk that an open access requirement might have a negative impact on the quality of the publications. Publication of research data could be hindered by various restrictions, the additional workload of researchers and inadequate skills.

A more precise estimate of how much the introduction of open science ideology in Estonia would cost and how this could affect the development of research and society will be made in a study within the Research and Innovation Policy Monitoring Programme in 2017. Initial calculations indicate that, for example, providing immediate open access to all scientific articles in Estonia would cost up to 3–4 million euros per year. Experiments conducted in some foreign universities show that such an investment could increase the international visibility and citation of Estonian researchers by several times. It is worth noting that a similar amount is currently spent each year on subscriptions to scientific journals by the consortium of Estonian university libraries. If the current subscription-based publishing model is replaced by an open access model, a reallocation of existing resources could be sufficient to cover that cost. However, Estonia can influence global scientific publishing trends only indirectly, primarily by supporting European initiatives fostering open access to scientific information. As a transitional arrangement, Estonia is able to implement the green open access model, which calls for self-archiving of publications in open access repositories. Developing and maintaining a central repository of scientific publications should be one of the priorities in the near future for Estonia.

Estonia's possibilities for standing out internationally in the field of open science are primarily related to the development of data infrastructure and data services. The most important task here is participating in the launch of the European Open Science Cloud by focusing on the fields where Estonia has experience in developing its national infrastructure and high level scientific competence, for example, in biodiversity informatics.

In conclusion, it should be noted that open access to research results is a general trend which Estonian researchers should increasingly take into account. Whether the transfer to the new models of publishing and data management will be smooth will depend both on political choices and the preparedness of research institutions to promote the open science ideology among researchers and other users of scientific information.

For further information see the webpage of the Estonian Research Council at http://www.etag.ee/en/activities/horizontal-topics/open-science/.

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[83] Estonian Research and Development and Innovation Strategy 2014-2020 „Knowledge-based Estonia". (2014). Ministry of Education and Research. – https://www.hm.ee/sites/default/files/estonian_rdi_strategy_2014-2020.pdf (02.11.2014).

[84] *Avatud teadus Eestis. Eesti Teadusagentuuri avatud teaduse ekspertkomisjoni põhimõtted ja soovitused riikliku poliitika kujundamiseks. Tööversioon 2016-02-29. (2016). SA Eesti Teadusagentuur* – http://www.etag.ee/wp-content/uploads/2016/03/AT_soovitused_20160229.pdf (28.10.2016).

The carabid beetle is adapted to its habitat.

Author: Enno Merivee (Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences)

How much does research integrity cost?

Toivo Maimets
University of Tartu, professor

Kadri Mäger
Estonian Research Council, programme manager

Scientific research is the cornerstone of modern developed societies. Research is the basis for new theoretical and technical solutions that promote human health, living environment and welfare, as well as support the development of nature, society, the economy, culture, and social cohesion. Research is the basis for a knowledge-based society, research-based education and correspondingly, human culture itself. Such a central role places a specific responsibility on researchers and everybody involved in research - the responsibility for the future.

When assessing research, researchers, and knowledge, trust is of critical importance. We believe that the knowledge discovered, concluded and created by people who know more than us in a respective field are based on accurate, complete and honest conclusions, and are presented fully and correctly. Research is a process where new knowledge is created on the basis of existing knowledge, thus making the solidity and integrity of their foundation extremely important.

Research integrity means that research is performed in compliance with the highest professional standards and ethical norms, and that researchers are fully responsible to, and honest with colleagues, students and the whole of society. Scientific method is based on facts, not biased opinions and therefore, extreme honesty and truthfulness are expected.

What happens when trust is lost?

A proper house cannot be built on an unsteady foundation. If researchers cannot rely on the research papers of their colleagues or their independence from ideological, economic or political interests, their work, results and credibility will suffer. A given area of research could find itself in a blind ally for years. This results in a waste of time and money, as well as the loss of reputation and career.

A very large part of contemporary research is funded by the public sector. If people's trust in researchers and their work erodes, the person violating the rules would not be the only one to suffer – the whole researchers community and the establishments where they work will also suffer. If the public loses trust in research and researchers, they might also lose interest and desire to finance research. Researchers' opinions should be an important basis for solving the major challenges facing our society. A lack of trust in research would make it impossible to take those opinions into account. Quite the opposite, they will be disregarded.

Why some violate research norms?

Research misconduct includes plagiarism, and falsification and manipulation of data at any stage of research. This list also includes sloppy science, ignoring conflicts of interest, improper use of resources, abuse of good relations with colleagues, violation of rules relating to human trials, experiments on animals or environmental protection, selective publishing and misappropriation of authorship.

Several reasons why researchers choose the path of misconduct have been identified:

1) Over the last several decades, the measurement of research quality (both that of individual researchers and research institutions) has become more and more important. This is primarily due to increasing political pressure to use (financial) resources more efficiently and to increase public expectations to implement understandable efficiency metrics. Although the measurement of the quality of research on the basis of quantitative indicators is very inaccurate, and often leads to completely misguided conclusions, the expectation for 'understandable metrics' is so large that it is often thought that bibliometric data, *i.e.* the number of articles, citations, the H index, etc., is sufficient. This is especially seen in countries where the organisation of research is more administrator-centred, and the self-confidence of the scientific community is low. The result is the "publish or perish" effect: where funding provided to research institutions and researchers as well as their career choices depends too much on such bibliometric indicators. The irrationality of such a situation has been pointed out for years, but changes are slow to emerge (see, for example, Lawrence[85], Macilwain[86]).

2) Hyper-competition for resources. For example, in biomedicine, constant growth in the field has produced a steady growth in resource needs. This has created a situation that does not encourage the best young researchers to choose this area of research. and it hinders the normal work of researchers[87]. Brian Martinson[88] gave an excellent example in his presentation at the 4th World Conference on Research Integrity in Rio de Janeiro in 2015. Over 40 years, the scientific community studying certain worms as a model has grown from 77 to more than 4000 people, and all of them compete for more or less the same amount of money. While researchers are basically fighting for their survival, (meaning salary and continuation of the work of their research team) it might resort to extreme methods to do so. Elisabeth Goodwin from the University

[85] Lawrence, P.A. (2007). The mismeasurement of science. – Current Biology, Vol 17, Issue 15, pp. 583-585.

[86] Macilwain, C. (2013). Halt the avalanche of performance metrics. – Nature, Vol 500, p. 255.

[87] Alberts, B., Kirchner, M.W., Tilghman, S., Varmus, H. (2014). Rescuing US biomedical research from its systemic flaws. – PNAS, Vol 111, No. 16, pp. 5773-5777.

[88] Martinson, B. (2015). Getting to Research Integrity: An Eco-Systemic Perspective. –http://www.wcri2015.org/ppt/1_june/Martinson_1june.pdf (19.10.2016).

of Wisconsin, manipulated data when applying for a project grant, in order to convince the evaluators of the value of the proposal, and to show herself in a more successful light. Her student who revealed what she had done, admitted that this most probably happened because of the obvious pressure to receive the research grant in order to keep the laboratory in business. For Goodwin the case ended with a suspended sentence of two years, a prohibition from applying for public grants for three years and a $100,000 fine[89].

With this Mr Martinson draws attention to the fact that in research, the competition for ideas has become largely a fight for resources. Geman and Geman[90] add: 'In fact, many of us spend more time advertising ideas than formulating them.'

3) Stressful situations, for example, the pressure for fast results, might lead to situations that make people cut corners. In this respect, the internal culture of the country, institution or team and their role models are very important.

4) De Vries et al.[91] pointed out that researchers see the most critical problems to be the accuracy and interpretation of data, research rules (particularly those perceived to be excessive and "over-regulating"), relationships with colleagues, competition, and the theft of ideas. In conclusion, problems are caused by everything that relates to the desire to be the most visible and successful in a given field.

Another similar study[92] showed that the ethical behaviour of researchers depended on organisational justice, *that is,* how fair the distribution of resources and the respective procedures are perceived to be.

5) Inevitably, much depends on the individual character of researchers. For example, one study found that persons who violate rules, usually have done it repeatedly, work alone, are characterised by narcissistic thinking and a tendency to always find justifications for their behaviour[93]. Qualitative analysis indicated that the wrongdoers were convinced that their acts would not be discovered and that they had the right to manipulate the data, so that it would comply with their hypothesis. Even more, they did not just want to be honoured and well known – they wanted to be superstars in their fields.

How often does this happen?

Fanelli[94] produced a meta-analysis of published surveys, where researchers were asked how often they themselves had engaged in misconduct or had seen a colleague do the same. The analysis included 21 studies conducted by various investigators during the period from 1987 to 2008. 2% of the respondents admitted to plagiarism, falsification or data manipulation. However, 14% said they had observed this behaviour by colleagues. As for questionable practices, 34% of respondents admitted to doing these themselves, and as many as 72% said they noticed their colleagues engaging in them. Fanelli concludes that the actual numbers might be considerably larger.

Gommel[95] conducted a survey among doctoral students. Nearly one-fifth of the respondents admitted to having engaged in misconduct at least once (falsification, data manipulation, idea theft, etc.) and nearly half admitted that before a course they had not known much about correct data management or authorship. This is a direct indication of the inadequate work of their supervisors and mentors.

How much does misconduct cost?

An analysis of the US Office of Research Integrity's materials indicates that in the period from 1992 to 2012 the estimated cost of recalled articles was $58 million[96]. The reasons for the recall of these articles were mainly plagiarism, falsification, data manipulation and other fraudulent behaviours. In one case in particular, the direct and indirect costs amounted to $525,000[97]. These included the long term hiring of experts for the investigation as well as other costs. The European Union is also funding research to identify the cost of misconduct and the socio-economic impact of research integrity.[98]

What should be done?

As the causes of the problem are very complex, of course, there are no simple solutions. It is, however, obvious that the scientific community itself needs to deal with this problem, because their public credibility and hence the future of

[89] See also Allen, J. (2008). Can of Worms. – Wisconsin Magazine, 109(1):28-33(63).

[90] Geman, D., Geman, S. (2016). Science in the age of selfies. – PNAS, Vol 113, No. 34, pp. 9384–87.

[91] De Vries, R.J, Andreson, M.S., Martinson, B.C. (2006). Normal Misbehavior: Scientists Talk About the Ethics of Research. – Journal of Empirical Research on Human Research Ethics: An International Journal, Vol 1, No. 1, pp. 43–50.

[92] Anderson, M.S., Crain, A.L., De Vires, R., Martinson, B.C. (2006). Scientists' Perceptions of Organizational Justice and Self-Reported Misbehaviors. – Journal of Empirical Research on Human Research Ethics, Vol. 1, No. 1, pp. 51–66.

[93] DuBois J.M., Anderson, E. E., Chibnall, J., Carroll, K., Gibb, T., Ogbuka, C., Rubbelke, T. (2013). Understanding Research Misconduct: A Comparative Analysis of 120 Cases of Professional Wrongdoing. – Accountability in Research, Vol. 20, Issue 5-6, pp. 320–338.

[94] Fanelli, D. (2009). How Many Scientists Fabricate and Falsify Research? A Systematic Review and Meta-Analysis of Survey Data. – PLoS ONE. 4(5): e5738. http://dx.doi.org/10.1371/journal.pone.0005738 (19.10.2016).

[95] Gommel M., Nolte, H., Sponholtz, G. (2015). Teaching Good Scientific Practice: Results from a Survey and Observations from Two Hundred Courses. – JUnQ, Vol. 5, Issue 2, pp. 11–16.

[96] Stern, A. M., Casadevall, A., Steen, R. G., Fang, F. C. (2014). Financial costs and personal consequences of research misconduct resulting in retracted publications. – eLife 2014;3:e02956. http://dx.doi.org/10.7554/eLife.029561 (19.10.2016).

[97] Michalek A.M., Hutson, A.D., Wicher, C.P., Trump, D.L. (2010). The Costs and Underappreciated Consequences of Research Misconduct: A Case Study. – PLoS Med 7(8): e1000318. http://dx.doi.org/10.1371/journal.pmed.1000318 (19.10.2016).

[98] Estimating the costs of research misconduct and the socio-economic benefit of research integrity. (2015). –http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/garri-9-2015.html (19.10.2016).

research are at stake. It is important to formulate the common values, which researchers believe create a self-evident need for compliance. Also, the problems and possible solutions need to be clearly formulated. One aspect of defining what is ethical falls into a grey zone, *i.e.* it is not always clear whether a given activity is misconduct, and in certain cases, the assessment depends on the context. The result might be that researchers who think they are acting honestly may become blackmail victims. To avoid that, on the one hand, possible sources of conflicts should be introduced to researchers early on in their studies and on the other hand, there should be expert committees that have enough authority to thoroughly analyse cases and present the results to the public.

Over the years, there have been various attempts within Estonian research institutions to formulate the issues related to research integrity and mark boundaries of ethical behaviour. The Code of Ethics of Estonian Scientists[99] could be considered one of the more successful attempts. However, a considerable amount of time has passed since its appearance, and many problems have surfaced from different perspectives. Therefore, the University of Tartu Centre of Ethics and the Estonian Research Council have joined forces to work on a new approach, which will hopefully benefit all stakeholders: research, researchers, research institutions and society as a whole.

[99] Estonian Academy of Sciences. The Code of Ethics of Estonian Scientists. – http://www.akadeemia.ee/_repository/File/ALUSDOKUD/Code-ethics.pdf (03.11.2016).

Water flea (*Daphnia sp.*) with eggs in female brood pouch.

Author: Sulev Kuuse (Institute of Molecular and Cell Biology, University of Tartu), 2007.

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