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Internationalisation of the Estonian research system through the lens of bibliometric indicators: criticism and policy recommendations

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School of Economics and Business Administration, University of Tartu, Estonia

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CONTENTS

INTRODUCTION

Throughout the umbrella chapter, numerous artificial intelligence solutions were used in the writing process. Primarily Grammarly, but also Google Bard and ChatGPT.

List of publications

This thesis is based on three original research articles, listed below, which are hereafter referred to as Study I, Study II and Study III:

I. **Hirv, T**. (2022). The interplay of the size of the research system, ways of collaboration, level, and method of funding in determining bibliometric outputs. *Scientometrics*, 127(3), 1295–1316.

II. **Hirv, T.** (2019). Research consortia determine a significant part of the bibliometric visibility of Estonian science. *Trames*, *23*(3), 287–308.

III. **Hirv, T**. (2018). Effects of European Union Funding and International Collaboration on Estonian Scientific Impact. *J. Sci. Res.*, *7*(3), 181–188.

Motivation for the Research

The value of this topic comes from the importance of the economics of science. The economics of science is a broad field that examines the relationship between science and the economy, such as how scientific research is funded, scientific discoveries are commercialised, and how science affects economic growth and development. This knowledge empowers us to make informed decisions, shape policies, and reap the benefits of science for society as a whole. Three fundamental problems led to the development of the modern economics of science (Figure 1).

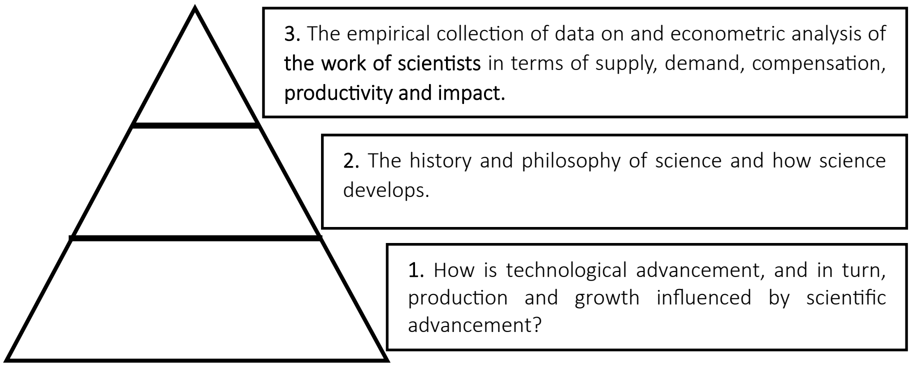

Figure 1. *Fundamental problems of the modern economics of science*
Source: author's adaptation based on Diamond (2008) Stephan (1996)

The first issue is how technological advancement and growth are influenced by scientific advancement. The second issue, which touches on the history and philosophy of science, focuses on how science develops. And third, the most specific and relevant issue regarding the thesis, deals with the empirical collection of data on and econometric analysis of the work of scientists in terms of supply, demand, compensation, productivity and impact (Stephan, 1996; Diamond, 2008). Within this framework, the thesis specifically focuses on the latter aspects of the third issue: examining the productivity and overall impact of scientists on their field.

The impact made by scientists is measured in a number of ways. Some people think the Nobel Prize is the only meaningful measure of success, but because they are rarely given, they are not well suited for general evaluation. The need for scientific accountability has led to a rise in quantitative performance evaluation. As a result, various experts now look at how many articles are published and how well they are cited as a measure of impact (Garfield, 1979).

In scientometrics literature, the terms *research*, *scientific*, and *citation impact* are often used synonymously (see, for example, Thelwall, 2017; Larivière et al., 2011; Glänzel, 2001) unless stated otherwise. This is because, in the context of scholarly publication, these terms all refer to the same thing: the impact of a scientist's work on their field (Hicks et al., 2015; DORA, 2012). In order to avoid confusion, I will refer to *citation impact* throughout the umbrella chapter.

Research has long been understood to have an international dimension, whether from the perspective of mobility, research collaboration, or other means of information dissemination (Altbach & Teichler, 2001). For example, according to the Organisation for Economic Co-operation and Development (OECD, 2021), science internationalisation encompasses the globalisation of scientific research involving scientists, institutions, and funding sources from various nations. Consequently, the internationalisation of science has become an increasingly important topic for scientists and policymakers.

Internationalisation may not be an option but a necessity for researchers from a small country to solve world-class science challenges (Aghaei Chadegani et al., 2013; Iglič et al., 2017). The size of a country is seen as a limitation for building up human and financial capital for research and the specific know-how required (Berghäll et al., 2002). It has been argued that small countries can compensate for such disadvantages through internationalisation (Reale E. et al., 2013; Schiermeier, 2019) by collaborating and accessing funding from abroad. For example, Estonia's dependence on EU structural funds and its success in competing for grants from the EU's multi-year research programmes are well known (Schiermeier, 2019).

As Estonia becomes more integrated into the EU Framework Programmes and global scientific networks, its scientists can better enhance their impact by accessing data, tools, equipment, and ideas. From this perspective, the Estonian story represents a small nation's remarkable technological success in updating its science system and developed one of the world's most sophisticated digital infrastructures in the last quarter of a century (Schiermeier, 2019). Since joining the European Union (EU) in 2004, Estonia has spent more than 1 billion euros of EU funds on modernising its science base (Ibid.), which has led to a very high citation impact in various fields, including *Ecology*, *Molecular Biology* and *Genetics* (Allik et al., 2020a; Lauk & Allik, 2018). This investment has also helped Estonia to form comprehensive international research networks (Must, 2014), which are essential for advancing scientific knowledge in the 21st century.

Despite the fact that the internationalisation of research has been widely analysed (see, for example, Woldegiyorgis et al., 2018; Kwiek, 2015; Rostan et al., 2014; Abramo et al., 2011; Horta, 2009), we still do not know enough about the effects of internationalisation on a small country's citation impact. Keeping in mind that the Estonian R&D and innovation strategy states that Estonia is active and visible in international R&D cooperation (Estonian Research Council, 2016; The Ministry of Education and Research, 2012), it is essential to understand more about the internationalisation of science.

As a result, the primary motivation for the research topic at hand is to determine whether internationalisation could explain the "puzzle" of Estonian science – the dramatic increase in Estonian citation impact despite low funding between 2008 and 2018. Termed "the puzzle" by Lauk and Allik (2018), this unexpected increase in impact has attracted global attention, even being featured in the prestigious academic journal, *Nature* (2019).

One potential piece of the puzzle might be internationalisation, encompassing international collaboration, funding, and most importantly, involvement in transnationally coordinated research projects. Suppose internationalisation is indeed the driving force behind the sudden surge in impact. What implications does it hold for the research policy perspective concerning researchers, research groups, and the country as a whole? This consideration, coupled with the escalating importance of international rankings and the expanding influence of research metrics, explains the rationale for selecting this topic for the thesis.

The Special Case of Estonia

Estonia, a small Baltic nation, has undergone remarkable scientific transformation since gaining independence from the Soviet Union in 1991. The country has forged strong partnerships with leading scientific institutions worldwide, leveraging foreign grants and expertise to build a dynamic research environment. Estonian scientific progress is interesting for several reasons:

1. It provides a case study of how a small country can rapidly develop its scientific capabilities in a relatively short period.
2. It highlights the importance of international collaboration in advancing scientific knowledge.
3. It offers insights into how countries can leverage foreign resources to support scientific development.

The following paragraphs will explore these key aspects in detail.

Rapid development: After regaining its independence, Estonia experienced significant growth and transformation in its scientific landscape and successfully managed to break away from the previous Soviet structure of science (Allik, 2003; Lewison & Must, 2001). The drastic change in the political situation that all Eastern European countries underwent after the collapse of the communist regime changed scientific collaboration patterns: what had been very difficult and even forbidden under communist rule was now allowed (Kozak et al., 2015). For example, under the Soviet occupation, Estonia suffered as an isolated garrison: university students and scholars were disconnected from global science, with limited access to English literature and travel opportunities (Schiermeier, 2019). After the occupation, the country underwent a remarkable scientific transition, leading to the emergence of a dynamic research environment.

Interdisciplinary collaborations: Researchers often engage in multidisciplinary projects, leveraging the country's scientific network to address complex research challenges (Must, 2014).

International collaboration and funding: Despite its size, Estonia actively engaged in international scientific collaborations and established partnerships with renowned research institutions worldwide (Kremer & Marx, 2009). Estonian researchers actively participated in European research programmes and initiatives (Ukrainski et al., 2014; Must, 2010). For example, Estonia excels in EU research grant competitions. Considering the size of the country, Estonia exceeds the EU average by 40% in the Horizon 2020 programme and surpasses the other 13 new Member States threefold (Schiermeier, 2019).

Research output and impact: Despite its relatively small population and low funding, Estonia has notably increased publications and citations (Allik, 2003;

2008; 2013; 2015). This is even more noticeable in recent bibliometric evaluations (Allik, 2016; Lauk & Allik, 2018; Allik et al., 2020b). These achievements reflect the effectiveness of Estonia's research and innovation policies and its scientific community's dedication and quality.

According to Allik (2003), annual R&D funding allocated by Estonian, Latvian, and Lithuanian governments in the 90s and early 00s seemed insufficient to yield the observed research output quantity and quality. Scientific publications from these Baltic nations exceeded what could reasonably be achieved with limited financial resources. Allik (2003) speculated that the only plausible explanation was *hidden money* that remained unaccounted for in R&D expenditures. He highlighted that numerous studies were conducted in collaboration with partners from scientifically more advanced nations in addition to foreign grants. For example, from 1996 to 1999, approximately 50% of articles by Estonian scientists involved collaborations with Western partners, such as Sweden, Finland, Germany, and the US (Lewison & Must, 2001).

Initially, Estonia, Latvia, and Lithuania had similar starting points. Each country published around 300 papers yearly in the early 90s (Allik, 2003). By 2007, Estonia published 1,295, Lithuania published 1,067, and Latvia published 426 articles (Allik, 2008). Despite the increase, the number of scientific publications in the Baltic countries remained relatively modest. Estonian scientists achieved only 34% of Finnish productivity per million in population. In comparison, Latvia and Lithuania reached only 10% and 13%, respectively. In citations per publication (1997–2007), Estonia was ranked 31st and surpassed all former communist bloc countries, including Hungary and the Czech Republic, as well as older EU members like Portugal and Greece (Allik, 2008). However, the impact of Estonian articles remained 17.2% below the global average. On average, the citation impact of Estonian science from 1997 to 2007 increased by 24.4% compared to publications from 1994 to 2004. The most remarkable increase was achieved in *Agricultural Sciences*, which could not surpass the Web of Science high-impact threshold in 2004 but did so in the 2008 benchmark.

From 2004 to 2014, Estonia underwent significant changes, joining the EU and NATO in 2004 and adopting the euro in 2011. The most significant impact on science came with EU membership, as Estonia has invested over 1 billion euros in EU funds to modernise its research base since 2004 (Schiermeier, 2019). According to publications from 2004 to 2014, Estonian science ranked 27th in terms of citations per paper. Each paper authored by at least one Estonian scientist was cited 12.17 times, exceeding the world average by 5% (Allik, 2015).

According to Lauk and Allik (2018), if there is one post-communist country that has managed to escape the curse of the past, it is Estonia, which occupies the highest position in rankings among all post-communist countries (Allik, 2003; 2008; 2013; 2015). This assertion is particularly evident in the rankings covering 2007 to 2017, where Estonia was ranked 20th in citation impact per article (Lauk & Allik, 2018). Estonia's standing improved even further if we consider the combined metric, which accounts for the average citation rate and the percentage of papers reaching the top 1%, placing Estonia in the impressive 12th position.

Lauk and Allik (2018) identified significant variations in the impact across different research areas. Estonian citation impact was found to be double the world average in certain fields, such as *Clinical Medicine*, where citations per article were 107.2% relative to the global average of zero. *Clinical Medicine* was followed by *Molecular Biology & Genetics* at 96%, *Plant & Animal Sciences* at 60.7%, *Physics at 59.7%*, and *Environment/Ecology* at 54.3%. At the lower end, *Economics & Business* showed a -36.5% impact, followed by *Computer Science* at -34.2% and *Social Sciences* at -27.2%.

The previous 12th position improved later on, and Estonia achieved country rankings of 8th (Allik et al., 2020a) and 6th (Allik et al., 2020b). According to Schiermeier (2019), the remarkable scientific achievements of Estonia demonstrate how swiftly a small nation can transform its scientific landscape through global assistance and effective national strategies, attracting the interest of other countries seeking to enhance their scientific capabilities.

The Structure of the Thesis

This thesis aims to provide insights into science internationalisation in the context of bibliometrically measurable outputs with an emphasis on smaller countries. The specific goals outlined below will be pursued to achieve this aim:

1. Provide a detailed overview of the theoretical and empirical background for the thesis (Chapters 1 and 2).
2. Describe the methods employed and the sample used in the studies (Chapter 3).
3. Present empirical studies to answer the research questions presented (Chapter 4).
4. Discuss the findings of the studies and outline the contributions made (Chapter 5).
5. Formulate policy recommendations based on the studies (Chapter 5).
6. Address the thesis' limitations and propose directions for further research (Chapter 5).

The rest of the introduction is dedicated to presenting the novelty of the thesis and its objectives. A detailed overview of the theoretical and empirical background for the thesis is provided in Chapter 1, which has several crucial subchapters that establish the foundation for the empirical articles. Subchapter 1.1 explains the backstory of the economics of science and clarifies the bibliometric terms used in the thesis, such as "scientific productivity" and "impact." Subchapter 1.2 discusses the key limitations of the bibliometric method. Building on this foundation, Subchapter 1.3 presents the classical theories of production and frames them within the context of knowledge production, which is crucial for comprehending the research questions.

Since the production of knowledge is a complex matter, Subchapter 1.4 is devoted to explaining why, in some instances, the output may increase more than the input. Subchapter 1.5 provides a theoretical framework for collaboration in science production, which is essential for understanding internationalisation. Subchapter 1.6 gives an overview of previous studies regarding European Framework Programmes, and Subchapter 1.7 provides information regarding transnationally coordinated research projects.

The main theoretical takeaways are summarised in Chapter 2. Chapter 3 describes the methods employed and the data used in the thesis. Chapter 4 consists of three original empirical studies.

Subchapter 5.1 discusses the findings of the research articles. Subchapter 5.2 provides policy implications by proposing suggestions for measuring citation impact in Estonia, which are also suitable for other countries with small research systems. Subchapter 5.3 opens some possible limitations of this thesis and presents ideas for further research, and Subchapter 5.4 summarises the contributions the thesis has made to the economics of science literature.

Research Design and the Research Gap

In order to fulfil the stated research aim, the following research question with subsequent sub-questions are formulated:

RQ: How does the interplay of the size of the research system, ways of collaboration, level, and method of funding affect citation impact?

Subsequent sub-questions:

- How do research consortia and international collaboration affect Estonian citation impact?
- Does international collaboration combined with external funding sources maximise Estonian citation impact?

All three original studies presented in the thesis contribute to the economics of science literature, each of them being related to specific aspects of the public research system and complementing each other in understanding science production and internationalisation. Study I provides answers to the main research RQ, and Studies II and III focus on its sub-questions.

In order to systematically unify all three studies, I used a complemented version of Lepori's (2011) model of public research systems, shown in Figure 2. The figure provides an overview of public research funding, distinguishing one notional and four organisational layers – the scale layer, the policy layer, funding agencies, performing organisations, and research groups/individual researchers – as well as two main allocation methods – core funding to research organisations and project funding to research groups.

Compared to the original design, I placed *Impact* at the top of the figure, representing the research impact generated by the research system that the government manages. Based on Thorsteinsdóttir's (2000) notion that size matters in publicly funded research, I added a notional layer, the scale layer, between them, potentially amplifying the impact from the research system. In the case of the scale layer, I use returns to scale synonymously with return to size, as proposed by Abramo et al. (2012, p. 706). The decision by governments to participate in transnationally coordinated research projects, such as the European Organisation for Nuclear Research (CERN), and the opportunities for research organisations and research groups to collaborate internationally or with industry through University-Industry Collaboration (UIC) are also considered.

Study I focuses on all connection points shown in Figure 2. It covers the return to size aspect, participating in transnationally coordinated research, the level and method of funding (core vs. project-based funding), and whether research institutions collaborate internationally and/or with industry. Study II focuses on the effect of transnationally coordinated research projects and international collaboration. Study III focuses solely on international collaboration and funding sources.

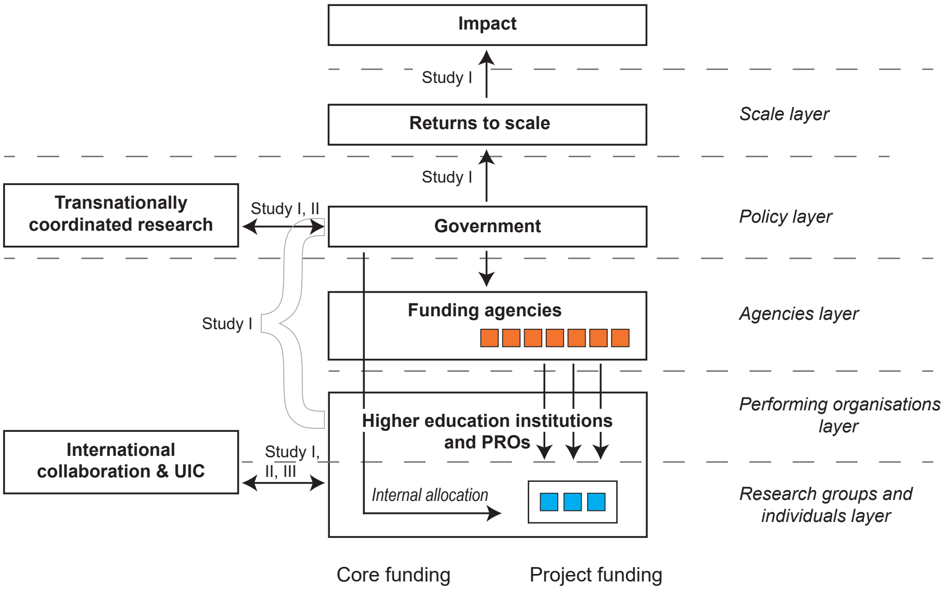

Figure 2. *Conceptual framework – an overall view of the public research system*
Source: author's adaptation based on Lepori's (2011) model

Study I's primary goal regarding the mentioned aspects is to bring out the strengths and weaknesses of European countries in maximising citation impact. These characteristics are stable in the medium to long run and are suitable for policy decisions. The major gap addressed in Study I is the lack of coherency in previous studies. The aspects mentioned have not been studied simultaneously but rather incoherently as separate issues. Study I is an initial step towards integration by using the complemented version of Lepori's (2011) model to bring relevant characteristics together in a structured manner (Figure 2).

Based on the Cognitive Theory of the Firm (Nooteboom, 2012) and the decreased transaction costs of collaboration due to digitalisation (Barjak, 2006; Goldfarb & Tucker, 2019), I propose that countries with larger research systems experience a higher citation impact when all else is equal (*ceteris paribus*), such as their tendencies to collaborate internationally.

Nooteboom's (2012) Cognitive Theory of the Firm describes how similarity and difference affect performance, suggesting that there is a trade-off between the two parties where learning and innovativeness increase to a certain extent and then start to deteriorate (Figure 3). The peak of the curve, when partners are neither too similar nor too diverse, is the best location for learning or achieving maximum research impact. This is supported by studies showing that articles with higher authorship interdisciplinarity tend to have greater citation rates (Chen et al., 2015; Okamura, 2019; Abramo et al., 2018).

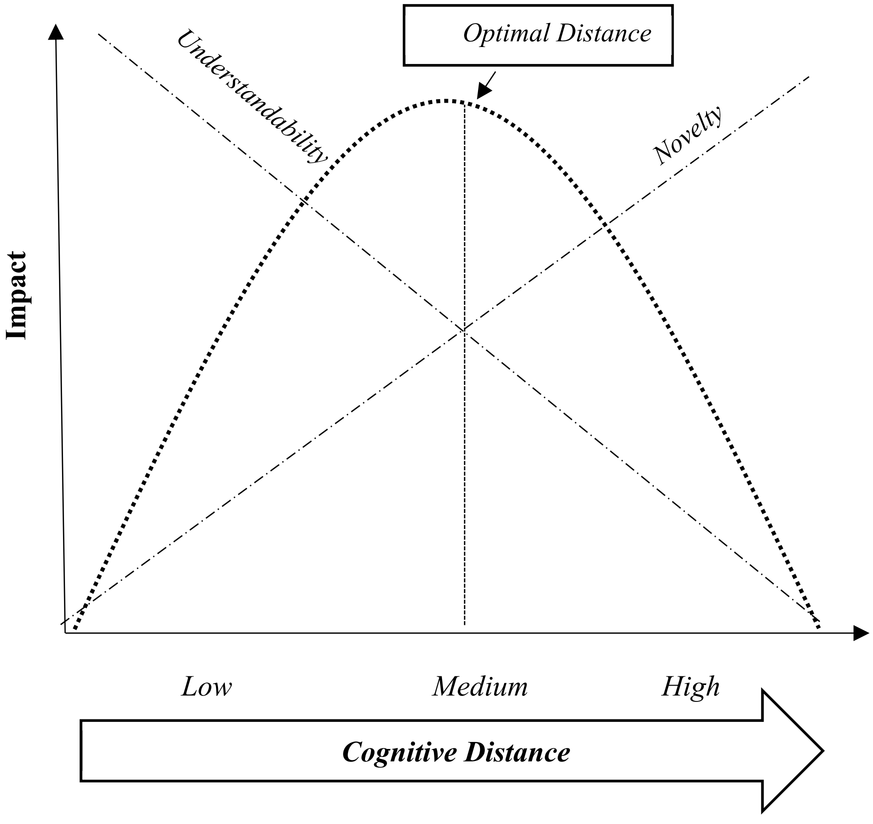

Figure 3. *Optimal Cognitive Distance*
Source: author's adaptations based on Nooteboom (2012) and Morley (2015)

Digitalisation has reduced costs in five areas (Goldfarb & Tucker, 2019): 1) search, 2) replication, 3) transport, 4) monitoring, and 5) authentication. Consequently, communication and collaboration in research have become increasingly important (Barjak, 2006). Within larger research systems, researchers have more flexibility to find the optimal cognitive distance between partners, possibly leading to increasing returns to scale. This implies that researchers can collaborate with partners who are both similar enough to ensure effective collaboration and different enough to introduce novel ideas.

Researchers from larger research systems do not need to search for external collaboration partners as much as researchers from smaller systems (Kamalski, 2009). This is because their system has a larger pool of potential partners. In the post-digital revolution era, collaboration has gained even more importance due to significantly lowered transaction costs in finding suitable research partners. For example, online file-sharing platforms and communication applications, such as MS Teams and Skype, make it easier for researchers to share data, communicate with each other, and collaborate on projects (Barjak, 2006).

In this context, I suggest that internal collaboration is more viable within larger research systems, while researchers from smaller nations need to seek partners abroad. Digitalisation has made this trend more noticeable by enabling researchers to connect with suitable counterparts beyond local research networks. Therefore, I expect favourable scaling effects when factoring in international collaboration.

In addition to returns to scale, another novel aspect of Study I is related to transnational research projects. The relationship between public funding and science output has become more complicated than previously covered because of transnationally organised R&D projects (participation in research consortia). For example, EU Member States now allocate significant amounts from their R&D budgets to these initiatives (Eurostat, 2011). Many current science challenges can only be overcome via transnational networks involving many nations and often even thousands of collaborators (Adams J., 2012; Castelvecchi, 2015). It is speculated that smaller states compensate for their lack of scale by financing and engaging in this kind of partnership (Reale E. et al., 2013).

Participating in transnationally coordinated research projects has the potential to yield advantages for a country’s innovation systems both in the immediate and distant future. Immediate gains include improved infrastructure and the prospect of collaborative endeavours. Over the long run, these efforts can strengthen research capabilities, increase global recognition, and foster enduring networks (Caloghirou et al., 2002)

Transnationally coordinated research projects and credit allocations are crucial matters for smaller countries that engage disproportionately in consortia collaboration compared to medium-sized or large countries (Must, 2014). Hyper-authorship, a phenomenon where excessively large numbers of authors are listed in a single article, is often seen as a by-product of transnational collaboration. This negative inclination is because all collaborators are unlikely to have contributed equally to the final manuscript (Cronin, 2001). Despite concerns about hyper-authorship, I argue that an increase in the proportion of transnationally coordinated consortia articles significantly increases the citation impact of countries.

In order to answer the research questions raised, the following research objectives are undertaken in Study I:

1. Investigate the relationship between the size of the research system and the citation impact of countries.
2. Determine the impact of transnationally coordinated research on the impact of European countries.
3. Investigate the effects of core and project-based funding on the number of research articles published and citations received.
4. Investigate the effect of University-Industry Collaboration on the impact of countries.
5. Bring out strengths and weaknesses of European countries in maximising impact.

Study II is a case study about Estonian research output regarding consortia participation and international collaboration. The research gap addressed in Study II is the effect of consortia on a national level, especially on a small country's citation impact. Using a bibliometric viewpoint, Study II looks at Estonian international collaboration and participation in consortia to understand how they affect research performance in terms of published articles (2005–2015) and citations received. I investigate this issue by field and highlight where the effect of consortia partnerships has been the largest. I propose that internationalisation, especially participation in consortia, is the root cause of *the puzzle* of Estonian science.

Study II provides an overview of which countries the collaborative partners of Estonian researchers come from, and which research fields have benefitted most from international collaboration. I also compare gains from collaboration and the Estonian internationalisation rate to other countries in the same geographical position (CEE countries). By doing this, I investigate how much CEE countries collaborate compared to EU15 countries – do they collaborate more to catch up in terms of citation impact?

In order to answer the research questions raised, the following research objectives are undertaken in Study II:

6. Investigate the relationship between transnationally coordinated research and Estonian scientific impact.
7. Determine the growth of research articles in Estonia and other countries in similar geographical positions, both domestic and those involving international collaboration.
8. Compare the citation impact of domestic and collaborative research articles across countries.
9. Provide an overview of the countries from which Estonian research collaboration partners come.

10. Provide an overview of the research fields that have benefitted the most from international collaboration.

Study III investigates the effect of European Union funding on Estonian citation impact. The contribution of Study III lies in differentiating the positive effect of common international collaboration from EU funding. I propose that even after excluding mass-authored articles, EU funding has enabled Estonian scientists to get a better outcome in international collaboration than would have been otherwise possible, and therefore has played a significant role in increasing the Estonian citation impact.

In order to answer the research questions raised, the following research objectives are undertaken in Study III:

11. Investigate the relationship between EU funding and citation impact.
12. Examine the synergistic effect of EU funding and international collaboration on the citation impact.

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First and foremost, I would like to thank God for His guidance throughout my PhD journey. I am grateful to my supervisor, Prof. Ukrainski, for her mentorship and support. I would also like to thank Prof. Friedrich and Prof. Varblane for their valuable feedback and support. I am also grateful to Micheal Haagensen for proofreading the dissertation.

I would also like to express my sincere gratitude to my family for their unwavering support. To my parents, thank you for always believing in me and for encouraging me to pursue my dreams. To my brother, thank you for being my biggest cheerleader and for always being there for me.

I would like to end my journey with a song verse by Melanie Fiona:

Have you heard the news today?
I'm leavin' town and I'm cashin' out
This town's too small for me to stay
The time is now, I'm headin' out

1. THEORETICAL AND EMPIRICAL BACKGROUND

1.1 Economics of Science

The economics of science covers topics such as how governments and businesses fund scientific research, how scientific discoveries are turned into commercial products, and how science contributes to economic growth and development (Stephan, 1996; Diamond, 2008). According to Romer (1992), understanding the difference between the economics of ideas and physical objects is essential for understanding economic growth. He divides objects into competing goods, such as capital and labour. He posits that ideas function as directives capable of supporting economic growth, even in the presence of limited raw materials, provided we discover more effective instructions (more efficient methods for organising production). The economic impact of science is indisputable, even though the gap between basic research and its economic consequences may be considerable.

The linear models of innovation explain the relationship between science and technology and the economy (Godin, 2006a). The technology push model postulates that innovation begins with fundamental (basis) research, follows applied research and growth, and ends with production and diffusion (Godin, 2006a; Bush, 1945):

Basic research → Applied research → Development → Sales

The basic push model represents a general progression of research and innovation activities, starting with basic research focusing on fundamental scientific understanding and knowledge. Applied research builds upon basic research findings to address practical applications and develop technologies or solutions. Development involves transforming applied research outcomes into tangible products, processes, or services. Finally, diffusion refers to disseminating and adopting these innovations in the broader society or industry.

On the other hand, the market pull model states that the market is the source of new ideas for directing R&D, which has a reactive role in the process. The stages in the market pull model are (Godin, 2006a):

Market need → Development → Manufacturing → Sales

While basic research is important in both models, its role and emphasis differ. In the technology push*,* basic research generates the initial technological advancements that can later be applied to various industries. In the market pull model, basic research is geared towards adapting and applying existing knowledge to meet specific market needs. The two models can also interact and complement each other, with basic research driving technology advancements that can eventually respond to market demands.

A great example of this is how Steve Jobs revolutionised the tech industry. Under Jobs' leadership, Apple introduced iconic products that transformed the tech industry, including the Macintosh computer, the iPod, the iPhone, and the iPad (Lashinsky, 2012; Levy, 2006). These products were beautifully designed and incorporated innovative features and technologies that set new standards in the industry. For example, he pioneered the development of the graphical user interface (GUI) and the mouse, which made personal computers more accessible to a broader audience.

Microsoft's success story is another example of a combination of technology push and market pull. Bill Gates is widely regarded as an innovator, having co-founded Microsoft Corporation in 1975 and played a pivotal role in developing the personal computer industry. His contributions to the technology industry have been transformative and profoundly impacted how we use technology today (Encyclopedia Britannica, 2023).

It is very unlikely that Apple and Microsoft would have become the successful companies they are today without basic research. In the early 1960s, Nelson (1959) and Arrow (1962) laid the foundation for the current economics of science. The public economic theory they created argues that the challenge in providing resources hinders the market in creating knowledge because the advantages of investing in research and development are not easily seen, can weaken over time, and affect many other parts of the economy. As a result, government intervention strives to attain an appropriate amount of investment in research and development, considering it a public good that brings advantages to the entire society. While Ostrom (1977) and Callon (1994) concur with this reasoning, they add that science is a quasi-public good, not a pure one.

In the traditional approach to public goods, goods are classified as either pure private or pure public, focusing primarily on exclusion. It was only with the work of scholars like V. Ostrom and E. Ostrom (1977) that a two-dimensional classification of goods emerged, recognising subtractability (rivalry) as another crucial determinant. This new approach considers how one person's use can diminish the availability of goods for others, creating a two-dimensional classification system (Table 1).

Table 1. *Types of goods*

		SUBTRACTABILITY	
EXCLUSION		Low	High
	Difficult	**Public goods** Useful knowledge Sunsets	**Common-pool resources** Libraries Irrigation systems
	Easy	**Toll or club goods** Journal subscriptions Day-care centres	**Private goods** Books Personal computers

Source: Hess and E. Ostrom adaptation (2007) based on V. Ostrom and E. Ostrom (1977).

In the theory of public financing (Samuelson, 1954), knowledge is considered a public good because it is difficult to restrict access once it is discovered. Using knowledge, such as Einstein's theory of relativity, does not diminish another person's ability to use it. This is also true of the concepts, insights, and wisdom derived from reading a book. Useful knowledge exhibits low subtractability, meaning that its consumption by one individual does not diminish its availability to others. For example, once a scientific discovery or idea is known, countless individuals can share and use it without depletion (Hess & Ostrom, 2007).

The described approach is considered idealistic and is not consistent with real-world practices. For example, libraries themselves exhibit high subtractability, where the availability of physical resources, such as books, can be depleted as they are borrowed or used by users (Hess & Ostrom, 2007).

When science is considered a good, scholarly publication becomes one of its most common forms. When scientists publish their research in scholarly journals, they make science available to other scientists, who can build on their findings. This helps to advance scientific knowledge and understanding. Journal subscriptions have low subtractability. Once subscribed, multiple individuals can access the content without depletion (Hess & Ostrom, 2007). However, users can be readily restricted from access by requiring payment or membership. For example, the challenge of rising subscription costs for serial publications exceeding the budgets allocated by academic institutions for libraries has been a persistent issue for academia for decades (Creaser & White, 2008; Sample, 2012; Gantz, 2013).

The internet has allowed people to share information and scientific knowledge more easily than ever (Barjak, 2006). This transformation has given rise to the concept of a *knowledge commons,* bridging the gap between public goods and club goods. A knowledge commons is a collection of information, data, and content owned and managed by a community of users (Hess & Ostrom, 2007). Notably, it differs from physical resource commons in that digital resources are non-subtractable, enabling multiple users to access them without depleting their quantity or quality.[1]

In the context of the economics of science, it is important to highlight that knowledge produced and stored in knowledge commons, or any scientific community, is not always linear to economic outcomes. It is important to keep in mind that bibliometrics looks at research impact mainly through the perspective of academia, where impact is defined through citations. This is only one part of the national innovations system, which covers the flow of technology and information among people, enterprises, and institutions, and which is key to the innovative process. For comparison, the *Swedish paradox* refers to a country investing significantly in research and development activities, yet the economic outcomes do not match the investments made (Ejermo & Kander, 2006; 2009). The paradox

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[1] Knowledge commons are often associated with open access, but it is essential to differentiate between the two. Open access pertains to the free and unrestricted availability of digital information. In contrast, the concept of knowledge commons encompasses a broader range of shared resources, including information, data, and culture. (Hess & Ostrom, 2007)

highlights the importance of promoting interactions between different knowledge commons to ensure that the knowledge generated through research can effectively flow.

The knowledge produced by researchers doing basic research may not be accessible or suitable to product developers who require new knowledge to create new products and services. For example, the tacit nature of scientific knowledge makes it difficult to copy research and commercialise it, especially for outsiders (Kealey & Ricketts, 2014). This can lead to a disconnect between the production of knowledge and its utilisation, which can ultimately limit economic growth.

Government efforts to ensure an optimal level of knowledge creation give rise to the principal–agent problem in the economics of science. This scenario unfolds when elected politicians and government agencies (the principals) aim to achieve societal goals through publicly funded research. However, the principals lack the expertise or human resources to act as knowledge producers, leading them to delegate the implementation to specialists and organisations (the agents), such as universities and their researchers (Eisenhardt, 1989; Nelson R. R., 1959; Arrow, 1962). According to Van der Meulen (1998), this delegation introduces two challenges. First, the principals cannot fully comprehend the actions of independent agents. Second, the principals must choose the best possible agents to fulfil the tasks.

In doing so, the principal needs a suitable selection and monitoring mechanism to meet the set objectives. Contract theory states that many institutions and rules affect knowledge production and evaluation criteria (Ostrom E., 2010; Van der Meulen, 1998; Eisenhardt, 1989). Ostrom (2010) highlights that these rules define who can participate in scientific research, what roles they can play, what actions they can take, how they communicate their findings, the scope of their research, and how they are rewarded. According to her, these rules help ensure scientific knowledge quality, credibility, and advancement by promoting responsible conduct, collaboration, and rigorous research practices.

Since governments are actively looking for ways to ensure scientific advances without spending too much taxpayer money, the ability to benchmark researchers' scientific standing is vital for public managers who must decide on science funding and set priorities. Sociologists and other scholars have studied the productivity of scientists using scientific publications since the early 19th century and beyond (Galton, 1874; Cattell, 1909; Lotka, 1926). *Productivity* is typically defined as the amount of output that scientists produce within a certain period or compared to the inputs utilised for the research (Lee & Bozeman, 2005). Therefore, historically, a scientist was considered more or less productive based on the number of publications they produced relative to their peers.

Polymath Francis Galton conducted the very first surveys on the number of scientists in England (Godin, 2007, p. 8; Galton, 1874) and published it as *English Men of Science* in 1874. A few decades later, psychologist James M. Cattell (1909) collected and published a large selection of biographical and statistical information about scientists, known as *American Men of Science.* Cattell was also politically active, condemned Columbia University's administration, and used the data from the second edition of the *American Men of Science* as evidence to suggest that universities that followed meritocratic methods of appointment and promotion employed more eminent scientists. Cattell's (1909) case demonstrates how the production of scientific knowledge is governed by a complex system of rules (Ostrom E., 2010); for example, who can participate in the scientific process and what criteria are used for promotions.

The first more widely known reference to the difference between the productivity of scholars was published by Lotka (1926) as the pioneering analysis of scientific productivity. Lotka's Law states that there are few extremely productive authors, and less productive authors write most scientific articles. Lotka argues that the number of authors (y) who publish n publications are equal to $\frac{C}{n^a}$, where C is the number of authors who publish one paper, and a is a constant. The classical value of a is 2, but it may also have other values $a > 0$, which makes the function decline. Lotka's Law is mathematically expressed in Formula 1.

$$f(y) = \frac{C}{n^a} \tag{1}$$

Some researchers have resorted to publishing in predatory or fake journals to amplify their publication records (Demir, 2018). This is similar to the Wells Fargo scandal, where employees created fake accounts to make it seem like they were meeting sales targets and achieving better results than they actually were (Tayan, 2019). Despite the rise in researchers publishing in predatory journals, citation counts remain a prevalent measure of research impact in academia. Citations are generally considered to be a more robust indicator against publishing in predatory or fake journals than the number of publications because they directly measure the impact of a scientist's work on the research field (Hicks et al., 2015; DORA, 2012).

According to most experts, bibliometrics owes its systematic growth primarily to Derek J.D. Price and Eugene Garfield because they were the first to study science using sophisticated quantitative methods. The few studies before the 1950s are generally relegated to prehistory (Godin, 2006). Many leaders in the field consider Price's groundbreaking work *Little Science, Big Science* (1963) to be the beginning of modern scientometrics, where he emphasises that science can be studied scientifically.

After 1950, there were no more isolated statistical surveys, instead such initiatives were funded by government agencies and international organisations. Investments in scientific research, technological advancements, patents, and higher education spending to boost scientific and technical capabilities have since been commonly used to measure economic development. As a result, Eugene Garfield refined the concept of publishing and citing earlier works to evaluate research and made it a science of its own (scientometrics). Like Cattell before him, Garfield (1979) thought that a broad multidisciplinary referral index could provide an appropriate overview of scientific activities and founded the Institute for Scientific Information (ISI) in 1954. Before Garfield's intervention, bibliometrics was mainly focused on the number of publications published, but after founding the ISI, the scientific landscape changed, and citation analysis became more critical.

Extensive discussions on what citations actually measure and how citations relate to scientific quality arose in the 1970s and 1980s (see, for example, Cronin, 1984), while this question appears to have received less attention in subsequent decades. Nowadays, it is frequently assumed that citations are at the heart of the concept of scientific impact, reflecting scientific quality (Aksnes et al., 2019; Lee, 2007; Clarivate Plc, 2023). Therefore, when science is a semi-public good, then citations per publication reflect the quality (impact) of the good offered (publication).

In the modern economics of science, the distinction between *research productivity* and *impact* has become blurry because some researchers use citations and the number of articles interchangeably to describe the same bibliometric phenomena (see, for example, Lindner et al., 2018; Ruiz-Castillo & Costas, 2014; Cole & Phelan, 1999; Hirsch, 2007). Despite these slightly different measures used for evaluating the scholarly output of researchers, the Pearson correlation between *impact* and *productivity* is 0.76, and the Spearman rank correlation between them is even higher (r=0.87) (Ruscio et al., 2012). Therefore, using *productivity* synonymously (or interchangeably) with *impact,* as in Study III, is not a significant shortcoming.

Currently, the most commonly used metric for covering both productivity and citation impact made through the accumulation of citations is the h-index. The h-index is a metric for evaluating the cumulative impact of an author's scholarly output and performance; it measures quantity with quality by comparing publications to citations (Hirsch, 2007). The h-index is useful because it corrects for the disproportionate weight of highly cited publications or publications that still need to be cited.

Scientific credibility, the accumulated impact made by a researcher, **plays a significant role in research funding**, as explained in the scientist's credibility cycle in Figure 4 (Latour & Woolgar, 1979; García & Sanz-Menéndez, 2005).

Scientists begin the credibility cycle by doing rigorous and high-quality research in their field of expertise. They design experiments or investigations, collect and analyse data, and draw conclusions based on their results. Scientists hope to publish their findings in credible peer-reviewed journals or other reputable channels (conference proceedings) once the research is concluded. Before publishing, the study is extensively examined by independent experts in the field through peer review, which helps authenticate its quality and significance. Other scholars in the field read the work after it is published and may cite it in their research papers if they deem it relevant and influential. Citations and the number of publications are used to assess the influence and significance of published research.

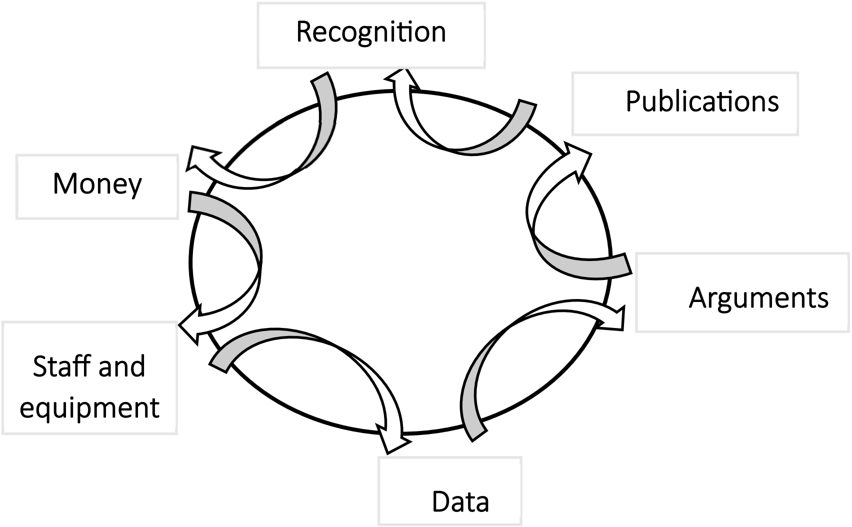

Figure 4. *The credibility cycle for a scientist*
Source: Latour and Woolgar (1979)

Funding opportunities are typically more available for researchers with a strong track record of successful research because funding agencies and grant review committees favour researchers with a proven history of impactful work, leading to more opportunities for additional funding. As the work of researchers is recognised and their reputation within the scientific community grows, their ability to hire additional staff and acquire more advanced equipment increases. In addition, they may be invited to review journals or participate in conferences, enhancing their credibility and helping them find new funding sources.

The credibility cycle is ongoing, and scientists are continuously engaged in new research, publication, and knowledge dissemination and continue to receive funding. As previously mentioned, the whole process is governed by the rules previously agreed upon (Ostrom E., 2010). These rules define who can participate, the roles they can have, the actions they can take, their means of sharing findings, the extent of their research, and based on what they receive rewards.

1.2 Main Limitations of Bibliometrics

Scholars have noted that citations may not be the perfect measure of impact for several reasons. First, the philosopher Thomas Kuhn wrote a book (1962) titled *The Structure of Scientific Revolutions* about the development of science, where he contested the notion of scientific progress as development by an accumulation of accepted facts and hypotheses.

Kuhn (1962) argued for an episodic model in which periods of *normal science,* which he referred to as periods of conceptual continuity when there is cumulative development, are broken by periods of *revolutionary science*. As a result, he

(1962) claimed that science guided by one paradigm would be incommensurable with science developed under a different paradigm, meaning there is no standard measure for assessing the different scientific theories. An example would be the notion that the bibliometric approach measures innovativeness by the number of publications and citations that demonstrate significance and status at a current point in time compared to competitors, while ignoring comparisons across periods of time.

Unfortunately, he never gave clear empirical guidelines for defining a paradigm (Masterman, 1970; Shapere, 1964), and his discussion remained primarily philosophic. He used the term *paradigm* to denote a set of theories and methodologies universally accepted by a scientific community, the practices that define a scientific discipline at a certain point in time until *scientific revolutions* emerge (Solimine, 2016; Mokyr, 1992).

The second main limitation of the use of bibliometrics in economics is concerned with endogeneity. In quantitively measuring impact, we have to keep in mind that, to some extent, science is socially constructed (Hicks S. R., 2004). Nygaard's (2015) argument on the topic is that the impact of the researcher is not only a function of individual or institutional properties, as suggested by an academic literacies approach, but also dependent on his/her environment – local, national, or international. According to Nygaard (2015), identity and impact of researchers are complex topics because scientists belong to different environments at the same time. For example, language bias may affect bibliometric analysis, as it primarily focuses on publications in widely recognised languages such as English (De Bellis, 2009; Waltman, 2016).

From a bibliometric perspective, impact is measured in terms of citations, potentially overemphasising the importance of the international environment at the expense of the local and national. Therefore, it is easier for researchers to gain impact in terms of citations when focusing on topics that attract global attention (Sjögårde & Didegah, 2022). For example, Thelwall and Maflahi (2015) suggest that internationally collaborative research may appear superior because it attracts a greater audience in each of the authors' home nations rather than because the research is superior. As a result, they recommend that research funders and policymakers should not justify rewarding international joint research by claiming that it is superior to national research unless it is accepted that the publicity of the research is a valuable outcome in itself.

The second important endogenous effect of institutional characteristics is their position towards publishing houses accused of predatory publishing. Predatory publishing refers to deceptive or unethical publishing practices, such as charging authors high fees without providing adequate editorial or peer-review services, publishing low-quality or fraudulent research, or falsely claiming affiliation with established publishers or academic organisations (Kearney & Collaborative, 2015). The Multidisciplinary Digital Publishing Institute (MDPI) is the largest publisher accused of predatory practices (Beall, 2012). MDPI publishes over 300 open-access journals in various fields, including some in high-impact areas such as medicine and engineering (Multidisciplinary Digital Publishing Institute, 2023). Some specific concerns about MDPI and its practices include (Shen & Björk, 2015; Beall, 2012; 2014):

1. Insufficient peer review: Critics have claimed that shortcomings in their peer-review system have led to the publication of low-quality or even fraudulent research.
2. Editorial conflicts of interest: Some critics have alleged that MDPI editors have conflicts of interest or are not sufficiently independent, which can compromise the integrity of the review process.
3. Misleading marketing and indexing: Some MDPI journals have been accused of using misleading marketing tactics, such as falsely claiming affiliation with well-respected academic organisations or being included in high-impact indexes when they may not meet the standards for inclusion.

Therefore, it is advised that readers approach MDPI publications with a critical outlook. They should assess the quality of each article based on its content, methodology, and supporting evidence. Additionally, considering factors like author reputation and journal impact factor (if available) can be beneficial.

Academic bodies in Norway, Finland, and Denmark that evaluate the quality and significance of scholarly journals have raised concerns about MDPI. In Finland and Denmark, most journals published by MDPI do not meet the criteria for inclusion in the rankings. Meanwhile, Norwegian policymakers have been more lenient in their evaluation, designating most of MDPI's journals as academic, and only some MDPI journals classified as unacceptable (Bjarte Fosso, 2020).

While publishing in MDPI journals is questionable in Nordic countries, it is common practice in Central and Eastern Europe. For example, approximately 34% of Romanian publications indexed SCI/SSCI (Science Citation Index/ Science Citation Index Expanded) for 2011–2021 were published in MDPI-associated journals. Poland followed Romania at 33%, Slovakia at 30%, and Latvia at 30% (Csomós & Farkas, 2023). For comparison, the corresponding numbers for the Nordic countries were only 3–6%.

Not only does MDPI affect the number of articles published, but articles published there could also have an open-access citation advantage (Davis & Walters, 2011; Eysenbach, 2006; Antelman, 2004). The open-access citation advantage (OACA), also referred to as full text on the net (FUTON) bias, is a form of bias where researchers tend to cite academic journals that offer open access (OA) more frequently than toll-access publications (Wentz, 2002).

As a result of the mentioned limitations, and others, the term *impact* in science appears to be undergoing a taxonomic shift, where it is no longer described as the effect on science as measured by citations but instead on all aspects of society (culture, economics, and politics) (Bornmann & Haunschild, 2017, p. 937).

1.3 Knowledge Production Functions and Funding Schemes

In order to understand small country internationalisation through the prism of bibliometric indicators, it is crucial to understand the properties of science production in more detail. For example, are inputs interchangeable, and what kind of returns to scale does the production have? What would production look like when collaboration is involved? Do the financing schemes relate to unobserved determinants of output? These are some relevant questions in the economics of science and are crucial for understanding the dynamics of science production in a small country.

The first well-known occurrence of the production function used to describe science output dates back to 1979, when Griliches (1979) introduced his Cobb-Douglas type Knowledge Production Function (KPF). The basic form of KPF describes how scientific output Y can be produced via specified production factors $Y = f(L\ (Labour), C\ (capital)$[2]. According to Griliches (1979), knowledge is a function of the current level of technological knowledge and production inputs, such as capital (physical and human) and unmeasured determinants of output. Let outlay production of knowledge (science) using Griliches' production function *F(Y, A, K, L, u)* with knowledge as output and capital and labour as inputs be:

$$Y = AK^{a}L^{\beta}u \tag{2}$$

where*:*

Y – total production of knowledge
L – labour input
K – capital input
A – the amount of knowledge that has been discovered. Usually, in empirical analyses, the amount of knowledge discovered is not used (or highlighted) because, in most cases, all participants in science production have access to previously discovered knowledge.
u – unobserved determinants of output
a and β – output elasticities of capital and labour.

More recent scientific literature has not gone into such detail regarding the theoretical aspects of basic research, and the inputs used (in country comparisons) are usually measured in Government Budget Allocations for R&D (GBARD) or Gross Domestic Product (GDP), which cover both the labour and capital used for knowledge production. There is assumed to be an approximately one-to-one relationship between inputs and outputs. Causality is argued by the observation that money is necessary to compensate for researchers' time and pay for equipment needed to perform the analysis (Shelton, 2020):

$$Y = X^{a} \tag{3}$$

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[2] Note: symbols of inputs used were changed compared to Griliches' (1979) article to make the function appear like a more typical Cobb-Douglas production function.

where Y is the number of articles, citations, or a combination of both, X is expenditures, and ***a*** **represents the returns to scale factor, which is explained in more detail in the next chapter.**

Studies on scientific impact and funding have not emphasised enough the role of socially constructed governing rules that guide science production. One of these socially constructed rules is financing approaches, which can have an effect on research output.

Project-based financing and core funding are the two basic methods for supporting research. Project funding is a portion of government budgetary allocations for R&D (GBARD) that is given to a group or individual to carry out an R&D activity with a restricted scope, budget, and time frame, typically based on the submission of a project proposal outlining the research activities to be conducted. By contrast, core (institutional) financing is defined as the portion of the GBARD given to institutions without any direct selection of the R&D projects or programmes to be carried out (Eurostat, 2022).

While the broader understanding is that increased competition in allocating research funding is associated with higher efficiency, the underlying situation is more dynamic and contextual (Georghiou, 2013), leaving the most efficient way of enhancing research open to debate. In Europe, the proportion of project-based financing varies significantly (Reale, 2017; Jongbloed & Lepori, 2015). This highlights the difference in how scientific, economic, and social goals are pursued (Lepori et al., 2007; Van Steen, 2012). Many scholars have noted that countries vary significantly in terms of the efficiency with which they convert input into bibliometric output (e.g., Guan & Zuo, 2014; Leydesdorff & Wagner, 2009; Rousseau & Rousseau, 1998). The key benefits of project-based funding include the following (OECD, 2018):

1. A propensity to boost the consistency and validity of research proposals.
2. A way to ensure that research proposals reach a minimum quality standard.
3. An incentive to test peer-to-peer ideas.
4. A fair and unbiased way of distributing funds.

Project-based ventures, on the other hand, also have some possible side effects. For example, concerning the quality of research, competition-based financing has been found to contribute to the proliferation of mainstream, thematically stable but often lower-quality science (Laudel, 2006; Sandström & Van den Besselaar, 2018) and has significantly higher costs than core funding (Gross & Bergstrom, 2019; Cocos & Lepori, 2020).

In addition, according to Mali et al. (2017), scientific excellence is negatively affected by the fragmentation of funding. In countries where citation impact is above average, it is concentrated in a small number of elite institutions where high-impact research is observed (Prathap, 2017). Those findings are coherent with Robert Merton’s (1968) theory from the late 1960s that the more one institution produces quality research, the more success it will have in getting new research grants. In reference to the biblical passage (Matthew 13:12), he named this phenomenon the Matthew effect. It is, to some extent, related to Kuhn's (1962) scientific revolutions theory. These elite institutions became elite because some scientific revolution started there, which created a chain reaction that made these elite institutions elite in the first place.

1.4 Returns to Size in Knowledge Production

Scholars have recently begun applying the fundamental principles of scaling (a concept related to the relationship between size and other characteristics) to create a comprehensive framework that explains the patterns and laws governing the distribution of settlements (where people live) as well as socio-economic production and growth (economic activities and development). These works particularly focus on the effects of increasing returns to size (superlinear effects) of social interaction. The foundational assumptions of settlement scaling are (Daems, 2021, p. 49):

1. Human interactions are exchanges of information and goods that occur in physical space.
2. The intensity, productivity, and quality of individual-level efforts are mediated and enhanced through interaction.
3. Any human activity can be thought of as generating benefits and incurring costs.
4. Human effort is bounded.
5. The size of human agglomeration is both a consequent and a determinant.

In the context of science production, there are different terms used, such as returns to scale, scaling (superlinear, linear, sublinear), and returns to size to describe a very similar phenomenon. For example, in the context of the study, I adopt the perspective that *returns to size* and *returns to scale* are synonymous, aligning with the proposal by Abramo et al. (2012, p. 706). This conceptualisation implies that as the size of the labour force (the number of researchers) increases, other production factors, such as resources and capital, also increase proportionately (Gautam & Ahmed, 2019; Abramo et al., 2012). Based on Louf (2015, p. 64), I also assume that superlinear scaling exhibits characteristics of increasing returns to scale. This phenomenon, as described by Bettencourt et al. (2007), involves synergies or positive interactions between components, leading to increased efficiency as the overall system grows. **As a result, I treat returns to size, superlinear scaling, and increasing returns to scale synonymousl**y.

Several studies suggest that the relationship between research output per capita and population size demonstrates superlinear scaling, indicating that innovative activities grow at a faster rate than the population (Bettencourt et al., 2007; Lobo et al., 2013). In Figure 5, the effect of scaling is described quantitatively.

The figure shows three different types of scaling: sublinear, linear, and superlinear. The left panel shows an example of each type of scaling. The right panel shows how the per capita quantities for each type of scaling change with population size.

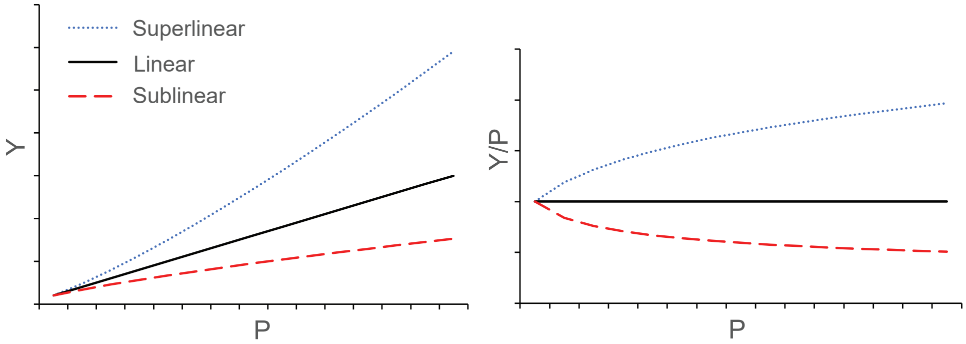

Figure 5. *Theoretical scaling graphs showing superlinear, linear, and sublinear growth*

In discussing returns to scale in science production, we must remember that ideas differ from other economic goods because they are non-rivalrous. The standard rationale for constant returns to scale is based on replication. For example, to double output production, we can replicate all inputs: build an identical factory and use the same materials and workers (Jones, 2005, pp. 1065–1069). Notably, knowledge does not need to be doubled due to non-rivalry. The same ideas can be used in the new settings. Therefore, the non-rivalry implies that production possibilities are possibly characterised by increasing returns to scale.

A situation where ideas are not easily exchangeable (rivalrous) is mathematically described as follows:

$$F = (A, \lambda, X) = \lambda Y \tag{4}$$

where A is an index of the amount of knowledge that has been discovered, X is a vector of the remaining inputs into production (K and L), and parameter λ represents the elasticity of new idea production with respect to the number of researchers. In the context of scientific research, a value of $\lambda=1$ indicates that doubling the number of researchers leads to a doubling of the output of new ideas, even when the existing knowledge base remains unchanged.

$$F = (\lambda A, \lambda X) > \lambda Y \tag{5}$$

Incorporating ideas as a production input naturally leads to models where increasing returns to scale (levels of scaling) are possible. There is a lack of definitive empirical evidence to support the presented arguments in the context of the economics of science when using citation counts or article numbers as output measures. Studies specifically examining returns to scale in science production have yielded inconclusive results, with all potential returns to scale being reported in Table 2.

Table 2. *Returns to Scale in previous studies*

Paper	**Level of comparison**	**Activities assessed**	**Results**	**Method(s) used**
Wang & Huang (2007)	Countries' overall R&D activities	Research	**Increasing returns to scale** in research are exhibited by more than two-thirds of the sample.	Data Envelopment Analysis and combined with Tobit regression Model
Kocher, Luptacik & Sutter (2006)	Countries' R&D in economics	Research	**Increasing returns to scale** are found in all countries in the sample except the US.	Data Envelopment Analysis
Cherchye & Abeele (2005)	Dutch universities' research in Economics and Business Management	Research	**Returns to scale varies** between decreasing, constant, and increasing depending on each university's specialisation.	Nonparametric methods
Johnes & Johnes (1993)	UK universities' research in economics	Research	**Constant returns to scale** are found in the sample as a whole.	Data Envelopment Analysis
Avkiran (2001)	Australian universities	Research, education	**Constant returns to scale** was found in most universities.	Data Envelopment Analysis
Ahn, Charnes, & Cooper (1988)	US universities	Research, education	**Decreasing returns to scale** on average.	Data Envelopment Analysis
Johnes J. (2006)	English universities	Research, education	Close to **constant returns to scale** exhibited by most universities.	Data Envelopment Analysis

Paper	**Level of comparison**	**Activities assessed**	**Results**	**Method(s) used**
Arbesman, Kleinberg, & Strogatz (2009)	US cities	Research (patents)	**Increasing returns to scale** exhibited by cities, with a reasonable range for the exponent.	Network Model with Descriptive Statistics
Lepori, Geuna, & Mira (2019)	US and European universities	Research	**Increasing returns to scale** was exhibited in the number of publications and citations at the university level.	Ordinary least squares
Bettencourt et al. (2007)	US metropolitan areas in US, EU and China	Research (patents)	**Increasing returns to scale** exhibited by **metropolitan areas.**	Descriptive Statistics
Lobo, Strumsky, & Rothwell (2013)	Metropolitan areas in the OECD	Research (patents)	**Increasing returns to scale** exhibited by metropolitan areas (very little variation**).**	Descriptive Statistics
Bonaccorsi & Daraio (2005)	Italian and France universities	Research	Evidence of weak **decreasing return to scale** in universities.	Pearson Correlation
Abramo, Cicero, & D'Angelo (2012)	Italian universities	Research	**Returns to scale varies** between constant and increasing depending on the research area. Constant was more common than increasing.	Descriptive Statistics, Local regression
Clermont, Dirksen, & Dyckhoff (2015)	German universities' research in Business Administration	Research, education	**Returns to scale varies** between constant and increasing.	Data Envelopment Analysis
Allik, Lauk, & Realo (2020a)	Countries' R&D	Research	**Negative returns to size** on average. Small and well-governed countries with a long-standing democratic past are efficient.	Descriptive Statistics, Generalised linear model

Paper	Level of comparison	Activities assessed	Results	Method(s) used
Sharma & Thomas (2008)	Countries’ R&D	Research (patents)	**Returns to scale varies** and is country-specific.	Data Envelopment Analysis
Mueller (2016)	Countries’ R&D	Research	Very weak evidence for **Increasing returns to scale.**	Machine Learning (Boosted regression trees)
Guan & Zuo (2014)	Countries’ overall R&D activities	Research	**Returns to scale varies** and is country-specific.	Data Envelopment Analysis
Cimini, Gabrielli, & Labini (2014)	Countries’ R&D	Research	**Returns to scale varies** and is country-specific, but the constant is the most reoccurring possibility.	Descriptive Statistics
King (2004)	Countries’ R&D	Research	**Increasing returns to scale** (impact intensity increased exponentially relative to wealth intensity).	Descriptive Statistics
Guan, Jian Cheng, et al. (2006)	Chinese firms	Innovation capability	**Decreasing returns to scale** were found among about 70% of the inefficient enterprises, and increasing returns to scale were found among the remaining 30% of the efficient enterprises.	Data Envelopment Analysis
Crespi & Geuna (2008)	Countries’ overall R&D activities	Research	The evidence indicates **decreasing returns to scale**.	Production Function Approach

Source: compiled by the author

In studies that looked at metropolitan areas or cities and patents as scientific output, results demonstrate superlinear scaling, or in other words, increasing returns to scale. Studies where the comparison level was a country, university, or department show mixed results – in some studies, returns to scale depended on the studied object. In other studies, all three possible options were represented.

These inconclusive results indicate that if returns increase or decrease, the difference can be slight compared to constant. It is essential to bring out that the technique for counting research publications, which may be one reason why, in some studies, increasing returns to scale has been seen in small countries (Guan & Zuo, 2014) and decreasing returns to scale in larger ones (Guan & Zuo, 2014; Allik et al., 2020a). One possible explanation is that the full counting scheme benefits more internationally linked countries with a comparatively poor science base compared to technologically stronger but less internationally connected countries (Gauffriau et al., 2007).

1.5 Premise for Collaboration

Few attempts have examined what constitutes *research collaboration*, and the concept has been taken for granted. In the economics of science literature, definitions of collaboration vary from broad definitions involving co-working to more delimited ones requiring teamwork with shared goals such as formulating or testing particular empirical hypotheses and co-authoring papers (Griesemer & Gerson, 1993). For example, according to Sonnenwald (2007), scientific collaboration is an interaction taking place within a social context among two or more scientists that facilitates the sharing of meaning and completion of tasks with respect to a common superordinate goal. Despite minor changes in wording, the literature seems to accept that the core of collaboration is a social mechanism in which participants pool their expertise, information, and resources to generate new knowledge.

According to the author's Web of Science search queries, 12.5 per cent of scientists in the information sciences use *scientific collaboration* and *scientific cooperation* to describe the same phenomenon. Based on the Cambridge Dictionary (2023), collaboration involves high interdependence, shared responsibility, and active communication among collaborators. Conversely, cooperation involves individuals or groups working independently towards a common goal, with less interdependence and shared responsibility. It is unclear whether scholars preferring one over another has been intentional, or they used the terms interchangeably.

Nowadays, international collaboration goes hand in hand with internationalisation. For example, according to the OECD (2021), science internationalisation refers to the process by which scientific research becomes increasingly globalised, with the participation of scientists, institutions, and funding sources from multiple countries. **It involves the exchange of scientific knowledge, techno-**

logies, and resources across borders, as well as the formation of international collaborations and networks.

In order to show how vital it is for knowledge production in a particular area (*i)* to have access to other knowledge centres, let us consider the factors involved. According to Beckmann (1994), knowledge is produced from scientific effort (L_i), local knowledge (K_i), and external knowledge (K_j) available to a location $J \neq i$. Assuming a Cobb-Douglas production function, we also need to consider the opportunity costs (w_i) for labour, for utilising local knowledge (c_i), and for accessing knowledge through contacts (c_{ij}) with location j (which should be thought of as an aggregate of various locations away from *i*).

Researchers aim to achieve the maximum benefit for themselves and the scientific community (B_i) through the efficient acquisition of new knowledge (Beckmann, 2000, p. 134):

$$B_i = \underset{L_i, K_i, K_j}{max} \qquad b_i = L_i^a K_i^\beta K_j^y - w_i - L_i - c_i K_i - c_{ij} K_j \tag{6}$$

Comparing the use of local and outside knowledge K_i and K_j.

$$\begin{gathered} 0 = \frac{\partial B_i}{\partial K_i} = \beta L_i^a K_i^{\beta-1} K_j^y - c_i \\ 0 = \frac{\partial B_i}{\partial K_j} = y L_i^a K_i^\beta K_j^{y-1} - c_{ij} \\ \text{Dividing } K_i \text{ with } K_j \; \frac{K_i}{K_j} = \frac{y}{\beta} \frac{c_i}{c_{ij}} \end{gathered} \tag{7}$$

When the cost of using external knowledge is high compared to internal knowledge, people or organisations tend to rely more on their internal knowledge instead of seeking external knowledge. External knowledge becomes relatively more expensive because c_{ij} is an increasing function depending on the distance the area $\underline{i}$, making external knowledge less attractive than internal knowledge. Therefore, the utilisation of external knowledge decreases as the cost ratio (c_{ij}/c_j) increases.

Digitalisation has revolutionised scientific communication, reducing communication costs (Goldfarb & Tucker, 2019) and changing the ratio of c_{ij}/c_j. These advancements enable effortless cross-border collaboration, data sharing, and communication among researchers and institutions, speeding up internationalisation. In order to share their thoughts or findings with colleagues in the past, scientists had to rely on old-school methods of communication such as phone calls, letters, and face-to-face meetings, unlike the modern connectivity of digital solutions.

Collaboration in science is desirable for many reasons, and is considered especially beneficial or even essential for research in small countries (Aghaei Chadegani et al., 2013; Iglič et al., 2017). The size of a country is seen as a limitation for building up human and financial capital for research and the required specific know-how. It is argued that small countries can compensate for such disadvantages through internationalisation (Reale E. et al., 2013; Schiermeier, 2019), such as by collaborating with researchers from abroad. Internationalisation may not be an option but a necessity for researchers from a small country to solve world-class science challenges (Aghaei Chadegani et al., 2013; Iglič et al., 2017)

Collaboration is a more convenient way to do research and, in some instances, could be necessary to maximise impact. The following presents a production function with constant elasticity of substitution (CES) explaining production in two research units when they collaborate (Beckmann, 1993, pp. 12–13):

$$Y = (c_1 v_1^{\Psi} + \ c_2 v_1^{\Psi})^{\frac{1}{\Psi}} \text{ for } \Psi = 0.5 \ recives$$

$$Y = \left(c_1 v_1^{0.5} + c_2 v_2^{0.5}\right)^2 = c_1^2 v_1 + c_2^2 v_2 + 2c_1 c_2 (v_1 v_2)^{0.5}$$

where: (8)

Parameters c_1 and c_2 can be a function of cognitive distance.

Parameters of v_1 and v_2 can be vectors of capital and labour.

The following equations explain what will happen if unit one produces alone, unit two produces alone, and when the two units collaborate. If they work together, they obtain a higher output than they could have achieved when producing alone:

If unit 1 produces alone $\mathrm{Y_1} = \mathrm{c_1^2 v_1}$

If unit 2 produces alone $\mathrm{Y_2} = \mathrm{c_2^2 v_2}$

In cooperation, they produce $\mathrm{X} = \mathrm{c_1^2 v_1 + c_2^2 v_2 + 2c_1 c_2 (v_1 v_2)^{0.5}}$ (9)

Which means

$$\mathrm{Y} > \mathrm{Y_1} + \mathrm{Y_2}$$

Therefore, it is inherent that collaboration is desirable and should be promoted.

The presented Production Function for Scientific Interaction Production highlights the collaborative nature of research, which can lead to increased output and impact. This concept can be linked to how EU structural funds and Framework Programmes have been used over the years to support research and innovation activities within Member States. For example, Estonia’s dependence on EU structural funds and its success in competing for grants from the EU’s multi-year research programmes are well known (Schiermeier, 2019).

In the context of research units being countries, the European Union structural funds and Framework Programmes can affect c_1, c_2, and v_1, v_2 in the following ways:

- **Infrastructure:** EU structural funds often support infrastructure development in Member States. Improved infrastructure can enhance both c_1 and c_2. For instance, better transportation and communication infrastructure can increase cognitive distance (c_1 and c_2) parameters by making it easier for units to collaborate effectively.
- **Collaboration:** Collaboration is a key aspect of the model. EU programmes promote cross-border collaborations among Member States. These collaborations can enhance c_1 and c_2 as units learn to work together more efficiently and effectively, reducing the cognitive distance.
- **Wage support**: Structural funds can help countries provide wage support for researchers, which means an increase in v_1 and v_2. This can make it more affordable for researchers to conduct research in their home countries, which can lead to increased c_1 and c_2.
- **Improved mobility**: Framework Programmes can help to improve mobility for researchers, making it easier for them to move between countries to collaborate with other researchers. This can lead to increased c_1 and c_2, as countries benefit from the knowledge and expertise of researchers from other countries.

In summary, EU structural funds and framework programmes can improve c_1 and c_2 by fostering collaboration, enhancing infrastructure, and facilitating better access to resources and knowledge. In addition, these programmes can impact v_1 and v_2 by supporting wages and improving mobility, increasing productivity in both units, and making cooperation more efficient and productive.

Table 3 illustrates different levels of collaboration in the current area between individuals, highlighting both intra-individual and inter-individual collaboration. The inclusion of the international collaboration column recognises the significance of global research networks and the valuable contributions that arise from collaborative endeavours that across borders. The table presents various levels of collaboration, ranging from individual work to integrated efforts, with each level reflecting an increasing degree of coordination, cooperation, and interdependence.

As already explained, cooperation involves individuals or groups working independently towards a common goal, with less interdependence and shared responsibility. Collaboration, on the other hand, involves high interdependence, shared responsibility, and active communication among collaborators. While both *collaborative work* and *integrated work* involve individuals working together within the same project or team, the second emphasises shared decision-making and interdependence. It suggests a more cohesive and interconnected approach to work, indicating higher collaboration and integration among team members. Examples of such cases at the international level are European Union Framework Programmes (Gusmão, 2001) and participation in international research consortia (Pulford et al., 2023). Both are explained in more detail in the following subchapters (1.6 and 1.7). These projects usually involve teams of researchers from different countries who must work together closely to achieve their goals. They must share their expertise and resources, and must be willing to make decisions together.

Table 3. *Different levels of collaboration and distinction between inter and intra forms*

Level of Collaboration	**Intra-Individual Collaboration**	**Inter-Individual Collaboration**	**International Collaboration**
Level 1: Individual Work	Working independently	–	–
Level 2: Cooperative Work	Collaboration on shared tasks, sharing resources, and exchanging ideas within the same project/team	Collaboration among individuals from different projects/teams, sharing resources, and exchanging ideas	Collaboration among individuals from different countries, sharing resources, and exchanging ideas
Level 3: Collaborative Work	Jointly working on tasks, actively contributing to shared goals within the same project/team	Jointly working on tasks, actively contributing to shared goals among individuals from different projects/teams	Jointly working on tasks, actively contributing to shared goals among individuals from different countries
Level 4: Integrated Work	Integrated efforts within the same project/team, involving shared decision-making and interdependent work	Integrated efforts across individuals from different projects/teams, involving shared decision-making and interdependent work	Integrated efforts across individuals from different countries, involving shared decision-making and interdependent work

Source: author's adaptations based on Katz and Martin (1997), Cambridge Dictionary (2023) and OECD (2021)

While the European Union Framework Programmes and international research consortia can significantly amplify collaborative output, they rely on participant willingness to collaborate. The potential reasons for pursuing collaboration are virtually limitless. There can be at least as many reasons for collaborating as the individuals involved (Katz & Martin, 1997). Previous authors have proposed many factors to account for the increase in multiple-author papers. Most of them include the following (Beaver & Rosen, 1978).

1. Access to any unique means and institutions.
2. Access to new knowledge and unique materials.
3. Increasing visibility and effectiveness.
4. Getting new experience.
5. Prevention of competition.

Scientific collaboration can be primarily classified into five areas, forming a typology: 1) data-driven, 2) resource-driven, 3) equipment-driven, 4) idea or theory-driven, and 5) multifactor collaboration. Recognising that categorisation involves subjective judgement and acknowledging potential overlaps, Table 4 presents research areas along with their most common collaboration motives in a simplified manner.

Table 4. *Classification of sciences by motivation for collaboration*

Data-driven collaboration	**Resource-driven collaboration**	**Equipment-driven collaboration**	**Idea/theory-driven collaboration**	**Multifactor collaboration**
Biomedical	Oceanography	Physics	Mathematics	Manufacturing
Genetics	Geology	Avionics	Philosophy	Anthropology
Epidemiology	Energy	Polymers	Computer Science	Chemistry
Sociology	Archaeology	Astronomy	Linguistics	Engineering
Economics			Science studies	

Source: author's adaptations based on Wagner (2005)

Biomedical research often involves analysing and interpreting large-scale data sets, such as genomics or clinical trial data ((Nelson M. L., 2009). The same also applies to genetics. Economics and sociology can also be idea and theory driven, but here I consider them as data-driven collaborations because of developments in the last decade, such as computing (social simulation, modelling, network analysis), media analysis (Lazer et al., 2009), and data mining (Feelders, 2002). Collaboration in oceanography often requires shared access to research vessels, remote sensing technologies, while in geology it often involves fieldwork and specialist equipment, such as drilling rigs or seismic instruments, which necessitate resource-driven collaborations (National Research Council of United States, 2005). Research in the energy field often necessitates sharing resources like renewable energy test facilities or high-performance computing infrastructure (European Commission, 2023). Physics research often involves collaborations that require access to high-energy particle accelerators and detectors (CERN, 2023). Collaborations in avionics may focus on developing and testing aircraft systems and require access to specialist flight simulators and testing facilities (Wagner, 2005). Astronomy requires access to observatories, telescopes) and advanced imaging and data analysis tools. Collaborations in mathematics are often driven by the exchange of ideas and theories to solve complex mathematical problems, and philosophy collaborations explore and develop theories on ethics, metaphysics, and other philosophical topics.

It is important to note that some research areas may overlap across categories, as collaborations can be motivated by multiple factors simultaneously. That being said, data-driven, resource-driven, and equipment-driven collaborations are often more commonly observed due to several factors. The increasing availability of large datasets, the need for specialist resources and equipment, and the interdisciplinary nature of many research projects contribute to the prominence of these types of collaborations. For example, anthropology as a field is known for its holistic and multidisciplinary approach to understanding human cultures, societies, and their historical development. Collaboration within anthropology often extends beyond a single category and involves a combination of data-driven, resource-driven, and interdisciplinary collaboration to tackle complex research topics and address the diversity of human experiences.

The most popular way to study research collaboration is through co-authorship (Melin & Persson, 1996; Katz & Martin, 1997). The data show that the more countries involved in the collaboration, the greater the gain in impact (Guerrero Bote et al., 2013). In general, international co-authorship, on average, results in publications with higher citation rates than purely domestic papers. Especially highly cited papers result from the teamwork of researchers from different countries (Tahamtan et al., 2016). However, the influence of international collaboration on national citation impact varies considerably between the countries (Glänzel, 2000; Levitt & Thelwall, 2010) and between fields. Sometimes, there is no citation advantage for one or both partners (Glänzel, 2001).

Contrary to what would be expected, it has been found in some cases that the citation impact of a country does not necessarily influence the benefit it derives from collaboration but does seem to positively influence the benefit obtained by the other countries collaborating with it (Guerrero Bote et al., 2013). For example, based on previous studies, gains from collaboration are largest in countries with low impact and R&D spending, such as Latin America (Chinchilla-Rodríguez et al., 2015), Vietnam (Nguyen et al., 2017) and African countries (Asubiaro, 2019). International collaboration is most beneficial for developing countries probably because they struggle to publish independently in internationally recognised journals and conference proceedings. For instance, it has been found that 77% of Vietnam's scientific output that was indexed in Web of Science involved international collaborations, with US and Japanese researchers being the most frequent partners (Nguyen et al., 2017). Most influential studies have found that the more a nation is involved internationally in terms of co-authorship, the greater the impact of scientific work (see, for example, Wagner C. S. et al., 2018; Leydesdorff & Wagner, 2009; Leydesdorff et al., 2019, etc.).

In the current age, we have to keep in mind that in addition to more traditional collaboration in academia, there has been growing recognition of the importance of collaboration between academia and industry to drive innovation, economic growth, and societal impact (Etzkowitz & Leydesdorff, 2000; 1995).

University-Industry Collaboration (UIC) refers to the formal and informal relationships between universities and industry for research, technology transfer, and knowledge exchange. This collaboration aims to benefit academia and industry by creating and disseminating knowledge, developing new technologies, and enhancing innovation and economic growth. UIC involves various activities such as joint research projects, consulting, licensing, spin-offs, and joint degree programmes (see, for example, Perkmann et al., 2013; Ankrah & Omar, 2015).

Many universities and industries are now actively engaging in collaborative initiatives to leverage each other's strengths and resources and to address real-world challenges (Ankrah & Omar, 2015). As a result, University-Industry Collaboration has become increasingly relevant (see, for example, Sun & Turner, 2022; Awasthy et al., 2020).

While research on university-industry collaborations (UIC) has mainly focused on how companies benefit from collaborations with academic institutions, there has been less coverage of the effects on academia. Studies have shown that research papers from UIC tend to receive more citations than those solely produced by universities, indicating that collaborations between university and industry researchers can boost citation impact (Morillo, 2016; Abramo et al., 2009; Lebeau et al., 2008). However, it should be noted that positive outcomes from such collaborations are not always the case. For example, research papers that disclose the receipt of funding from industry tend to receive more citations if their findings align with the interests of the industry (Farshad et al., 2013; Kulkarni et al., 2007). Based on Danish data from 1985 to 2013, Bloch et al. (2019) highlight that there is no significant difference in citation impact for national collaboration papers for public-only and public-private collaborations. On the other hand, for international collaboration, they observed a much higher citation impact for papers involving public-private collaboration.

1.6 Science Production in the European Union Science Programmes

The question should not be whether scientific collaboration increases impact but what role special collaboration cases have, such as European Union research programmes and consortia. European Union Framework Programmes are not simply collaboration projects but rather integrated efforts across individuals from different countries, involving shared decision-making and interdependent work.

In a funding and policy context, the European Union has strongly changed the European research area. Setting up a Framework Programme (FP) was not only to pursue a European effort to reduce the technology gap with the United States, which worried policymakers, but also to provide a coherent long-term view (Heller-Schuh et al., 2011). For example, FPs were created to strengthen the European industry's scientific and technological capabilities and international competitiveness and solve society's significant challenges.

Support for European-level research collaboration can be traced back to the 1953 founding of CERN and/or 1962 to the founding of the European Southern Observatory (ESO) (Nedeva, 2013). The widening technology gap between Europe and the United States fuelled discussions in the 1960s about promoting increased cooperation across Europe (Caloghirou et al., 2002). Subsequently, the first European Union Framework Programme was initiated in 1984. Since the first programmes, the number of participating countries has increased, and the size of FPs has increased almost twenty-fold, thus improving the subject's political importance for every EU country (Edler et al., 2003). Nowadays, on average, FPs and other EU research funds account for about 10–15% of what the 28 EU Member States spend per year on research and development (R&D) (Abbott & Schiermeier, 2019). Also, programmes can have a far more significant effect on promoting studies than these statistics indicate since, in many instances, the EU needs participants to balance funding with their own investments (Abbott & Schiermeier, 2019).

The mentioned programmes are mainly networking environments that aim to establish cooperation between research partners (Caloghirou et al., 2002; Breschi et al., 2009) and are one of the main European Union research policy instruments (Edler et al., 2003). The vast majority of funding for such programmes is collective, meaning that programmes are funded from the common EU budget. The key incentives for participating in different EU research instruments can be distinguished as follows (Polt & Streicher, 2005; Lepori, 2011; Aström et al., 2012; Reale E. et al., 2013; Lepori et al., 2014):

- cost-sharing/obtaining funding;
- networking/finding new partners;
- development of technology/knowledge/research excellence;
- commercialisation of innovation output and market;
- career-boosting/visibility-enhancing motives.

In previous research, funding is reported as the highest motivation (Kuitunen et al., 2008; Aström et al., 2012) for participation, and this motive is argued to be not even comparable to other motives. Aström et al. (2012) suggested that project financing is more of a boundary condition than a motive because in most cases, the project does not exist without it.

Literature on participation in FPs mainly focuses on the additionality output that FPs offer and network analysis of participation.

One part of the FP literature deals with the consequences of engagement. Results and impact can be measured in several ways, one of which is to seek additionality. Additionality usually refers primarily to the direct output of R&D operations, such as publications, patents, prototypes, and new products (Buisseret et al., 1995).

In general, there is considerable evidence of *pure additionality* among participants, implying that they would not have completed the project without the FP's support (Polt & Streicher, 2005; Matt et al., 2012). For many of those who would have carried out the project without EU support, additional funding allowed them to add one or more dimensions to the project. For example, according to Switzerland's EU Framework Programmes Unit (2019), participating in FPs has provided Switzerland with an extra funding source for research and innovation, complementing domestic funding mechanisms. Furthermore, participation in FPs prompts significant additional investments in research and innovation by the parties involved within Switzerland.

FPs have had substantial effects on researcher behaviour as well. While access to funding is a primary motivation for researchers to engage in FPs, it is not solely driven by monetary factors. In Switzerland, a substantial majority of respondents perceive FPs as offering opportunities for international collaboration that are not available through national funding instruments (EU Framework Programmes Unit, 2019). It has been found that collaborations formed to capitalise on funding opportunities may not be effective in enhancing researcher productivity in the short run but can be an important promoter of effective collaborations in the longer run (Defazio et al., 2009; Primeri & Reale, 2012).

Another part of the literature on EU initiatives has focused on network analysis (Breschi & Cusmano, 2004; Heller-Schuh et al., 2011) because policy-makers are interested in convergence between EU countries. Studies show that national R&D policies and instruments with high international orientation mobilise domestic researchers (Enger, 2020, p. 13; Dinges & Lepori, 2006). This is especially true for smaller Member States, where the FP participation rate is significantly higher than in larger counterparts (Ukrainski et al., 2014). Small countries like Estonia are more focused on collaborating within Europe than larger countries (Okubo & Zitt, 2004, p. 217; Tijssen, 2008). As a result, EU membership has positively affected co-publishing between new and old Member States and between the new Member States themselves (Makkonen & Mitze, 2016). Europeanisation has been happening primarily among smaller European states, as demonstrated by country-specific studies in Finland (Hakala et al., 2002) and Norway (Langfeldt et al., 2012; Enger, 2020).

The main idea from studies using network analysis is that although participation in FPs is good for everyone, there is a strong relationship between R&D funding and the country's position in the network (Ortega & Aguillo, 2010). There are long-standing scientific networks upheld by a few organisations, creating what is termed an *oligarchic base*, implying accumulated advantages for those positioned at the network's core. The research indicates that the existence of *closed clubs* limits opportunities for less influential institutions (Enger, 2018). These findings align with Robert Merton's theory (Matthew effect) from the late 1960s, proposing that the more an institution produces quality research, the more successful it becomes in securing grants and scholarships.

Overall, the effects of participation overlap with the motivation to participate in EU programmes. For example, studies find that the involvement in EU FPs includes substantial input and behavioural effects (pro-collaboration) for a majority of the participants. For instance, FPs have brought learning effects by generating new applications (Polt & Streicher, 2005), contributing to increased scientific productivity in the long run (Defazio et al., 2009; Primeri & Reale, 2012), acting as an important channel of knowledge transfer (Di Cagno et al., 2014), and having been helpful in increasing scientific productivity by creating research networks that would not otherwise have been set up (Matt et al., 2012). Previous studies have looked at additionality in the case of the higher number of publications or funding, but the comparison of funding sources and their citation impact has yet to be investigated.

1.7 Science Production in 21st Century Consortia

One of the pioneers of scientometrics, De Sola Price (1963), says that to understand how to live and work in the age of a newly dawned research environment, we need to understand the transition from little science to big science. In the modern era, we are forced to talk about science production through networks such as consortia, which can be seen as a special form of knowledge creation (Weinberg, 1961) and is different from the more common research process seen in universities (Esparza & Yamada, 2007).

A consortium is, by definition, an association of two or more individuals, companies, organisations, or governments (or any combination of these entities) to participate in a shared activity or pool their resources to achieve a common goal (Sonnenwald, 2007; Cambridge University Press, 2023). Over time, the definition has stayed the same, but the twenty-first century has introduced a new consortia type.

A Large-Scale International Science Project (LISP) is defined as a consortium between two or more countries that agree to cooperate toward the achievement of a scientific, research and development, or engineering goal (Vincenzi & Shore, 2019). It is often used interchangeably with transnationally coordinated research (see, for example, Thelwall, 2020; Haegeman et al., 2015) to describe large-scale scientific endeavours that involve international collaboration and coordination.

In the post-World War II era, these scientific ventures have evolved into sophisticated, interdisciplinary, and globally coordinated efforts. Consequently, they face significant challenges escalating risks and expenses, earning them the moniker *Big Money and Big Machines* (Office of Technology Assessment, 1995). These projects have grown so much in magnitude that individual countries are unwilling to shoulder both the financial burden and the associated risks (Smith et al., 1999). Notable examples of such cooperative undertakings, motivated by one or more of these factors, include The Joint European Torus (JET), The International Thermonuclear Experimental Reactor (ITER), and The Large Hadron Collider (Vincenzi & Shore, 2019). International collaboration has been increasing exponentially (Leydesdorff & Wagner, 2008), and nowadays, more and more researchers from various countries and institutions are working together in consortia on specific research questions.

International research consortia not only provide quasi-public goods (Vincenzi & Shore, 2019) but are also concerned with the production of common goods that are rivalrous in consumption but non-excludable (Encyclopædia Britannica, Inc., 2013). Although research consortia do not provide them per se, they are motivated by challenges related to these goods. Many transnational research collaborations address global challenges such as climate change, pandemics, and sustainable development. The outputs of such research, such as innovative solutions, strategies, or policy recommendations, can benefit society as a whole by addressing common concerns and promoting the well-being of communities globally. For example, governments finance consortia or projects that coordinate and perform studies in strategic fields of interest to society or the economy. In most cases, governments are interested in enabling researchers to adapt best to social demands and tackle societal problems such as Covid-19, ageing, and climate change (Gray, 2011; Turpin et al., 2011; Cutcher-Gershenfeld et al., 2016).

Investing in transnationally coordinated research[3] initiatives can lead to both short-term and long-term benefits (Caloghirou et al., 2002) to national innovation systems. Short-term benefits include enhanced infrastructure and collaboration opportunities. Long-term benefits include improved research capacity, international reputation, and sustainable networks.

Consortia stand out for their exceptional scale, the complexity of research tasks, and the duration of experiments, requiring international cooperation and long-term support from consortia-related governments. Since the Second World War, the number of authors in the largest research teams has increased dramatically (Galison et al., 1992; Cronin, 2001). The largest teams are more diverse than the average in terms of composition and lean more towards inter-institutional and international collaboration (Gazni et al., 2012). CERN and the European Space Agency (ESA) are the best examples of the new type of consortia that the twenty-first century has mainstreamed. In cases like ESA or CERN – all programme functions are transferred to the supranational level, and the role of national states is limited to providing funding to that agency (Reale E. et al., 2013).

A significantly higher number of authors per paper separates articles produced by modern consortia from other collaboration types. The hyper-authorship phenomenon refers to scientific research papers that involve an exceptionally high number of authors. This phenomenon has become more prevalent in recent years, particularly in multidisciplinary and collaborative research fields. Hyper-authorship is characterised by papers that list dozens, hundreds, or even thousands of authors, often resulting from large-scale collaborative projects or international research consortia. The most authors on a single peer-reviewed academic paper is 15,025, which was achieved by the COVIDSurg, GlobalSurg Collaboratives at the University of Birmingham, and the University of Edinburgh (Jim Pattison Group, 2021). A physics paper held the previously recognised record with 5,154 authors (Castelvecchi, 2015).

Scholars are critical of mass authorship (hyper-authorship) because it is doubtful that all collaborators could have possibly written, edited, and approved the final work (Cronin, 2001; Ioannidis, 2008). There is no clear line in the literature from where we should categorise an article as a product of mass authorship. Some authors have drawn the line and stated that more than 100 or 50 authors should be interpreted as mass authorship (Rousseau et al., 2018; King C., 2016). Others

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[3] Research consortia and transnationally coordinated research are often used interchangeably. The vast majority of transnationally coordinated research is conducted through research consortia. Consortia provide a framework for researchers from different countries to collaborate on a common goal, and they offer a number of advantages, such as shared resources, expertise, and funding. (Vincenzi & Shore, 2019)

are more conservative and state that the number should be much lower, such as sixteen (Mohallem & Fonseca, 2015).

The hyper-authorship phenomenon associated with transnationally co-ordinated research makes evaluating individual researchers, research groups, and countries based on citations harder. The vast body of scientometric literature leaves this unique case of public or semi-public partnerships in science undealt with regarding its effect on small countries. These partnerships are not comparable to traditional collaboration commonly seen in universities. Based on previous research (Thelwall, 2020; Adams et al., 2019; Must, 2014), it is possible that consortia research could increase the citation impact of countries significantly.

2. SUMMARY OF KEY THEORETICAL TAKEAWAYS

The theoretical framework established the significance of the economics of science research within the broader scholarly landscape. It contextualised the research by introducing pertinent theories, models, concepts, and prior studies.

The economics of science is a branch that studies economic aspects and principles underlying scientific research and innovation. The thesis focuses on scientific productivity and impact – how scientific output is measured, how citation impact is evaluated, and how scientific collaboration contributes to advancing knowledge.

The economics of science, initially established by Nelson (1959) and Arrow (1962), focuses on the challenge of resource provision in knowledge creation. Their theory asserts that difficulties in perceiving the benefits of research and development (R&D) and its weakening impact over time obstruct the growth of available knowledge. As a result, they encourage government interventions to balance R&D investment as a public good, benefitting society as a whole.

The traditional view of public goods (Samuelson, 1954; Nelson R. R., 1959; Arrow, 1962) has shifted with scholars like V. Ostrom and E. Ostrom (1977), emphasising subtractability's role alongside exclusion, blurring the lines between public and club goods. The digital era has introduced the concept of a *knowledge commons*, a shared resource of information, data, and content that is collectively owned and managed by a community of users (Hess & Ostrom, 2007). It is important to keep in mind that in the realm of science economics, the basic research output produced in knowledge commons, or in any scientific community, is not linearly tied to economic outcomes. For example, *the Swedish paradox* exemplifies the disconnect between R&D investment and economic outcomes (Ejermo & Kander, 2006; 2009).

As explained, viewing science as a commodity raises questions about its measurement. What is the unit of this *good*, and how much is available to the public? Based on Hess and Ostrom (2007), I take the position that scholarly publications are a common form of science as a good and classify them as a quasi-public good because they do not fully meet the criteria of a pure public good since many publications require payment for access and usage assumes a high level of tacit knowledge.

Production of this quasi-public good takes place in an ongoing cycle. Scientists start the credibility cycle (Latour & Woolgar, 1979) by doing thorough research, and aiming to publish it in reputable sources. Peer reviews confirm quality and importance. Scholars read and cite published work to assess its impact. Funding becomes more available with a strong research history, leading to growth in resources and reputation. Reviewing journals and attending conferences enhances credibility, aiding funding. This ongoing cycle is shaped by agreed-upon rules outlining participation, roles, actions, sharing, scope, and rewards.

In the economics of science, *productivity* refers to the quantity or output of research activities produced by an individual researcher, research group, institution, or country within a certain period. It measures the volume of research output, including the number of papers, publications, patents, or other scholarly works produced. *Citation impact,* on the other hand, refers to the influence and significance of research output, such as a scientific paper or publication, within the academic community. Based on previous studies mentioned in the framework, I take the stance that in modern economics of science, the distinction between *research productivity* and *impact* has become slightly blurry, and their use interchangeably or combinatorially (h-index) to describe two encompassing bibliometric phenomena is justified. For example, it is found that the Pearson correlation between impact (number of citations) and productivity (number of publications) is 0.76, and the Spearman rank correlation is r=0.87) (Ruscio et al., 2012).

Special attention is given to the limitations of the bibliometric method because the topic is less widely studied than mainstream economics, and readers need to be made aware of them. I highlight three main limitations:

1. Scholars have pointed out that citations might not be the ideal measure of impact for various reasons. In his book *The Structure of Scientific Revolutions*, philosopher Thomas Kuhn (1962) challenged the idea of scientific progress as a simple accumulation of accepted facts and hypotheses. Instead, he proposed an episodic model with *normal science* periods of cumulative development interrupted by *revolutionary science* periods. Kuhn argued that scientific theories guided by different paradigms are incommensurable, making it difficult to establish a standard measure for assessing them.
2. Science is socially constructed through shared agreements on the rules that guide its production. These shared agreements shape who can participate, what actions they can take, and how outcomes are determined (Ostrom E., 2010). For example, Nygaard (2015) argues that a researcher's impact is not solely determined by individual or institutional factors but also depends on their local, national, or international environment. From a bibliometric standpoint, the impact is typically measured in terms of citations, which may overly emphasise the importance of the international environment over the local and national contexts.
3. Predatory practices may increase endogeneity. Predatory publishing involves deceptive or unethical practices, such as charging high fees to authors without providing proper editorial or peer-review services, publishing low-quality or fraudulent research, and falsely claiming affiliations with reputable publishers or academic organisations (Kearney & Collaborative, 2015). The largest publisher accused of predatory practices is MDPI (Multidisciplinary Digital Publishing Institute) (Beall, 2014; Beall, 2012). While publishing in MDPI journals is considered questionable in Nordic countries, it is more common practice in Central

> and Eastern European countries. For example, around 34% of Romanian publications indexed in Web of Science during 2011–2021 were published in journals associated with MDPI (Csomós & Farkas, 2023).

The framework in the thesis offers a conceptual lens through which the research questions can be examined. The theories and models included in the theoretical framework are chosen based on a complemented version of Lepori's (2011) schema of public research systems. By grounding the research in established theories and concepts, it adds credibility and enhances the validity and reliability of the findings.

Based on Griliches' (1979) Knowledge Production Function (1979), the Cognitive Theory of the Firm (Nooteboom, 2012), Beckmann's Collaboration Model with Transaction Costs (Beckmann, 2000), and digital innovations (Goldfarb & Tucker, 2019), I argue that larger research systems have greater citation impact. I argue that researchers in larger research systems have better opportunities to optimise the cognitive distance between research partners, which can potentially lead to positive returns to size and increase citation impact.

Beckmann (2000) suggested in his theoretical collaboration model that the utilisation of outside knowledge increases as the costs decrease. In the past, researchers relied on traditional communication methods like phone calls, letters, and face-to-face meetings to share their study thoughts or findings with colleagues. Digitalisation has changed that, and now researchers have more possibilities for collaborating. I argue that in larger research systems, researchers can collaborate internally, but researchers from smaller countries have to find suitable partners from abroad. Therefore, if we control for international collaboration, I expect to see positive returns to size.

The framework outlines the importance of international collaboration by using Beckmann's (1993) Production Function for Scientific Interaction. Beckmann states that although there are exceptions, in most cases, gains from collaborating are proportional compared to the inputs contributed. In summary, Beckmann's (1993) production function provides a theoretical framework for understanding how collaboration can lead to increased research output. This concept was also explained in the context of EU structural funds, which seek to enhance research and innovation by supporting infrastructure development, cooperation networks, and human capital growth.

The theoretical framework brought out participation in research consortia and European Union Framework Programmes as special cases of collaboration focused on *integrated work*. While *collaborative work* and *integrated work* involve individuals working together within the same project or team, the latter emphasises shared decision-making and interdependence. It suggests that the team is more collaborative and integrated, with a greater willingness to share information and ideas and to work together to solve scientific problems.

- **European Union Framework Programmes**

The European Union has brought significant changes in the European research area through its Framework Programmes (FPs). These initiatives were established to bridge the technology gap with the United States, provide a long-term vision, and address societal challenges (Heller-Schuh et al., 2011). The roots of European-level research collaboration can be traced back to the formation of organisations like CERN and ESO (Nedeva, 2013). The first EU Framework Programme was launched in 1984, and since then, it has grown in size and participation. Currently, FPs and other EU research funds constitute about 10–15% of the annual research and development expenditure of EU Member States (Abbott & Schiermeier, 2019). These programmes mainly serve as networking environments to foster cooperation among research partners and are funded collectively from the EU budget.

Prior studies have indicated that funding is the primary driving factor (Kuitunen et al., 2008; Aström et al., 2012), and it is considered incomparable to other motivations. For example, project financing is often seen as a precondition rather than a motive since many projects would not exist without it.

The literature on EU initiatives has extensively relied on network analysis as policymakers are interested in understanding country-level participation factors and the convergence between national and EU policies. Studies suggest that national R&D policies with a strong international orientation motivate domestic researchers, particularly in smaller Member States like Estonia, where participation rates are notably higher compared to larger counterparts. Smaller countries tend to prioritise collaboration within Europe, while for larger countries, it is not so important.

Previous research has examined additionality concerning an increased number of publications and funding, but no investigation has been conducted on the comparison of funding sources and their effect on citation impact.

- **Participation in International Research Consortia**

Scientometrics pioneer De Sola Price (1963) emphasises the shift from Little Science to Big Science in the modern research landscape. Consortia play a key role in this transition. A consortium involves multiple entities pooling resources to achieve shared goals. Research consortia produce both public and common goods, which are resources rivalrous in consumption but non-excludable. They address global challenges like climate change and pandemics, benefitting society as a whole. Governments finance such collaborations to advance strategic interests in society and the economy (Cutcher-Gershenfeld et al., 2016).

Consortia play a significant role in large-scale, complex research tasks, necessitating international collaboration and long-term support from governments. The number of authors in research teams has notably increased since World War II, with the largest teams being more diverse and internationally collaborative (Galison et al., 1992; Cronin, 2001). The European Organisation for Nuclear Research and the European Space Agency exemplify such consortia. They transfer programme functions to the supranational level while Member States provide the funding. Modern consortia involve a higher number of authors per paper, leading to hyper-authorship with hundreds to thousands of authors.

Mass authorship (hyper-authorship) has drawn criticism from bibliometricians as it raises doubts about individual contributions and approval (Cronin, 2001). Scholars differ on where to draw the line for mass authorship, with some suggesting more than 50 authors and others proposing a much lower number, like sixteen. The phenomenon makes evaluating researchers, groups, and countries based on citations challenging. Traditional collaboration in universities differs significantly from these large partnerships, leaving its effects on citation patterns unexplored. I argue that a higher percentage of a country's research articles coordinated by transnational consortia is associated with a significant increase in the country's citation impact.

3. DATA AND METHODS USED

This chapter provides a comprehensive overview of the data sources and research methodologies employed in the Study. This section establishes the foundation for the research findings, outlining the data sources and the analytical approaches employed (Table 5). By detailing the data sources and methods, this chapter ensures transparency, replicability, and a thorough understanding of the research process. In the research articles, I used *citation impact* synonymously with *research* and *scientific impact*, as it is common practice in scientometrics (see, for example, Thelwall, 2017; Larivière et al., 2011; Glänzel, 2001).

Table 5. *Overview of the research tasks and methods used*

Study	Task	Data	Method
I	1) Investigate the relationship between the size of the research system and the country's citation impact. 2) Determine the impact of transnationally coordinated research on the impact for European countries. 3) Investigate the effects of core and project-based funding on the number of research articles published and citations received. 4) Investigate the effect of University-Industry-Collaboration on the impact for countries. 5) Identify the strengths and weaknesses of European countries in maximising impact.	Web of Science, Eurostat, European Commission	Random-effect-within-between model (REWB)
II	6) Investigate the relationship between transnationally coordinated research and the impact of Estonian science. 7) Determine the growth of research articles in Estonia and other countries in similar geographical positions, both domestic and internationally collaborated. 8) Compare the citation impact of domestic and collaborative research articles across countries. 9) Provide an overview of Estonian research partners. 10) Provide an overview of the research fields that have benefitted the most from international collaboration.	Web of Science	Descriptive statistics, social network visualisation

Study	Task	Data	Method
III	11) Determine whether articles with EU funding have a higher scientific impact than articles with only national funding. 12) Examine the synergistic impact of EU funding and international collaboration on the citation impact.	Web of Science	Descriptive statistics; decision tree, ordinary least squares, Probit regression

This thesis relied extensively on bibliometric data provided by Clarivate Analytics (previously Thomson Reuters). InCites, owned by Clarivate Analytics, is a customised citation-based research analytics tool that enables users to analyse individual, institutional, and national productivity, and benchmark their output against peers worldwide (Clarivate Analytics, 2018). The data in InCites are extracted from the WoS Core Collection, which is among Scopus, one of the most common databases regarding scientometric studies (Falagas et al., 2008; Aghaei Chadegani et al., 2013; Mongeon & Paul-Hus, 2016). The Essential Science Indicators (ESI) scheme from the InCites database, and research and review articles were chosen as the basis of this research. ESI surveys more than 11,000 journals worldwide to rank authors, institutions, countries, and journals in 22 broad fields based on publication and citation performance (Clarivate Plc, 2023). The main restriction of the ESI schema is that it excludes conference proceedings, arts and humanities, and books, and focuses only on research articles (Clarivate Analytics, 2018). The ESI schema was chosen to guarantee comparability with previous studies covering the impact of Estonian research publications (Allik, 2003; 2008; 2013; 2015).

I used advanced search options from InCites to decide on collaboration. Collaboration recognition is based on the address section of the article. If addresses are from two (or more) different countries, then it is considered an outcome of international collaboration. Unfortunately, given the large quantities of publications involved, fractional counting, as proposed by numerous experts in the field (see, for example, Leydesdorff et al., 2019; Gauffriau & Larsen, 2005), was not possible.

Variables used in Study I are described in Table 6. Study I uses metrics representing 30 countries from 2008 to 2018 (27 European Union Member States plus Norway, Switzerland, and the United Kingdom). In addition to data from the Web of Science, I used Eurostat and European Commission reports. Missing time series values were solved using linear interpolation and extrapolation.

In order to account for the time delay between changes in research funding and their subsequent impact on research outputs, I used a lagged funding variable. This approach assumes that a change in expenditures will manifest in output with a 4-year lag (*t–4*). The decision to use a 4-year lag was made based on the panel vector autoregression model proposed by Abrigo and Love (2016). Consequently, research expenditures made in 2008 were expected to influence research output in 2012. Government budget allocations for R&D were preferred to gross domestic expenditure on R&D (GERD) or business enterprise expenditure on R&D (BERD) because Lepori's theoretical model, which was used to bring relevant characteristics together, focused only on publicly funded research.

I used a within-between random effects (REWB) model suggested by Allison (2009) that includes random effects (u_i), and between-group and within-group estimates. The usage of REWB was necessary to deal with the invariant variable and get the most information from the given data. Unlike the more traditional RE model, which assumes zero correlation between independent variables and random effects, the REWB model is more flexible (allows correlation). In the analysis, I interpreted the country's random effect as a country-specific unknown *ability*.

The project-based financing square was added to provide more flexibility when the relationship between impact is nonlinear. Variables used in the models were either calculated in percentage points or were taken into a logarithmic form to ensure comparability.

Table 6. *Variables used in Study I*

	VARIABLE	DESCRIPTION	SOURCE
DEPENDENT VARIABLES	STD. ARTICLES	Number of Web of Science articles per million people.	Author's calculations based on Clarivate Analytics data
	CNCI	The Category Normalised Citation Impact (CNCI) of a document is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication, and subject area. By default, CNCI is standardised to have a mean of one, but I set it to a hundred for ease of interpretation.	Clarivate Analytics

	VARIABLE	DESCRIPTION	SOURCE
INDEPENDENT VARIABLES	RESEARCHERS	Total number of researchers reflects the size of the country's research.	Eurostat
	GBARD	Government budget allocations for R&D *per capita.* Expenditures are normalised by Eurostat using Purchasing Power Parity (PPP).	Author's calculations based on Eurostat data
	COMPETITION	Percentage of project-based funding out of total GBARD (government budget allocations for R&D). All values besides Latvian are taken from Reale's (2017) report. The Latvian value is taken from Jonkers and Zacharewicz's (2016) report.	Analysis of National Public Research Funding-PREF. Final Report (Reale, Analysis of National Public Research Funding-PREF, 2017); Jonkers and Zacharewicz (2016)
	HYPER-AUTHORSHIP	Percentage of publications that have more than 50 authors.	Author's calculations based on Clarivate Analytic data
	COLLABORATION	Percentage of publications that have international co-authors.	Clarivate Analytics
	INDUSTRY	Percentage of publications that have co-authors from industry.	Clarivate Analytics

To investigate citation impact in Study II, I used three different units of measurement: CNCI (Category Normalized Citation Impact[4]), an average percentile in the subject area (both provided by InCites), and the High Quality Science Index (HQSI) proposed by Allik (2013). HQSI is calculated as the sum of normalised mean impact scores (citations per paper) for a country (or territory) and the percentage of publications in the top 1 per cent based on citations by rank, year, and form of document. Before summation, the number of citations per paper and

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[4] The Category Normalized Citation Impact (CNCI) of a document is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication and subject area

the percentage of highly cited papers were normalised according to the following formula: *(X-M)/S*, where *M* is the country's mean value, *X* is the value of a country, and *SD* is the standard deviation. I investigated changes in country rankings when the co-authorship allowed in the analysis was limited. I considered three different scenarios: 1) hyper-authorship was not limited; 2) the number of authors was limited to fifty; 3) the number of authors was limited to sixteen. Using different scenarios gave a better overview of Estonian scientific capabilities compared to the world average and other countries.

Using WoS advanced search options, I obtained an overview of which consortia Estonian authors were mostly involved with and examined how mass authorship affected the country's collaboration pattern by influencing the average number of authors per paper. In order to test Beckmann's (1993) theory that collaboration increases output, I compared the citation impact of countries based on domestic articles compared to articles with international collaboration and presented it as a scatterplot.

To examine how quickly research in Estonia and other CEE countries internationalised in terms of co-authorship, I compared the growth rates of collaboration articles and domestic ones. The equation is as follows: $Y = a.e^{b.t}$, where Y is the number of papers, b is the growth rate coefficient of articles, and t is the independent variable (here time).

A simplified table with which Estonia has collaborated did not provide a satisfying overview of collaboration activities; therefore, a social network was created by means of VOSviewer. Used network visualisation is a technique to represent complex data and relationships between entities in a network or graph format. In this technique, data was represented as a collection of nodes or vertices, each representing an entity or object, and edges or links represented the relationships or connections between the nodes. Network visualisation provided a way to identify patterns, clusters, and subgroups in complex data sets, making it easier to understand the underlying structure of the data. I also used the Excel radar graph with the InCites' Global Institutional Profiles Project (GIPP) to visualise collaboration patterns in different research areas among Estonian collaboration partners.

In Study III, I analysed the set of hypotheses described above using a database of published publications between 2008–2015, which have at least one author from Estonia and are included in Clarivate Analytics' citation indexes. Since Study III's fundamental aim was to examine the effect of EU funding on Estonia's citation impact, publications with more than 16 authors were dropped. The omission of intensely collaborative articles limits this Study to those papers that have a major contribution from Estonian authors (Mohallem & Fonseca, 2015; Gonzalez-Brambila et al., 2013)

Study III used the InCites database, and the funding acknowledgement (FA) section included in InCites since 2008 to determine funding sources, as well as the search refinement options of WoS. Because of the small sample size, the collected articles were divided into four more general research areas based on regrouping the categories from the ESI schema to match the categories in the

Estonian Research Information System. A short overview of the data used in Study III is described in Table 7.

Table 7. *List of the variables used in Study III*

	Variable	***Description***
INDEPENDENT VARIABLES	Inverted percentile in the subject area (the main dependent variable)	In the subject area in which the paper is listed in its field, document type and database is based on cumulative citations earned by the paper (Clarivate Analytics, 2018). Because of a departure from convention, **low percentile values mean high citation impact** (and vice versa)
	Citation status	Shows whether publication is cited (has at least one citation) or not
DEPENDENT VARIABLES	Funding type	Without FA; National; EU; Both; Other
	Research area	*Technology & Engineering; Natural Sciences; Health; Social Sciences*
	The portion of articles in the first quartile	Articles that are in the first quartile of the most cited articles
	International and domestic collaboration	If there is, in addition to Estonia, another country's address in the article's address section, then it was classified as a product of international collaboration. If there are two domestic addresses in the address section, we classify it as domestic collaboration
	Publication date	Publication date is the date on which a publication was first published
	Journal impact factor	Describes how much of an impression a scientific journal makes where an article was published
	Number of authors	Shows how many authors (1–16) were involved in writing an article. It is included in regression models to take into account physical labour contributed to an article

Study III used an unconventional understanding of percentiles because percentiles in InCites were at one time called *inverted percentiles* (Bornmann, 2013, p. 588), meaning that low percentile values mean high citation impact and vice versa. In such usage of percentiles, the maximum percentile value is 100, indicating no citations received.

In the used sample, approximately one-fifth of the sample's publications did not have a citation(s) and were ranked in the 100th percentile. Truncated OLS (ordinary least squares) and Probit (both with robust standard errors) regression models were used to deal with over-representation in this percentile.

Percentiles were preferred to Category Normalized Citation Impact (CNCI) or citation impact per article because they are less sensitive to outliers in small samples than measures involving individual data points. According to Wilcox (2011), percentile calculation is based on the relative position of data points rather than their specific values. When outliers are present in a dataset, they can significantly impact measures like the mean, as outliers disproportionately affect the calculation. In other words, percentiles are more robust to outliers because they focus on the distribution as a whole and consider the position of data points relative to others.

Statistical analysis in Study III was conducted using Stata 14.1 and IBM SPSS 23. In addition to the mean comparison of columns (Welch's t-test) and regression models, I also used a decision tree to analyse how the form of funding and the presence of international collaboration influence the inverted percentile of the subject area.

According to Quinlan (1986), a decision tree is a machine learning method that models decisions or actions based on a tree-like structure of conditional rules. It is a supervised learning algorithm that can be used for both classification and regression tasks. Decision trees are advantageous because they are easily interpretable and can handle both numerical and categorical features. They can capture complex relationships and interactions between variables, making them suitable for tasks that involve nonlinear decision boundaries.

The decision tree starts with a root node that represents the entire dataset. The tree then splits the data based on different features and their associated values, creating branches and sub-nodes. Each internal node represents a decision based on a feature, and each leaf node represents a class label or a predicted value. The splitting process continues until a stopping criterion is met, such as reaching a maximum depth (Quinlan, 1986). In order to generate the tree, I used the CHAID (Chi Squared Automatic Interaction Detection) approach and a significance level of 0.05 for splitting decisions.

Endogeneity is the main challenge with this kind of funding research. The literature review described that funding is decided by past scientific performance where funding is typically assigned to the most competent researchers. It is a common challenge to distinguish financing implications from researchers' abilities. As Kyvik (1995) notes, larger research groups (laboratories) are more likely to attract and recruit top researchers; I used research group size (number of authors) as a metric for the ability of the principal researcher in regression models. In order to make models more flexible, the number of authors squared was added, but its use was limited due to technical limitations when applying marginal effects in Probit models. Also, time dummies were included in regression models to consider possible exogenous effects such as macroeconomic trends.

4. EMPRICAL STUDIES

5. DISCUSSION AND CONCLUSION

5.1 Summary of the Studies

The thesis presents three studies focusing on the internationalisation of science in a small country. I investigated how internationalisation affects science production by considering the size (scale), funding level, financing method, and collaboration. All three studies presented contribute to the literature on the economics of science, each related to different aspects of science production and internationalisation. The research tasks that were undertaken and their results are outlined in Table 8.

Table 8. *Tasks and results*

Study	Objectives	Results
I	Investigate the relationship between the size of the research system and the country's citation impact.	The size of the country's research system does not have an effect on citation impact.
	Determine the impact of transnationally coordinated research on the impact of European countries.	Transnationally organised research programmes positively affect countries' citation impact. All countries benefit equally from the increased visibility and exposure that comes with participating in transnationally organised research programmes.
	Investigate the effects of core and project-based funding on the number of research articles published and citations received.	Project-based funding has a U-shaped relationship with the number of citations per article. No effect was found on the number of research papers produced.
	Investigate the effect of University-Industry-Collaboration on the citation impact of countries.	University-Industry-Collaboration increases citation impact.
	Identify the strengths and weaknesses of European countries in maximising citation impact.	EU-13 countries are severely disadvantaged due to a lack of R&D spending. UIC (University-industry collaboration) is more prevalent in countries with high living standards and R&D investment, such as Scandinavian countries, Switzerland, and Belgium. Smaller countries engage more in international and consortia collaboration than larger countries. Only Malta and Italy strongly preferred institutional funding, and Latvia and Estonia preferred project-based financing.

Study	Objectives	Results
II	Investigate the relationship between transnationally coordinated research and the impact of Estonian science.	Participation in international consortia has increased Estonia's normalised citation impact approximately two-fold. The effect was most seen in *Molecular Biology & Genetics*, *Clinical Medicine*, and *Physics*.
	Determine the growth of research articles in Estonia and other countries in similar geographical positions, both domestic and internationally collaborated.	During the observed period, domestic publications grew at a rate of 5.2 per cent, compared to 9.3 per cent for collaboration publications. Estonia collaborates more internationally than the EU15 countries do. Therefore, collaboration is a viable mechanism to catch up to advanced countries in terms of citation impact, and as a result, the gap in impact has been slightly narrowing.
	Compare the citation impact of domestic and collaborative research articles across countries.	There is a proportional relationship between national and collaboration citation impact, such as theorised in the theoretical framework (formulas 9–10).
	Provide an overview of the countries from which Estonian researchers' collaboration partners come.	Finland, Sweden, the United States, Germany, and the United Kingdom were the countries with whom Estonia collaborated the most.
	Provide an overview of the research fields that have benefitted the most from international collaboration.	*Space Science* benefits the most from internationalisation, with a 29-percentile difference between international and national articles. Space Science is followed by *Immunology* (21) and *Psychiatry/Psychology* (19).
III	Investigate the relationship between EU funding and scientific impact.	Articles with EU funding have a higher citation impact than those with only national funding.
	Examine the synergistic impact of EU funding and international collaboration on the citation impact.	The findings show that the most cited research papers are generated through a combination of EU funding and international collaboration.

The lack of coherence in previous studies regarding the aspects mentioned in the complemented version of Lepori's model was a significant shortcoming addressed in Study I. The topics discussed, such as size, level of funding, and scheme of funding, were not previously investigated simultaneously but somewhat inconsistently as distinct problems. Study I was the first step towards integration by systematically combining characteristics using the complemented version of Lepori's (2011) theoretical framework of public science funding.

First, the size of the country's research system does not affect the citation impact; therefore, the main hypothesis was rejected. This is surprising because international collaboration correlates 0.72 with citation impact and -0.33 with research system size. When all relevant production aspects are taken into account in multivariate regression, it has constant returns to scale on the country level. This finding suggests that other factors are more influential in determining citation impact than the size of the research system.

Second, Study I confirmed Must's (2014) suspicions that consortia collaboration affects not only very small and less productive countries but also productive ones. Study I revealed that countries that spend most on transnationally organised science produce more hyper-authored papers, but at the same time, these articles make up a smaller proportion of total articles in those countries. As a result, smaller countries are more affected by the so-called hyper-authorship phenomenon. This implies that studying impact or collaboration trends between countries based solely on co-authorship data has become more challenging. For example, research evaluators face significant challenges in judging contributions made by authors who participate in international consortia. The hyper-authorship phenomenon shown in Study I explains why many small countries, such as Estonia, Cyprus, and Iceland, punch above their weight in citation impact.

In addition to the benefits already discussed concerning increased impact, it is important to consider that investments in transnationally coordinated research initiatives by small countries yield both short-term advantages, such as enhanced infrastructure and collaboration opportunities, as well as long-term benefits, such as improved research capacity, international reputation, and sustainable networks (Cutcher-Gershenfeld et al., 2016). These effects collectively contribute to elevating the impact and global presence of smaller countries within the scientific community.

Third, Study I finds that not only the amount of funding but also the method of financing is a significant determinant of citation impact. Surprisingly, project-based funding has a U-shaped relationship with the number of citations per article despite having no impact on the number of research papers produced. The *Matthew effect* in finance could explain this. It has been found that the fragmentation of funding hurts scientific excellence (Mali et al., 2017). In countries with higher-than-average impact, high-impact research is focused in a few elite institutions (Prathap, 2017). Regarding core funding, universities receive a sufficient sum directly from the government. However, when it comes to a high share of project-based funding, research groups may end up receiving approximately the same amount by receiving more research grants due to the Matthew effect.

Fourth, UIC is a significant factor in determining citation impact. Collaboration with industries and businesses often leads to the creation of research projects that are directly aligned with real-world challenges and needs (see, for example, Sun & Turner, 2022; Awasthy et al., 2020). This applied focus enhances the relevance of the research, making it more likely to be cited by practitioners and other researchers in the field.

I also compiled a summary list as the final phase of the study to see which characteristics countries are doing well in and where they lag. EU-13 countries are severely disadvantaged due to a lack of R&D spending. However, as the findings indicate, there are other factors where they need to catch up. UIC is more prevalent in countries with high living standards and high R&D investment, such as Scandinavian countries, Switzerland, and Belgium. Smaller countries engage in more international and consortia collaboration than larger countries. Only a few countries strongly preferred institutional (Malta, Italy) or project-based funding (Latvia and Estonia), which leads to higher citation impact.

Study II is an Estonian case study on consortia engagement and international collaboration. The research gap addressed in Study II is the effect of consortia research on the national level, particularly on the effects of research on a small country. The findings suggest that international collaboration plays a significant role in determining the impact of Estonian science. For example, it has a powerful effect on overall collaboration patterns. Participation in international consortia have increased the number of authors per article from six to over a hundred. More importantly, participation in international consortia has increased Estonia's normalised citation impact approximately two-fold.

On average, articles with up to 16 authors, which marks the beginning of mass authorship, account only for 55% of total citations. If the limit is increased to 50 authors, then they account for 68% of the citations. These findings support the discovery made in Study I that transitionally organised research programmes substantially affect the citation impact of smaller countries.

According to Web of Science (WoS), most articles with hyper-authorship (involving more than 16 authors) emerge from collaborative efforts within consortia. Notably, CERN takes the lead with 423 articles, trailed by the IDEFICS CONSORTIUM with 62 articles, and EUROPEAN MALE AGEING STUDY GRP with 48 articles. The WoS search found 865 group-authored publications and 347 research groups/consortia names. However, many are name combinations of the same groups (groups write their names slightly differently in different articles).

The hyper-authorship phenomenon affects different research areas to varying degrees. For example, in *Molecular Biology & Genetics*, articles with up to 16 contributors account for only 16% of citations. This is followed by *Physics* (27%) and *Clinical Medicine* (30%). It is important to note that these research fields had the highest impact in Lauk and Allik's (2018) study.

Country rankings based on citation impact depend on how much co-authorship is accepted in the analysis. The range 1–5,575 does not differ significantly from 1–50 (r=0.97), but the difference is more visible when compared to the (r=0.89) range 1–16. While the association is still extremely strong, there are several notable variations. Iceland, for example, falls from first to twelfth place in scientific achievement, Peru from sixth to thirtieth, and Estonia from twelfth (Lauk & Allik, 2018) to thirty-first. This confirms the finding from Study I that the hyper-authorship phenomenon mainly impacts countries with very small research systems. This forces us to look at the Estonian ranking in previous benchmarks (Allik, 2016; Lauk & Allik, 2018; Allik et al., 2020b) in a new light. For example, compared to Allik's (2003) study, Estonia has not made significant progress in improving its ranking in bibliometric benchmarks.

While it is well established that collaboration raises overall citation rates, I was interested in seeing how collaboration alters the dynamics between countries. The MIRRIS Interim Report (2014) hints that Estonia benefits more from internationalisation than other countries, which is not entirely true. If the research consortia collaborations are excluded, I conclude that there is a proportional relationship between national and collaboration citation impact – as the citation rates for domestic articles increase, so do the citation rates for collaboration articles. On average, internationally collaborated articles are 60% more cited than domestic ones. In addition to Beckmann's (1993) production function with interaction, this is also consistent with Lancho et al. (2012) and Nygaard's (2015) theory that collaboration publications have a broader reach and attract attention from scholars around the world, leading to a higher number of citations.

If international collaboration helps compensate for the lack of resources, does Estonia do it enough? In 2005, collaboration articles accounted for 50% of Estonian publications. Since then, international collaboration has become more dominant in Estonia. Domestic publications grew annually at 5.2 per cent during the observed period, compared to 9.3 per cent for collaboration publications. Estonia collaborates more globally than the EU15 region and catches up in terms of impact with more advanced countries who are not collaborating internationally as much.

Surprisingly, the main collaboration partners for Estonia have not significantly changed compared to the 90s (Lewison & Must, 2001). Finland, Sweden, the United States, Germany, and the United Kingdom are the countries in which Estonia collaborates the most. Social network research supports the idea that top-cited papers include collaboration with researchers from countries with very high citation impact. Collaborations with Russia, Ukraine, Lithuania, and Latvia did not affect Estonian citations as much as collaborations with more scientifically advanced countries. I also found that partnerships involving a broader range of countries result in articles with higher citation impact. Estonia's main collaboration partners in this social network are brokers with ties to many other nations. Estonia's most significant collaborative partners, Finland and the United States, are similarly present in all research fields. In comparison, collaborations with

Germany are less common in the *Social Sciences*. The most common collaborations with Sweden are in *Life Sciences* and *Clinical Medicine*.

International collaboration is found in 72 per cent of *Immunology* publications and 69 per cent of *Molecular Biology and Genetics* publications. The lowest proportion of international co-publications is found in *Mathematics* (32%), followed by *Economics and Business* (28%). *Space Science* benefits the most from internationalisation, with a 29-percentile difference in citations between international and domestic articles. *Space Science* is followed by *Immunology* (21), *Psychiatry/Psychology* (19), and *Pharmacology/Toxicology* (19).

Study III in the thesis looked at the effect of European Union financing on Estonian research. The contribution of Study III lies in differentiating the positive effect of common international collaboration. The findings show that the 54% rise in citation impact seen between 2007 and 2014 (Allik, 2015) was partially due to a combination of EU funding and international collaboration. Generally, articles with EU funding are more likely to be cited than those with national funding, are more likely to be the product of international collaboration, have a higher number of contributors, and are published in journals with higher impact factors.

The effect of EU funding was particularly evident in *Natural Sciences*, where publications funded jointly by the EU and the public sector received considerably more citations than articles funded solely by the public sector. Second, and most importantly, the findings show that the most cited research papers are generated through a combination of EU funding and international collaboration. These findings imply that, in terms of citation impact, the EU will help Estonian scientists achieve better international collaboration outcomes than would otherwise be possible. According to Matt et al. (2012) and Switzerland's EU Framework Programmes Unit (2019), such collaborations and research networks would not have been set up without funding from the European Union. Also, these collaborations are why Estonia is slightly above the proportional national-international citation trendline shown in Study II.

In *Technology and Engineering*, the positive impact of EU funding was not seen. When taking into account the number of authors involved, publications financed jointly by the national sector and the EU had even less impact than articles funded solely by the national sector. Furthermore, international collaboration was not a significant factor in determining the impact of citations in this research field. One potential explanation is that this research field was established as a national priority, and there needs to be more incentive to recruit strong international collaborators. Also, the Study did not include conference proceedings and book chapters, which may have affected the results.

5.2 Policy Recommendations

Estonia should continue prioritising internationalisation and collaboration in its research and development (R&D) policies. As a small country, Estonia faces inherent challenges in building up the human and financial capital required for world-class research. Internationalisation can help to address these challenges by providing access to a wider pool of researchers, funding sources, and knowledge. This can lead to increased research productivity, innovation, and competitiveness.

Estonia should continue to participate in transnationally coordinated research in order to access enhanced research infrastructure, resources, and expertise. It offers benefits such as resource access, collaboration with diverse international partners, and increased citation impact. Estonia should persist in such initiatives to access enhanced research infrastructure and resources, contributing to long-term research capacity building, international reputation, and sustainable networks. However, challenges like hyper-authorship require the attention of policymakers.

Policymakers should collaborate with bibliometricians to gain a more nuanced understanding of the impact of transnationally coordinated research. This collaboration could involve the development of new metrics to assess citation impact, addressing the issue of hyper-authorship. Currently, there exists a substantial gap between estimates from the European Innovation Scoreboard, which the Ministry of Education and Research uses, and those presented by independent bibliometricians.

While transnationally organised research greatly enhances a country's impact, it should be kept in mind that most of it is artificial due to credit allocation issues that emerge with mass authorship. Transnationally coordinated research projects and research consortia are seen as a perversion of science because of the high number of co-authors, which, in some cases, can go into the thousands (Thelwall, 2020; Cronin, 2001). When efforts are on a grander scale, with a study group involved, it is believed that 50 or 100 researchers could not have written, edited, and approved the final work and meet authorship criteria. Most commonly used databases, such as Web of Science (WoS), Google Scholar, and Scopus, do not fractionalise citation counts, meaning all authors who participate get a full citation associated with a given article. This approach can lead to misleading conclusions about a country's scientific capabilities, exemplified by Estonia's exceptionally high ranking in certain bibliometric benchmarks.

To illustrate, Estonian bibliometricians published two articles in Postimees, the most widely-read newspaper in Estonia. The first article (Allik & Lauk, 2023a) asserted that, based on works published in the last 11 years, Estonia had become the fourth country globally in terms of citation impact, surpassing all but Iceland, Singapore, and Panama. The second article (Allik & Lauk, 2023b) stated that regarding citation impact, the University of Tartu ranks ahead of all universities in the Nordic countries. In contrast, the European Innovation Scoreboard (2023) used by the Estonian Ministry of Education and Research as a primary bibliometric data source in Estonian Research and Development, Innovation and

Entrepreneurship Strategy 2021–2035, suggests Estonia's citation impact is around 83% of the European Union average, far lower than portrayed in these media stories.

As a recommendation, a possible solution in the Estonian context, bibliometricians should follow the Procedure for Determining the Base Funding of Research and Development Institutions (2020) ratified by the *Riigikogu* (Estonian parliament). This procedure stipulates that an article with more than 100 authors is given a coefficient of 0.5, and an article with more than 1,000 authors is assigned a coefficient of 0.3. While the optimality of these coefficients is debatable, adopting such measures would align with the Ministry's perspective on productivity and impact.

The prevalence of hyper-authorship necessitates the Estonian Research Council to review the practice of preparing bibliometric overviews of grant applicants. During the process of evaluating research projects that are seeking funding, it is widely recognised that reviewers not only assess the project's content but also factor in the applicant's credibility, which is based on the applicant's previous accomplishments (Latour & Woolgar, 1979; García & Sanz-Menéndez, 2005). In situations with uncertainty or insufficient information, decision-makers tend to rely on indirect indicators for their assessment, such as citation rates and the journals where the applicant has published. These factors serve as cognitive tools influencing the decision-making process regarding whether or not to fund a research project. As a result, the Estonian Research Council (2023) uses a practice where bibliometric data on each applicant is added to project materials, which can be used by the Expert Panel and the Evaluation Committee to have a more comprehensive overview of the research activity of the applicant. Applicants with hyper-authored publications could have an unfair advantage if the hyper-authorship phenomenon is not considered.

Policymakers should acknowledge that collaboration does offer higher citation rates, but this could come at a cost. Papers that engage in international collaboration tend to have a broader impact due to their association with multiple countries (Lancho Barrantes et al., 2012). While there could be a higher citation impact when focusing on global matters, this impact could align differently from their national context, which becomes less significant as the collaborative environment expands. This raises the question of whether this could lead scientists to overlook national institutional contexts in favour of international settings where readership numbers are greater.

In order to catch up with more scientifically advanced countries, Estonia needs to contribute more resources to R&D. Collaboration is a two-way path, and partners must be able to give something of equal value in return in order to reap the benefit. High R&D expenditures, when combined with international collaboration, can present a compelling formula for advancing the impact of science in Estonia. This give-and-take exchange can lead to accelerated progress and shared scientific achievements, enabling Estonia to keep pace with and potentially even surpass currently more scientifically advanced countries.

Policymakers should persist in acknowledging the distinctive character of EU funding as a collaborative mechanism and continue promoting active participation. EU funding acts as a mediator, enabling Estonian scientists to access international networks and resources that would not have been otherwise possible. By encouraging EU collaboration, policymakers maintain an environment where Estonian scientists can take full advantage of the benefits of international collaboration, thereby elevating the nation's scientific expertise.

Although strongly favouring core funding or project-based funding over a balanced approach is associated with higher scientific impact, it may not be the best option in the long run. It is important to emphasise that the balanced funding strategy has shown fewer citations, but its impact can be positive for culture, sustainability, and the economy, which was not discussed here. For instance, project-based funding carries uncertainty since securing future funding might be challenging for organisations. This uncertainty hampers long-term planning, including aspects like hiring staff or investing in equipment. Researchers can also be left uncertain about their job prospects from year to year, etc.

Although university-industry collaboration is strongly associated with higher citation impact, it goes hand in hand with the economic structure. It cannot be forced upon by policy in the short run. Less developed countries will probably catch up when the economic structure is advanced enough for a more knowledge-based economy.

5.3 Limitations and Further Research

Limitations

Even though limitations are unlikely to affect the credibility of the findings, this must be considered in any analysis. Limitations due to the bibliometric method are discussed separately in the subchapter of the theoretical framework and are presented here in an abbreviated form.

- **Taxonomic shift**

The thesis focuses only on bibliometric outputs and ignores other equally important aspects of science. The term *impact* appears to be undergoing a taxonomic shift, where it is no longer described as the effect on science alone (as measured by citations) but instead on all aspects of society (culture, economics, and politics) (Bornmann & Haunschild, 2017).

- **Time Comparison**

A drawback of the bibliometric approach lies in its focus on current metrics rather than longitudinal comparisons, making it an incomplete measure of innovativeness. This is particularly concerning given the global decline in macro innovations since the Industrial Revolution. When looking at macro innovations produced, then it raises concerns. Macro innovations are described as innovations that significantly affect various individuals or processes within an organisation by necessitating significant changes to the organisation's systems and policies. Unfortunately, since the Industrial Revolution, these innovations have been in global decline (Woodley of Menie et al., 2019; Huebner, 2005).

- **National vs. International Environments**

It remains open as to what benefits (capital, know-how, or both) Estonian scientists receive from international collaboration. Moreover, to what extent do these benefits cause scientists to disregard national institutional environments in favour of international environments where topics attract more readers?

- **Data Completeness**

The term *reliability* can be characterised as the degree to which the results are unaffected by the method used to achieve them (Glänzel, 1996; Moed et al., 1985). When discussing limitations, we must address issues in collecting and handling bibliometric data. The main issue with reliability is the data's completeness (Moed & Vriens, 1989). It has been suggested that using WoS or Scopus to evaluate research can introduce prejudices that favour natural sciences, engineering, and biomedical research over social sciences and the arts and humanities (Mongeon & Paul-Hus, 2016). More importantly, the studies in the thesis are at risk of using only the ESI research schema, which excludes the arts and humanities entirely.

Avenues for Future Research

In light of the findings presented in this thesis, several promising avenues for future research merit exploration. **First**, further studies should examine internationalisation and how counting publications can affect rankings based on bibliometric outputs. Common full counting attributes full credit value for a publication to each author equally, regardless of their contribution. As a result, country-based estimates are based on articles their researchers are associated with. Fractional counting, on the other hand, reduces this problem by assigning fractions or proportions of authorship credit to each author based on their contribution to a publication. Therefore, estimates are based on how much a country's researchers contributed to a publication. The problem with fractional counting is that common databases do not use it. The OECD dataset makes it possible to study the gap between full and fractional counts. For example, it was noticed that the production of scientific publications from the Baltic nations exceeded what could be realistically accomplished given their constrained financial resources (Allik, 2003). This is an important avenue to look into because internationalisation could amplify research output in the case of full counting and give misleading information. In addition, further studies should focus on the increasing prevalence of hyper-authorship and how much it affects the distribution of baseline funding – are coefficients set by the *Riigikogu* (2020) of 0.5 for publications with more than 100 authors and 0.3 for publications with more than 1,000 authors adequate for determining baseline funding?

Second, EU structural funds have been used for many years to support a wide range of investments in low-income European countries. These funds have been used to improve infrastructure, create collaboration networks, support wages, and improve mobility. It is important to understand how these funds have been allocated to understand the impact of structural funds. This means looking at the proportion of funds that have been used for each purpose.

Third, a potential research avenue is how much endogeneity MDPI-associated publishing adds to bibliometric evaluation. For instance, MDPI is not very popular in Nordic countries but is in CEE countries (Csomós & Farkas, 2023). Do CEE and other countries associated with MDPI have more publications and citations?

5.4 Contribution to Literature

The thesis contributed to the literature in several ways. The insights gained from this thesis inform policy and decision-makers on fostering research excellence and making better use of internationalisation. For starters, Study I contributed to the existing literature by exploring several key aspects related to citation impact, such as size, transnational research programmes, and project-based funding. The main contributions of Study I are summarised as follows:

1. Understanding the Effect of Research System Size: The analysis revealed that the size of a country's research system does not significantly affect citation impact.
2. Showing that Transnationally Organised Research Programmes are Part of The Research System: The study demonstrated that transnationally organised research programmes positively affect the citation impact of countries. By providing empirical evidence on the benefits of transnational research programmes, this places transnationally organised research programmes into Lepori's (2011) schema of the publicly funded research system.
3. Uncovering the Relationship Between Project-Based Funding and Citations: The analysis revealed a U-shaped relationship between project-based funding and the number of citations per article.

Study II contributes to the existing literature by quantifying the impact of international consortia on Estonia's citation impact, examining disciplinary variations, and shedding light on the importance of collaboration to keep up with advanced countries. The key contributions of this study are summarised as follows:

1. Quantifying the Impact of International Consortia: The findings reveal that participation in international consortia has doubled Estonia's citation impact. On average, articles with up to 16 authors, which marks the

beginning of mass authorship, account only for 55% of total citations. By quantifying the impact of international consortia, this study provides empirical evidence to support the notion that consortia significantly enhance impact in countries with very small research systems.

2. Demonstrating a Proportional Relationship Between National and Collaboration Citation Impact: The study revealed that the benefit from international collaboration in terms of citations follows a proportional relationship between national and collaboration citation impact, as Beckmann (1993, pp. 12–13) proposed. On average, internationally collaborated articles are 60% more cited than domestic ones.
3. Assessing Collaboration as a Mechanism for Bridging the Gap with More Advanced Countries: The study highlights that Estonia collaborates more internationally than the EU15 countries, indicating that collaboration bridges the citation impact gap with advanced countries.

Study III contributes to the existing literature by providing novel insights into the impact of EU funding and international collaboration on citation impact, particularly focusing on the citation impact of funded research. The key contributions of this study are outlined as follows:

1. Examining the Impact of EU Funding: The study explores the impact of EU funding on research outcomes by analysing the citation impact of articles with EU funding compared to those funded solely at the national level. The findings reveal that articles with EU funding exhibit a higher citation impact than those funded only domestically. This research adds to the existing literature by providing a bibliometric analysis of EU funding acknowledgements – potentially one of the first studies to undertake such an investigation. This contribution enhances our understanding of the influence of EU funding on the impact of scientific articles.
2. Reinforcing the Role of International Collaboration: While the impact of international collaboration has been extensively studied in previous research, this study aligns with the existing body of knowledge by reaffirming the positive relationship between international collaboration and impact.
3. Highlighting the Impact of Combined EU Funding and International Collaboration: The findings of this study demonstrate that the most cited research papers result from a combination of EU funding and international collaboration. This novel finding adds a new dimension to the existing literature, emphasising the significance of synergistic effects between EU funding and international collaboration in producing highly influential research.

In summary, the thesis significantly contributes to the literature on citation impact and internationalisation. The findings bring clarity to assumptions about the relationship between the size of the research system and its impact, emphasise the positive influence of transnational research programmes, and highlight the effect of the share of project-based funding. The study also underlines the importance of international collaboration in bridging the gap with more advanced countries and reveals the combined effect of EU funding and international collaboration on highly cited research. These insights increase our understanding of the internationalisation process in small research systems and factors shaping the research impact.

REFERENCES

Abbott, A., & Schiermeier, Q. (2019). How European scientists will spend [euro] 100 billion. *Nature, 569*, 472–476.

Abramo, G., Cicero, T., & D'Angelo, C. A. (2012). Revisiting size effects in higher education research productivity. *Higher Education, 63*, 701–717.

Abramo, G., D'Angelo, C. A., & Di Costa, F. (2018). The effect of multidisciplinary collaborations on research diversification. *Scientometrics, 116*, 423–433.

Abramo, G., D'Angelo, C. A., & Solazzi, M. (2011). The relationship between scientists' research performance and the degree of internationalization of their research. *Scientometrics, 86*, 629–643.

Abramo, G., D'Angelo, C. A., Di Costa, F., & Solazzi, M. (2009). University–industry collaboration in Italy: A bibliometric examination. *Technovation, 29*, 498–507.

Abrigo, M. R., & Love, I. (2016). Estimation of panel vector autoregression in Stata. *The Stata Journal, 16*, 778–804.

Adams, J. (2012). The rise of research networks. *Nature, 490*, 335–336.

Adams, J., Pendlebury, D., Potter, R., & Szomszor, M. (2019). Global research report multi-authorship and research analytics. *Institute for Scientific Information*.

Aghaei Chadegani, A., Salehi, H., Yunus, M., Farhadi, H., Fooladi, M., Farhadi, M., & Ale Ebrahim, N. (2013). A comparison between two main academic literature collections: Web of Science and Scopus databases. *Asian social science, 9*, 18–26.

Ahn, T., Charnes, A., & Cooper, W. W. (1988). Some statistical and DEA evaluations of relative efficiencies of public and private institutions of higher learning. *Socio-economic Planning sciences, 22*, 259–269.

Aksnes, D. W., Langfeldt, L., & Wouters, P. (2019). Citations, citation indicators, and research quality: An overview of basic concepts and theories. *Sage Open, 9*, 2158244019829575.

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

Allik, J. (2008). Quality of Estonian science estimated through bibliometric indicators (1997-2007). *Proceedings of the Estonian Academy of Sciences, 57*.

Allik, J. (2013). Factors affecting bibliometric indicators of scientific quality. *Trames, 17*, 199–214.

Allik, J. (2015). Progress in Estonian science. *Proceedings of the Estonian Academy of Sciences, 64*, 125–127.

Allik, J. (2016). Scientific publications: Estonia rises to the top. *Estonian Research*, 27–32.

Allik, J., & Lauk, K. (2023a, April). *Teadusrikkuselt on Eesti maailmas viie esimese riigi seas*. Retrieved from Teadusrikkuselt on Eesti maailmas viie esimese riigi seas: https://arvamus.postimees.ee/7751118/juri-allik-ja-kalmer-lauk-teadusrikkuselt-on-eesti-maailmas-viie-esimese-riigi-seas

Allik, J., & Lauk, K. (2023b, May). *Tartu Ülikool – Põhjamaade mõjukaim ülikool*. Retrieved from Tartu Ülikool – Põhjamaade mõjukaim ülikool: https://arvamus.postimees.ee/7778287/ak-tartu-ulikool-pohjamaade-mojukaim-ulikool

Allik, J., Lauk, K., & Realo, A. (2020a). Factors predicting the scientific wealth of nations. *Cross-Cultural Research*, 1069397120910982.

Allik, J., Lauk, K., & Realo, A. (2020b). INDICATORS OF THE SCIENTIFIC IMPACT OF NATIONS REVISITED. *TRAMES: A Journal of the Humanities & Social Sciences, 24*.

Allison, P. D. (2009). *Fixed effects regression models.* SAGE publications.

Altbach, P. G., & Teichler, U. (2001). Internationalization and exchanges in a globalized university. *Journal of Studies in international Education, 5*, 5–25.

Ankrah, S., & Omar, A. L.-T. (2015). Universities–industry collaboration: A systematic review. *Scandinavian Journal of Management, 31*, 387–408.

Antelman, K. (2004). Do open-access articles have a greater research impact? *College & research libraries, 65*, 372–382.

Arbesman, S., Kleinberg, J. M., & Strogatz, S. H. (2009). Superlinear scaling for innovation in cities. *Physical Review E, 79*, 016115.

Arrow, K. J. (1962). Economic Welfare and the Allocation of Resources for Invention, University of Minnesota, The Rate and Direction of Inventive Activity: Economic and Social Factors. *Economic Welfare and the Allocation of Resources for Invention, University of Minnesota, The Rate and Direction of Inventive Activity: Economic and Social Factors*. Princeton University Press.

Aström, T., Jansson, T., Melin, G., Hakansson, A., Boekholt, P., & Arnold, E. (2012). On motives for participation in the Framework Programme.

Asubiaro, T. (2019). How collaboration type, publication place, funding and author's role affect citations received by publications from Africa: A bibliometric study of LIS research from 1996 to 2015. *Scientometrics, 120*, 1261–1287.

Awasthy, R., Flint, S., Sankarnarayana, R., & Jones, R. L. (2020). A framework to improve university–industry collaboration. *Journal of Industry-University Collaboration*.

Avkiran, N. K. (2001). Investigating technical and scale efficiencies of Australian universities through data envelopment analysis. *Socio-economic planning sciences, 35*, 57–80.

Barjak, F. (2006). Research productivity in the internet era. *Scientometrics, 68*, 343–360.

Beall, J. (2012). Predatory publishers are corrupting open access. *Nature, 489*, 179–179.

Beall, J. (2014). Chinese publisher MDPI added to list of questionable publishers. *Scholarly Open Access: Critical Analysis of Open-Access*.

Beaver, D., & Rosen, R. (1978). Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics, 1*, 65–84.

Beckmann, M. J. (1993). A Production Function for Scientific Interaction. In *Mathematical Modelling in Economics* (pp. 11–17). Springer.

Beckmann, M. J. (1994). On knowledge networks in science: collaboration among equals. *The Annals of Regional Science, 28*, 233–242.

Beckmann, M. J. (2000). Interurban knowledge networks. In *Learning, innovation and urban evolution* (pp. 127–135). Springer.

Berghäll, E., Heikkilä, T., Hjerppe, R., Kiander, J., Kilponen, J., Lavrač, V., & Stanovnik, P. (2002). *The role of science and technology policy in small economies.* Government Institute for Economic Research.

Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the national academy of sciences, 104*, 7301–7306.

Bjarte Fosso, O. (2020, January). Forskere blir ledet til etiske overtramp. *Forskere blir ledet til etiske overtramp*. Retrieved from https://www.universitetsavisa.no/ytring/forskere-blir-ledet-til-etiske-overtramp/114691

Bloch, C., Ryan, T. K., & Andersen, J. P. (2019). Public-private collaboration and scientific impact: An analysis based on Danish publication data for 1995–2013. *Journal of Informetrics, 13*, 593–604.

Bonaccorsi, A., & Daraio, C. (2005). Exploring size and agglomeration effects on public research productivity. *Scientometrics, 63*, 87–120.

Bornmann, L. (2013). How to analyze percentile citation impact data meaningfully in bibliometrics: The statistical analysis of distributions, percentile rank classes, and top-cited papers. *Journal of the Association for Information Science and Technology, 64*(3), 587–595. https://doi.org/10.1002/asi.22792

Bornmann, L., & Haunschild, R. (2017). Does evaluative scientometrics lose its main focus on scientific quality by the new orientation towards societal impact? *Scientometrics, 110*, 937–943.

Breschi, S., & Cusmano, L. (2004). Unveiling the texture of a European Research Area: emergence of oligarchic networks under EU Framework Programmes. *International journal of technology management, 27*, 747–772.

Breschi, S., Cassi, L., Malerba, F., & Vonortas, N. S. (2009). Networked research: European policy intervention in ICTs. *Technology Analysis & Strategic Management, 21*, 833–857.

Buisseret, T. J., Cameron, H. M., & Georghiou, L. (1995). What difference does it make? Additionality in the public support of R&D in large firms. *International Journal of Technology Management, 10*, 587–600.

Bush, V. (1945). The endless frontier. *National Science Foundation–EUA. Washington*.

Callon, M. (1994). Is science a public good? *Science, Technology, & Human Values, 19*, 395–424.

Caloghirou, Y., Vonortas, N. S., & Ioannides, S. (2002). Science and technology policies towards research joint ventures. *Science and Public Policy, 29*, 82–94.

Cambridge University Press. (2023, April). Cambridge Dictionary | English Dictionary, Translations & Thesaurus. *Cambridge Dictionary | English Dictionary, Translations & Thesaurus*. Retrieved April 12, 2023, from https://dictionary.cambridge.org/

Castelvecchi, D. (2015). Physics paper sets record with more than 5,000 authors. *Nature, 15*.

Cattell, J. M. (1909). Biographical Directory of American Men of Science. *Science, 29*, 699–700.

CERN. (2023). *CERN Accelerating science*. Retrieved July 17, 2023, from WHAT IS CERN'S MISSION?: https://home.cern/about/who-we-are/our-mission#:~:text=What%20is%20CERN's%20mission%3F&text=At%20CERN%2C%20our%20work%20helps,the%20boundaries%20of%20human%20knowledge.

Chen, S., Arsenault, C., & Larivière, V. (2015). Are top-cited papers more interdisciplinary? *Journal of Informetrics, 9*, 1034–1046.

Cherchye, L., & Abeele, P. V. (2005). On research efficiency: A micro-analysis of Dutch university research in Economics and Business Management. *Research policy, 34*, 495–516.

Chinchilla-Rodríguez, Z., Zacca-González, G., Vargas-Quesada, B., & Moya-Anegón, F. (2015). Latin American scientific output in Public Health: combined analysis using bibliometric, socioeconomic and health indicators. *Scientometrics, 102*, 609–628.

Cimini, G., Gabrielli, A., & Labini, F. S. (2014). The scientific competitiveness of nations. *PloS one, 9*, e113470.

Clarivate Analytics. (2018). *InCites indicators handbook.* Clarivate Analytics.

Clarivate Plc. (2023, July 10). *Clarivate*. Retrieved from Essential Science Indicators: Learn the Basics: 2023)., Clarivate PC (2023) Essential Science Indicators: Learn the Basics. Available at: https://clarivate.libguides.com/esi (Accessed: 11 July

Clarivate Plc. (2023). Libguides: Incites benchmarking & analytics: Understanding the metrics. *Libguides: Incites benchmarking & analytics: Understanding the metrics*. Clarivate Analytics. Retrieved from https://clarivate.libguides.com/incites_ba/understanding-indicators#::text=The%20h%2Dindex%20represents%20the,cited%20at%20least%2020%20times.

Clermont, M., Dirksen, A., & Dyckhoff, H. (2015). Returns to scale of Business Administration research in Germany. *Scientometrics, 103*, 583–614.

Cocos, M., & Lepori, B. (2020). What we know about research policy mix. *Science and Public Policy, 47*, 235–245.

Cole, S., & Phelan, T. J. (1999). The scientific productivity of nations. *Minerva*, 1–23.

Creaser, C., & White, S. (2008). Trends in journal prices: an analysis of selected journals, 2000–2006. *Learned publishing, 21*, 214–224.

Crespi, G. A., & Geuna, A. (2008). An empirical study of scientific production: A cross country analysis, 1981–2002. *Research Policy, 37*, 565–579.

Cronin, B. (1984). The citation process. *The role and significance of citations in scientific communication, 103*.

Cronin, B. (2001). Hyperauthorship: A postmodern perversion or evidence of a structural shift in scholarly communication practices? *Journal of the American Society for Information Science and Technology, 52*, 558–569.

Csomós, G., & Farkas, J. Z. (2023). Understanding the increasing market share of the academic publisher "Multidisciplinary Digital Publishing Institute" in the publication output of Central and Eastern European countries: a case study of Hungary. *Scientometrics, 128*, 803–824.

Cutcher-Gershenfeld, J., Baker, K. S., Berente, N., Carter, D. R., DeChurch, L. A., Flint, C. G., ... others. (2016). Build it, but will they come? A geoscience cyberinfrastructure baseline analsys. *Data Science Journal, 15*, 1.

Daems, D. (2021). *Social complexity and complex systems in archaeology.* Routledge.

Davis, P. M., & Walters, W. H. (2011). The impact of free access to the scientific literature: a review of recent research. *Journal of the Medical Library Association, 99*.

De Bellis, N. (2009). *Bibliometrics and citation analysis: from the science citation index to cybermetrics.* scarecrow press.

Defazio, D., Lockett, A., & Wright, M. (2009). Funding incentives, collaborative dynamics and scientific productivity: Evidence from the EU framework program. *Research policy, 38*, 293–305.

Demir, S. B. (2018). Predatory journals: Who publishes in them and why? *Journal of Informetrics, 12*, 1296–1311.

Di Cagno, D., Fabrizi, A., & Meliciani, V. (2014). The impact of participation in European joint research projects on knowledge creation and economic growth. *The Journal of Technology Transfer, 39*, 836–858.

Diamond, A. (2008). Economics of science. *The new palgrave dictionary of economics, 7*, 328.

Dinges, M., & Lepori, B. (2006). Public project funding of research activities: National differences and implications for the creation of a European Research Council. *Platform fteval conference-New Frontiers in Evaluation, Vienna 24th–25th April.*

DORA. (2012). San Francisco declaration on research assessment. *San Francisco declaration on research assessment*. DORA San Francisco, CA, USA.

Edler, J., Kuhlmann, S., & Behrens, M. (2003). *Changing governance of research and technology policy: The European research area.* Edward Elgar Publishing.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. *Academy of management review, 14*, 57–74.

Ejermo, O., & Kander, A. (2006). The Swedish Paradox. *Centre for Innovation, Research and Competence in the Learning Economy, Lund University, Paper*.

Ejermo, O., & Kander, A. (2009). The Swedish paradox revisited. *Chapters*, 49–76.

Encyclopædia Britannica, Inc. (2013, July 10). Retrieved from Common Good: https://www.britannica.com/topic/common-good

Encyclopedia Britannica. (2023, April 27). Bill Gates | Biography, Microsoft, & Facts. Encyclopædia Britannica. Retrieved from Bill Gates | Biography, Microsoft, & Facts: https://www.britannica.com/biography/Bill-Gates

Enger, S. G. (2018). Closed clubs: Network centrality and participation in Horizon 2020. *Science and Public Policy, 45*, 884–896.

Enger, S. G. (2020). The Factors Behind Participation: Evidence from the European Framework Programme, Horizon 2020.

Esparza, J., & Yamada, T. (2007). The discovery value of "Big Science". *The Journal of experimental medicine, 204*, 701–704.

Estonian Research Council. (2016). *Eesti teaduse rahvusvahelise tutvustamise strateegia 2016–2022.* Tech. rep. Retrieved from https://www.etag.ee/wp-content/uploads/2013/11/Teadusagentuur_dokument_est.pdf

Estonian Research Council. (2023). *Guidelines regarding bibliometric background information.* Retrieved July 27, 2023, from ETAG: https://etag.ee/wp-content/uploads/2023/02/Guidelines-regarding-bibliometric-background-information-2023-1.pdf

Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix–University-industry-government relations: A laboratory for knowledge based economic development. *EASST review, 14*, 14–19.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research policy, 29*, 109–123.

EU Framework Programmes Unit. (2019). *The Impact of Switzerland's Participation in the EU Framework Programmes.* Bern: State Secretariat for Education, Research and Innovation (SERI).

European Commission. (2023). *EU Science Hub*. Retrieved July 17, 2023, from Energy Storage – Energy Storage Research Infrastructures: https://joint-research-centre.ec.europa.eu/tools-and-laboratories/open-access-jrc-research-infrastructures/energy-storage-research-infrastructures_en

European Commission. (2023). European Innovation Scoreboard. Retrieved September 13, 2023, from https://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/european-innovation-scoreboard/eis#

Eurostat. (2011). R&D budget statistics – transnationally coordinated research. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:R_&_D_budget_statistics_-_transnationally_coordinated_research

Eurostat. (2022). Government budget allocations for R&D (GBARD). *Government budget allocations for R&D (GBARD).* Retrieved from https://ec.europa.eu/eurostat/cache/metadata/en/gba_esms.htm#contact1616163588011

Eysenbach, G. (2006). Citation advantage of open access articles. *PLoS biology, 4*, e157.

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, web of science, and Google scholar: strengths and weaknesses. *The FASEB journal, 22*, 338–342.

Farshad, M., Sidler, C., & Gerber, C. (2013). Association of scientific and nonscientific factors to citation rates of articles of renowned orthopedic journals. *European Orthopaedics and Traumatology, 4*, 125–130.

Feelders, A. (2002). Data mining in economic science. *Dealing with the data flood*, 166–175.

Galison, P., Hevly, B., & Weinberg, A. M. (1992). Big science: The growth of large-scale research. *Physics Today, 45*, 89.

Galton, F. (1874). *English men of science: Their nature and nurture.* Routledge.

Gantz, P. (2013). Journal print subscription price increases no longer reflect actual costs. *Learned publishing, 26*, 206–210.

García, C. E., & Sanz-Menéndez, L. (2005). Competition for funding as an indicator of research competitiveness. *Scientometrics, 64*, 271–300.

Garfield, E. (1979). Is citation analysis a legitimate evaluation tool? *Scientometrics, 1*, 359–375.

Gazni, A., Sugimoto, C. R., & Didegah, F. (2012). Mapping world scientific collaboration: Authors, institutions, and countries. *Journal of the American Society for Information Science and Technology, 63*, 323–335.

Gauffriau, M., & Larsen, P. O. (2005). Counting methods are decisive for rankings based on publication and citation studies. *Scientometrics, 64*, 85–93.

Gauffriau, M., Larsen, P. O., Maye, I., Roulin-Perriard, A., & von Ins, M. (2007). Publication, Cooperation and Productivity Measures in Scientific Research. *Scientometrics, 73*(2), 175–214. https://doi.org/10.1007/s11192-007-1800-2

Gautam, M., & Ahmed, M. (2019). Too small to be beautiful? The farm size and productivity relationship in Bangladesh. *Food Policy, 84*, 165–175.

Georghiou, L. (2013). *Effectiveness of National Research Systems.* unpublished. Retrieved from https://era.gv.at/object/document/366/attach/background_paper_ session _1.pdf

Glänzel, W. (1996). The need for standards in bibliometric research and technology. *Scientometrics, 35*, 167–176.

Glänzel, W. (2000). Science in Scandinavia: A bibliometric approach. *Scientometrics, 48*, 121–150.

Glänzel, W. (2001). National characteristics in international scientific co-authorship relations. *Scientometrics, 51*, 69–115.

Godin, B. (2006). On the origins of bibliometrics. *Scientometrics, 68*, 109–133.

Godin, B. (2006a). The linear model of innovation: The historical construction of an analytical framework. *Science, Technology, & Human Values, 31*, 639–667.

Godin, B. (2007). From eugenics to scientometrics: Galton, Cattell, and men of science. *Social studies of science, 37*, 691–728.

Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of Economic Literature, 57*, 3–43.

Gonzalez-Brambila, C. N., Veloso, F. M., & Krackhardt, D. (2013). The impact of network embeddedness on research output. *Research Policy, 42*, 1555–1567.

Gray, D. O. (2011). Cross-sector research collaboration in the USA: a national innovation system perspective. *Science and Public Policy, 38*, 123–133.

Griesemer, J. R., & Gerson, E. M. (1993). Collaboration in the museum of vertebrate zoology. *Journal of the History of Biology*, 185–203.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *The bell journal of economics*, 92–116.

Gross, K., & Bergstrom, C. T. (2019). Contest models highlight inherent inefficiencies of scientific funding competitions. *PLoS biology, 17*, e3000065.

Guan, J. C., Yam, R. C., Mok, C. K., & Ma, N. (2006). A study of the relationship between competitiveness and technological innovation capability based on DEA models. *European journal of operational research, 170*, 971–986.

Guan, J., & Zuo, K. (2014). A cross-country comparison of innovation efficiency. *Scientometrics, 100*, 541–575.

Guerrero Bote, V. P., Olmeda-Gómez, C., & de Moya-Anegón, F. (2013). Quantifying the benefits of international scientific collaboration. *Journal of the American Society for Information Science and Technology, 64*, 392–404.

Gusmão, R. (2001). Research networks as a means of European integration. *Technology in society, 23*, 383–393.

Haegeman, K., Doussineau, M., Boden, M., & others. (2015). *Measuring progress in transnational coordination of research programming in Europe.* Tech. rep., Joint Research Centre (Seville site).

Hakala, J., Kutinlahti, P., & Kaukonen, E. (2002). Becoming international, becoming European: EU research collaboration at Finnish universities. *Innovation: The European Journal of Social Science Research, 15*, 357–379.

Heller-Schuh, B., Barber, M., Henriques, L. M., Paier, M., Pontikakis, D., Scherngell, T., ... others. (2011). *Analysis of Networks in European Framework Programmes (1984–2006).* Tech. rep., Joint Research Centre (Seville site).

Hess, C., & Ostrom, E. (2007). *Understanding knowledge as a commons.*

Hicks, D., Wouters, P., Waltman, L., De Rijcke, S., & Rafols, I. (2015). Bibliometrics: the Leiden Manifesto for research metrics. *Nature, 520*, 429–431.

Hicks, S. R. (2004). *Explaining postmodernism: Skepticism and socialism from Rousseau to Foucault.* Scholargy Publishing, Inc.

Hirsch, J. E. (2007). Does the h index have predictive power? *Proceedings of the National Academy of Sciences, 104*, 19193–19198.

Horta, H. (2009). Global and national prominent universities: internationalization, competitiveness and the role of the State. *Higher Education, 58*, 387–405.

Huebner, J. (2005). A possible declining trend for worldwide innovation. *Technological Forecasting and Social Change, 72*, 980–986.

Iglič, H., Doreian, P., Kronegger, L., & Ferligoj, A. (2017). With whom do researchers collaborate and why? *Scientometrics, 112*, 153–174.

Ioannidis, J. P. (2008). Measuring co-authorship and networking-adjusted scientific impact. *PloS one, 3*, e2778.

Jim Pattison Group. (2021, February 12). *Guinness World Records*. Retrieved from Most authors on a single peer-reviewed academic paper: https://www.guinnessworldrecords.com/world-records/653537-most-authors-on-a-single-peer-reviewed-academic-paper

Johnes, G., & Johnes, J. (1993). Measuring the research performance of UK economics departments: an application of data envelopment analysis. *Oxford economic papers, 45*, 332–347.

Johnes, J. (2006). Data envelopment analysis and its application to the measurement of efficiency in higher education. *Economics of education review, 25*, 273–288.

Jones, C. I. (2005). Growth and ideas. In *Handbook of economic growth* (Vol. 1, pp. 1063–1111). Elsevier.

Jongbloed, B., & Lepori, B. (2015). The funding of research in higher education: Mixed models and mixed results. In *The Palgrave international handbook of higher education policy and governance* (pp. 439–462). Springer.

Jonkers, K., & Zacharewicz, T. (2016). *Research Performance Based Funding Systems: a Comparative Assessment.* Luxembourg: Publications Office of the European Union. https://doi.org/10.2791/659483

Kamalski, J. (2009). Small countries lead international collaboration. *Research Trends, 1*, 4.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research policy, 26*, 1–18.

Kealey, T., & Ricketts, M. (2014). Modelling science as a contribution good. *Research Policy, 43*, 1014–1024.

Kearney, M. H., & Collaborative, I. P. (2015). Predatory publishing: what authors need to know. *Predatory publishing: what authors need to know, 38*, 1–3. Wiley Online Library.

King, C. (2016). Multiauthor Papers: Onward and Upward; 2013. *July. URL: http://archive.sciencewatch.com/newsletter/2012/201207/multiauthor_{p}{a}{p}ers.*

King, D. A. (2004). The scientific impact of nations. *Nature, 430*, 311–316.

Kocher, M. G., Luptacik, M., & Sutter, M. (2006). Measuring productivity of research in economics: A cross-country study using DEA. *Socio-Economic Planning Sciences, 40*, 314–332.

Kozak, M., Bornmann, L., & Leydesdorff, L. (2015). How have the Eastern European countries of the former Warsaw Pact developed since 1990? A bibliometric study. *Scientometrics, 102*, 1101–1117.

Kremer, R. K., & Marx, W. (2009). Aspects of the scientific cooperation of Estonia and Germany in view of bibliometry. *Proceedings of the Estonian Academy of Sciences, 58*.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions. Chicago (University of Chicago Press) 1962.*

Kuitunen, S., Haila, K., Kauppinen, I., Syrjanen, M., Vanhanen, J., Ahonen, P. P., . . . Paavola, T. (2008). Finns in the EU 6th framework programme: Evaluation of participations and networks, evaluation report. *Helsinki: Tekes*.

Kulkarni, A. V., Busse, J. W., & Shams, I. (2007). Characteristics associated with citation rate of the medical literature. *PloS one, 2*, e403.

Kwiek, M. (2015). The internationalization of research in Europe: A quantitative study of 11 national systems from a micro-level perspective. *Journal of studies in international education, 19*, 341–359.

Kyvik, S. (1995). Are big university departments better than small ones? *Higher Education, 30*(3), 295–304. https://doi.org/10.1007/BF01383753

Lancho Barrantes, B. S., Guerrero Bote, V. P., Rodríguez, Z. C., & de Moya Anegón, F. (2012). Citation flows in the zones of influence of scientific collaborations. *Journal of the American Society for Information Science and Technology, 63*, 481–489.

Langfeldt, L., Godø, H., Gornitzka, Å., & Kaloudis, A. (2012). Integration modes in EU research: Centrifugality versus coordination of national research policies. *Science and Public Policy, 39*, 88–98.

Larivière, V., Vignola-Gagné, E., Villeneuve, C., Gélinas, P., & Gingras, Y. (2011). Sex differences in research funding, productivity and impact: an analysis of Québec university professors. *Scientometrics, 87*, 483–498.

Lashinsky, A. (2012). *Inside Apple: How America's most admired–and secretive–company really works.* Hachette UK.

Lazer, D., Pentland, A., Adamic, L., Aral, S., Barabási, A.-L., Brewer, D., . . . others. (2009). Computational social science. *Science, 323*, 721–723.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The construction of scientific facts.* Princeton University Press.

Laudel, G. (2006). The art of getting funded: how scientists adapt to their funding conditions. *Science and Public Policy, 33*, 489–504.

Lauk, K., & Allik, J. (2018). A PUZZLE OF ESTONIAN SCIENCE: HOW TO EXPLAIN UNEXPECTED RISE OF THE SCIENTIFIC IMPACT. *TRAMES: A Journal of the Humanities & Social Sciences, 22*.

Lebeau, L.-M., Laframboise, M.-C., Larivière, V., & Gingras, Y. (2008). The effect of university–industry collaboration on the scientific impact of publications: the Canadian case, 1980–2005. *Research Evaluation, 17*, 227–232.

Lee, S. (2007). Scientific Productivity. *The Blackwell Encyclopedia of Sociology*.

Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social studies of science, 35*, 673–702.

Lepori, B. (2011). Coordination modes in public funding systems. *Research policy, 40*, 355–367.

Lepori, B., Geuna, A., & Mira, A. (2019). Scientific output scales with resources. A comparison of US and European universities. *PloS one, 14*, e0223415.

Lepori, B., Reale, E., & Larédo, P. (2014). Logics of integration and actors' strategies in European joint programs. *Research Policy, 43*, 391–402.

Lepori, B., Van den Besselaar, P., Dinges, M., Van der Meulen, B., Potì, B., Reale, E., ... Theves, J. (2007). Indicators for comparative analysis of public project funding: concepts, implementation and evaluation. *Research evaluation, 16*, 243–255.

Lewison, G., & Must, Ü. (2001). Estonian international co-operation in science in the 1990s: New politics, new methods. *8th international conference on scientometrics and informetrics proceedings-ISSI-2001*, (pp. 385–393).

Levitt, J., & Thelwall, M. (2010). Does the higher citation of collaborative research differ from region to region? A case study of economics. *Scientometrics, 85*, 171–183.

Levy, S. (2006). *The perfect thing: How the iPod shuffles commerce, culture, and coolness.* Simon and Schuster.

Leydesdorff, L., & Wagner, C. (2009). Macro-level indicators of the relations between research funding and research output. *Journal of informetrics, 3*, 353–362.

Leydesdorff, L., Bornmann, L., & Wagner, C. S. (2019). The relative influences of government funding and international collaboration on citation impact. *Journal of the Association for Information Science and Technology, 70*, 198–201.

Lindner, M. D., Torralba, K. D., & Khan, N. A. (2018). Scientific productivity: An exploratory study of metrics and incentives. *PloS one, 13*, e0195321.

Lobo, J., Strumsky, D., & Rothwell, J. (2013). Scaling of patenting with urban population size: evidence from global metropolitan areas. *Scientometrics, 96*, 819–828.

Lotka, A. J. (1926). The frequency distribution of scientific productivity. *Journal of the Washington academy of sciences, 16*, 317–323.

Louf, R. (2015). Wandering in cities: A statistical physics approach to urban theory. *arXiv preprint arXiv:1511.08236.*

Makkonen, T., & Mitze, T. (2016). Scientific collaboration between 'old'and 'new'member states: Did joining the European Union make a difference? *Scientometrics, 106*, 1193–1215.

Mali, F., Pustovrh, T., Platinovšek, R., Kronegger, L., & Ferligoj, A. (2017). The effects of funding and co-authorship on research performance in a small scientific community. *Science and Public Policy, 44*, 486–496.

Masterman, M. (1970). *The nature of a paradigm.* (I. Lakatos, & A. Musgrave, Eds.) Cambridge University Press.

Matt, M., Robin, S., & Wolff, S. (2012). The influence of public programs on inter-firm R&D collaboration strategies: project-level evidence from EU FP5 and FP6. *The Journal of Technology Transfer, 37*, 885–916.

Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics, 36*, 363–377.

Merton, R. K. (1968). The Matthew effect in science: The reward and communication systems of science are considered. *Science, 159*, 56–63.

Ministry of Education and Research (Estonia). (2022). Estonian Research and Development, Innovation and Entrepreneurship Strategy 2021—2035. Retrieved from https://www.hm.ee/media/1617/download

Moed, H. F., & Vriens, M. (1989). Possible inaccuracies occurring in citation analysis. *Journal of Information Science, 15*, 95–107.

Moed, H. F., Burger, W. J., Frankfort, J. G., & Van Raan, A. F. (1985). The use of bibliometric data for the measurement of university research performance. *Research policy, 14*, 131–149.

Mohallem, J. R., & Fonseca, N. E. (2015). Brazilian impact factor of physics journals-the third side of the coin. *Anais da Academia Brasileira de Ciências, 87*, 1233–1238.

Mokyr, J. (1992). The lever of riches.[Includes innovation].

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics, 106*, 213–228.

Morillo, F. (2016). Public–private interactions reflected through the funding acknowledgements. *Scientometrics, 108*, 1193–1204.

Morley, L. (2015). *Testing for the effects of organisational and individual cognitive-distance in small business and creative industries innovation partnerships.* Ph.D. dissertation, University of Warwick.

Mueller, C. E. (2016). Accurate forecast of countries' research output by macro-level indicators. *Scientometrics, 109*, 1307–1328.

Multidisciplinary Digital Publishing Institute. (2023). Publisher of open access journals. *Publisher of open access journals*. Retrieved from https://www.mdpi.com/

Must, Ü. (2010). Collaboration in EU Framework Programmes–the case of the social sciences and humanities. *Innovation–The European Journal of Social Science Research, 23*, 79–83.

Must, Ü. (2014). The impact of multi-authored papers: The case of a small country. *Collnet Journal of scientometrics and information management, 8*, 41–47.

National Research Council of United States. (2005). The Culture of Collaborative Research. In *The Geological Record of Ecological Dynamics: Understanding the Biotic Effects of Future Environmental Change 2* (pp. 131–147). National Academies Press.

Nedeva, M. (2013). Between the global and the national: Organising European science. *Research Policy, 42*, 220–230.

Nelson, M. L. (2009). Data-driven science: A new paradigm. *Educause Review, 44*, 6–7.

Nelson, R. R. (1959). The simple economics of basic scientific research. *Journal of political economy, 67*, 297–306.

Nguyen, T. V., Ho-Le, T. P., & Le, U. V. (2017). International collaboration in scientific research in Vietnam: an analysis of patterns and impact. *Scientometrics, 110*, 1035–1051.

Nooteboom, B. (2012). Cognitive Theory of the Firm: A Pragmatic Perspective. In *Handbook on the Economics and Theory of the Firm.* Edward Elgar Publishing.

Nygaard, L. P. (2015). Publishing and perishing: an academic literacies framework for investigating research productivity. 1–14.

OECD. (2018, October). Effective operation of competitive research funding systems. Organisation for Economic Co-Operation and Development (OECD). https://doi.org/10.1787/2ae8c0dc-en

OECD. (2021, June). Recommendation of the Council on International Co-operation in Science and Technology. *Recommendation of the Council on International Co-operation in Science and Technology*. Organisation for Economic Co-Operation and Development (OECD). Retrieved from https://legalinstruments.oecd.org/public/doc/133/133.en.pdf

Office of Technology Assessment. (1995). *International partnerships in large science projects.* DIANE Publishing.

Okamura, K. (2019). Interdisciplinarity revisited: evidence for research impact and dynamism. *Palgrave Communications, 5*, 1–9.

Okubo, Y., & Zitt, M. (2004). Searching for research integration across Europe: a closer look at international and inter-regional collaboration in France. *Science and Public Policy, 31*, 213–226.

Ortega, J., & Aguillo, I. (2010). Network collaboration in the 6th Framework Programmes: country participation in the health thematic area. *Scientometrics, 84*, 835–844.

Ostrom, E. (2010). Beyond markets and states: polycentric governance of complex economic systems. *American economic review, 100*, 641–672.

Ostrom, V., & Ostrom, E. (1977). Public goods and public choices. *1977*, 7–49.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'este, P., ... others. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research policy, 42*, 423–442.

Polt, W., & Streicher, G. (2005). Trying to capture additionality in Framework Programme 5—main findings. *Science and Public Policy, 32*, 367–373.

Prathap, G. (2017). Scientific wealth and inequality within nations. *Scientometrics, 113*, 923–928.

Price, D. J. (1963). *Little science, big science... and beyond.* Columbia University Press New York.

Primeri, E., & Reale, E. (2012). How Europe shapes academic research: Insights from participation in European union framework programmes. *European Journal of Education, 47*, 104–121.

Pulford, J., El Hajj, T., Tancred, T., Ding, Y., Crossman, S., Silvester, L., ... Bates, I. (2023). How international research consortia can strengthen organisations' research systems and promote a conducive environment and culture. *BMJ Global Health, 8*, e011419.

Quinlan, J. R. (1986). Induction of decision trees. *Machine learning, 1*, 81–106.

Reale, E. (2017). *Analysis of National Public Research Funding-PREF.* Final Report. https://doi.org/10.2760/19140

Reale, E., Lepori, B., Nedeva, M., Thomas, D., Primeri, E., Chassagneux, E., & Laredo, P. (2013). Investments in joint and open research programmes and analysis of their economic impact (JOREP) Final report. *European Commission, Directorate-General for Research and Innovation.< http://ec. europa. eu/research/innovation-union/pdf/ jorep_{f}{i}{n}al_{r}{e}{p}ort. pdf.*

Reale, E., Lepori, B., Primeri, E., Chassagneux, E., Laredo, P., Nedeva, M., & Thomas, D. A. (2013). National patterns of transnational research: the case of joint research programs. *Eu-SPRI Conference.*

Romer, D. (1992). Two strategies for economic development: using ideas and producing ideas. *The World Bank Economic Review, 6*, 63–91.

Rostan, M., Ceravolo, F. A., & Metcalfe, A. S. (2014). The internationalization of research. In *The internationalization of the academy* (pp. 119–143). Springer.

Rousseau, R., Egghe, L., & Guns, R. (2018). *Becoming metric-wise: A bibliometric guide for researchers.* Chandos Publishing.

Rousseau, S., & Rousseau, R. (1998). The scientific wealth of European nations: Taking effectiveness into account. *Scientometrics, 42*, 75–87.

Ruiz-Castillo, J., & Costas, R. (2014). The skewness of scientific productivity. *Journal of informetrics, 8*, 917–934.

Ruscio, J., Seaman, F., D'Oriano, C., Stremlo, E., & Mahalchik, K. (2012). Measuring scholarly impact using modern citation-based indices. *Measurement: Interdisciplinary Research and Perspectives, 10*, 123–146.

Sample, I. (2012). Harvard University says it can’t afford journal publishers’ prices. *The Guardian, 24*, 20–32.

Samuelson, P. A. (1954). The pure theory of public expenditure. *The review of economics and statistics, 36*, 387–389.

Sandström, U., & Van den Besselaar, P. (2018). Funding, evaluation, and the performance of national research systems. *Journal of Informetrics, 12*, 365–384.

Saublens, C. (2014). Participation of EU13 countries in FP7: Mobilising Institutional Reforms for Better RDI Systems/Institutions in Europe. *Participation of EU13 countries in FP7: Mobilising Institutional Reforms for Better RDI Systems/Institutions in Europe*. Part.

Schiermeier, Q. (2019). Estonia’s research revival. *Nature.*

Shapere, D. (1964). The structure of scientific revolutions. *The Philosophical Review, 73*, 383–394.

Sharma, S., & Thomas, V. (2008). Inter-country R&D efficiency analysis: An application of data envelopment analysis. *Scientometrics, 76*, 483–501.

Shelton, R. D. (2020). Scientometric laws connecting publication counts to national research funding. *Scientometrics*, 1–26.

Shen, C., & Björk, B.-C. (2015). ‘Predatory’open access: a longitudinal study of article volumes and market characteristics. *BMC medicine, 13*, 1–15.

Sjögårde, P., & Didegah, F. (2022). The association between topic growth and citation impact of research publications. *Scientometrics, 127*, 1903–1921.

Smith, R. K., Ahmed, M. U., & Takanashi, A. (1999). International collaboration for technological change in the 21st century. *International Journal of Technology Management, 18*, 285–292.

Solimine, G. (2016). The Role of Libraries Between Fragmentation and Complexity of Knowledge. *The Role of Libraries Between Fragmentation and Complexity of Knowledge*, 119–124.

Sonnenwald, D. H. (2007). Scientific collaboration. *ARIST, 41*, 643–681.

Stephan, P. E. (1996). The economics of science. *Journal of Economic literature, 34*, 1199–1235.

Sun, J. C., & Turner, H. A. (2022). The Complementarity Investment in University-Industry Collaboration. *Innovative Higher Education*, 1–18.

Tahamtan, I., Safipour Afshar, A., & Ahamdzadeh, K. (2016). Factors affecting number of citations: a comprehensive review of the literature. *Scientometrics, 107*, 1195–1225.

Tayan, B. (2019). The Wells Fargo cross-selling scandal. *Rock Center for Corporate Governance at Stanford University Closer Look Series: Topics, Issues and Controversies in Corporate Governance No. CGRP-62 Version, 2*, 17–1.

Teadus- ja arendusasutuste baasfinantseerimise määramise tingimused ja kord, RT I, 09.10.2020, 13. (2020). Retrieved June 30, 2023, from https://www.riigiteataja.ee/akt/109102020013

The Ministry of Education and Research. (2012). *Kõrghariduse ja teaduse rahvusvahelistumise prioriteetsed tegevused 2013–2021.* Tech. rep., The Ministry of Education and Research. Retrieved from https://www.hm.ee/sites/default/files/rvl_prioriteetsed_tegevused_2013-2020_51112.pdf

Thelwall, M. (2017). Avoiding obscure topics and generalising findings produces higher impact research. *Scientometrics, 110*, 307–320.

Thelwall, M. (2020). Large publishing consortia produce higher citation impact research but coauthor contributions are hard to evaluate. *Quantitative Science Studies, 1*, 290–302.

Thelwall, M., & Maflahi, N. (2015). Are scholarly articles disproportionately read in their own country? An analysis of Mendeley readers. *Journal of the Association for Information Science and Technology, 66*, 1124–1135.

Thorsteinsdóttir, H. (2000). Public-sector research in small countries: does size matter? *Science and Public Policy, 27*, 433–442.

Tijssen, R. J. (2008). Are we moving towards an integrated European Research Area? Some macro-level bibliometric perspectives. *Collnet Journal of Scientometrics and Information Management, 2*, 19–25.

Turpin, T., Woolley, R., & Garrett-Jones, S. (2011). Cross-sector research collaboration in Australia: the Cooperative Research Centres Program at the crossroads. *Science and Public Policy, 38*, 87–97.

Ukrainski, K., Masso, J., & Kanep, H. (2014). Cooperation patterns in science within Europe: The standpoint of small countries. *Scientometrics, 99*, 845–863.

Wagner, C. S. (2005). Six case studies of international collaboration in science. *Scientometrics, 62*(3), 3–26.

Wagner, C. S., Whetsell, T., Baas, J., & Jonkers, K. (2018). Openness and impact of leading scientific countries. *Frontiers in Research Metrics and Analytics, 3*, 10.

Waltman, L. (2016). A review of the literature on citation impact indicators. *Journal of informetrics, 10*, 365–391.

Van der Meulen, B. (1998). Science policies as principal–agent games: Institutionalization and path dependency in the relation between government and science. *Research policy, 27*, 397–414.

Van Steen, J. (2012). Modes of public funding of research and development: Towards internationally comparable indicators.

Wang, E. C., & Huang, W. (2007). Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach. *Research policy, 36*, 260–273.

Weinberg, A. M. (1961). Impact of large-scale science on the United States. *Science, 134*, 161–164.

Wentz, R. (2002). Visibility of research: FUTON bias. *The Lancet, 360*, 1256.

Wilcox, R. R. (2011). *Introduction to robust estimation and hypothesis testing.* Academic press.

Vincenzi, M., & Shore, B. (2019). Managing membership in large-scale international science projects. *Technology in Society, 59*, 101129.

Woldegiyorgis, A. A., Proctor, D., & de Wit, H. (2018). Internationalization of research: Key considerations and concerns. *Journal of Studies in International Education, 22*, 161–176.

Woodley of Menie, M., Figueredo, A., & Sarraf, M. (2019). Slowing life history (K) can account for increasing micro-innovation rates and GDP growth, but not macro-innovation rates, which declined following the end of the Industrial Revolution. *Behavioral and Brain Sciences, 42*.

SUMMARY IN ESTONIAN

Eesti teadussüsteemi rahvusvahelistumine bibliomeetriliste näitajate vaatenurgast: kriitika ja poliitilised soovitused

Antud töö kontekstis vaadatakse teaduse mõjukust (*citation impact*) bibliomeetria vaatenurgast, mis tõlgendab mõju läbi teadustöö kogutud viidete arvu. Valitud uurimisteema peamiseks motiiviks on välja selgitada, kas rahvusvahelistumine võib olla Eesti teaduse „pusle“ põhjuseks – järsk tõus Eesti teaduse mõjukuses aastatel 2008–2018. Taolist järsku mõjukuse suurenemist madala teadus- ja arendustegevuse rahastamise taustal on nimetatud „pusleks“, kuna suurenemise taga olevad tegurid on teadmata (Lauk & Allik, 2018). Eesti teaduse kõrget mõjukust on kajastatud kohalikes ajalehtedes ning see on pälvinud ka ülemaailmset tähelepanu, leides kajastust mainekas teadusajakirjas Nature (2019).

Schiermeieri (2019) Nature'is avaldatud hinnangul näitavad Eesti märkimisväärsed teaduslikud saavutused, kuidas väike rahvas saab kiiresti muuta oma teadusmaastikku läbi rahvusvahelise toe ja tõhusate riiklike strateegiate ning olla seeläbi eeskujuks teistele.

Üheks võimalikuks „pusle“ tükiks võib olla rahvusvahelistumine – rahvusvaheline koostöö, rahastus ja osalemine transnatsionaalselt koordineeritud uurimistöös (rahvusvahelistes konsortsiumites). Kui rahvusvahelistumine on ootamatu mõjukuse tõusu taga, siis mida see tähendab teaduspoliitika seisukohalt teadlaste, rühmade ja riigi jaoks?

Käesoleva dissertatsiooni eesmärk on anda ülevaade teaduse rahvusvahelistumisest bibliomeetriliselt mõõdetavate väljundite kontekstis, rõhuasetusega väiksematel riikidel.

Eesmärgi täitmiseks on formuleeritud järgmine uurimisküsimus koos alamküsimustega:

- **Kuidas mõjutab teadussüsteemi suurus, koostööviisid, rahastamise tase ja meetod bibliomeetrilist väljundit?**

Alamküsimused:

- Kuidas mõjutavad uurimiskonsortsiumid ja rahvusvaheline koostöö Eesti teaduse mõjukust?
- Kas rahvusvaheline koostöö koos välisrahastusallikatega maksimeerib Eesti teaduse mõjukust?

Töö sissejuhatuses tuuakse välja uurimisküsimuste uudsus ja antakse ülevaade eesmärkide saavutamiseks ette võetud ülesannetest. Teoreetiline ja empiiriline taust on esitatud peatükkides üks ja kaks, luues aluse uurimiskonteksti mõistmiseks. Kolmas peatükk kirjeldab uuringutes kasutatud meetodeid ja valimit. Neljas peatükk koosneb dissertatsiooni raames läbi viidud empiirilistest uuringutest, mis annavad vastuseid esitatud küsimustele. Viies peatükk hõlmab endas arutelu uuringu tulemuste üle ning annab poliitikasoovitusi. Dissertatsioon lõpeb tuues välja piirangud ja uued potentsiaalsed uurimissuunad.

Dissertatsiooni raames avaldatud teadusartiklid:

1. **Hirv, T.** (2022). The interplay of the size of the research system, ways of collaboration, level, and method of funding in determining bibliometric outputs. Scientometrics, 127(3), 1295–1316.
2. **Hirv, T**. (2019). Research consortia determine a significant part of the bibliometric visibility of Estonian science. Trames, 23(3), 287–308.
3. **Hirv, T**. (2018). Effects of European Union Funding and International Collaboration on Estonian Scientific Impact. J. Sci. Res., 7(3), 181–188.

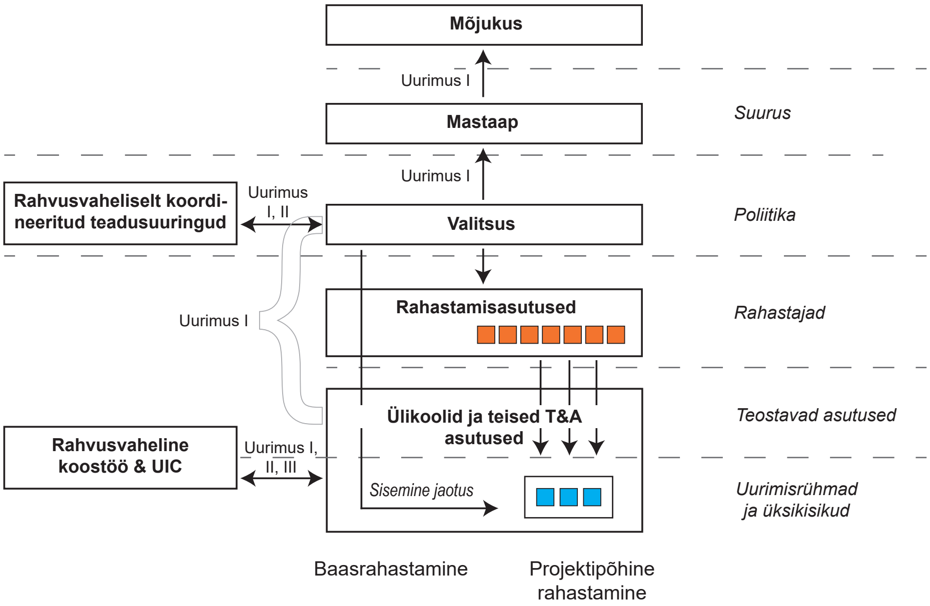
Kõik kolm dissertatsiooni raames läbi viidud uurimust panustavad teadusökonoomika kirjandusse, igaüks neist on seotud konkreetsete avaliku uurimissüsteemi aspektidega ning täiendavad üksteist teaduse tootmise ja rahvusvahelistumise mõistmisel. Uurimus I annab vastuse põhiküsimusele ja uurimused II ja III keskenduvad selle alamküsimustele.

Kolme uurimuse süstemaatiliseks ühendamiseks kasutati kohandatud Lepori (2011) avaliku uurimissüsteemi mudelit, nagu on kujutatud joonisel 1.

Joonis annab ülevaate teadussüsteemist, eristades ühte ettekujutuslikku ja nelja organisatsioonilist kihti – suurus, poliitika, rahastajad, teostavad asutused ning uurimisrühmad/üksikisikud – ning kahte peamist raha jaotusmeetodit – baasfinantseerimine uurimisorganisatsioonidele ja projektipõhine finantseerimine uurimisrühmadele.

Võrreldes algse kujundusega asetati „Mõjukus“ joonise tippu, kujutades valitsuse juhitavas uurimissüsteemis tekkinud uurimismõju. Lähtudes Thorsteinsdóttiri (2000) seisukohast, et avalikult rahastatud teadustöös on uurimissüsteemi suurus oluline, lisati „Mõjukuse“ ning „Poliitika“ vahele ettekujutuslik kiht „Mastaap“ (*return to size*), mis võib potentsiaalselt suurendada uurimissüsteemist tulevat uurimismõju. Mõistet mastaap kasutati samatähenduslikult skaleeritavusega (*returns to scale*) nagu on välja pakkunud Abramo et al. (2012, p. 706). Lisatud on ka valitsuse otsus osaleda rahvusvaheliselt koordineeritud uurimistöös nagu näiteks CERN (European Organization for Nuclear Research) ning organisatsioonide ja uurimisrühmade võimalus teha koostööd rahvusvaheliselt või erasektoriga (ettevõtete-ülikoolide koostöö ehk UIC – *university-industry-collaboartion*).

Uurimus I keskendub kõikidele joonisel näidatud ühenduspunktidele. See hõlmab nii mastaabi potentsiaalset mõju, rahvusvaheliselt koordineeritud uurimistöös osalemist, rahastamise taset ja meetodit (baasfinantseerimine vs projektipõhine rahastamine) ning seda, kas teadusasutused teevad koostööd rahvusvaheliselt ja/või ettevõtetega. Uurimus II keskendub riikidevaheliselt koordineeritud uurimisprojektide ja rahvusvahelise koostöö mõjule ning Uuring III keskendub rahvusvahelisele koostööle ja rahastamisallikatele.



Joonis 1. Kontseptuaalne raamistik – ülevaade avalikust uurimissüsteemist
Allikas: autori koostatud Lepori (2011) mudeli põhjal

Dissertatsioon tugineb uurimisküsimustele vastamisel Clarivate Plc (varasemalt tuntud kui Clarivate Analytics ja Thomson Reuters) bibliomeetrilistele andmetele. Clarivate Plc hallatav InCites on kohandatav uurimisanalüüsi platvorm, mis võimaldab kasutajatel analüüsida individuaalset, institutsionaalset ja riiklikku bibliomeetrilist tulemuslikkust ning seda võrrelda rahvusvaheliselt (Clarivate Analytics, 2018). InCites'i andmed pärinevad Web of Science'i Core Collectionist, mis on üks levinumaid andmebaase bibliomeetriliste uuringute jaoks (Falagas et al., 2008; Aghaei Chadegani et al., 2013; Mongeon & Paul-Hus, 2016).

Tabel 1. *Ülevaade uurimisülesannetest, andmeallikatest ja kasutatud meetoditest*

Uurimus	Ülesanded	Andmed	Meetod
I	Uurida seost teadussüsteemi suuruse ja teadustöö mõjukuse vahel.	Web of Science, Eurostat, Euroopa Komisjon	Korreleeritud juhuslike efektidega regressioonmudel
	Uurida rahvusvaheliselt koordineeritud teadusuuringute mõju riikide teaduse mõjukusele.		
	Uurida baasrahastuse ja projektipõhise rahastamise mõju avaldatud teadusartiklite arvule ja nende mõjukusele.		
	Uurida ülikoolide-ettevõtete koostöö mõju teaduse mõjukusele.		
	Välja tuua Euroopa riikide tugevad ja nõrgad küljed teadusuuringute mõju maksimeerimisel.		
II	Uurida riikidevaheliselt koordineeritud teadusuuringute seost Eesti teadusliku mõjukusega.	Web of Science	Kirjeldav statistika, sotsiaalvõrgustiku visualiseerimine
	Määrata kodumaise kui ka rahvusvahelise koostööga teadusartiklite kasv Eestis ja teistes sarnase geograafilise asukohaga riikides.		
	Võrrelda kodumaiste ja koostööuuringute mõju riikide teaduslikule mõjule.		
	Anda riikide lõikes ülevaade Eesti teadlaste koostööpartneritest.		
	Anda ülevaade enim rahvusvahelisest koostööst kasu saanud uurimisvaldkondadest.		
III	Uurida seost ELi rahastamise ja teaduse mõjukuse vahel.	Web of Science	Kirjeldav statistika, otsustuspuu, tavaline vähimruutude meetod, Probiti regressioon
	Uurida ELi rahastamise ja rahvusvahelise koostöö sünergilist mõju teadustöö mõjukusele.		

UURIMUS I

Arutlusel olnud teemasid nagu suurus, rahastamise tase ja rahastamisskeem ei ole varasemad uuringud käsitlenud üheaegselt vaid eraldiseisvate küsimustena. Uurimus I on esimene samm integratsiooni suunas kombineerides tegureid süstemaatiliselt kasutades autori mugandatud Lepori (2011) teaduse avaliku rahastamise teoreetilist raamistikku.

Uurimusest selgub, et riigi teadussüsteemi suurus ei mõjuta teadusartiklite ning saadud viidete arvu. Seega lükati ümber esitatud hüpotees, mis väitis, et teadussüsteemi suurus on seotud tehtava teaduse mõjukusega. See on üllatav, sest rahvusvaheline koostöö korreleerub 0.72 teadustöö mõjukusega ja -0.33 teadussüsteemi suurusega.

Teiseks kinnitas uurimus Musta (2014) kahtlusi, et transnatsionaalselt koordineeritud teadustöö ei mõjuta ainult väikese teadustöö produktiivsusega riike. Uurimusest I selgub, et riigid, mis kulutavad absoluutarvudes enim riikidevaheliselt organiseeritud teadusele, toodavad rohkem massautorlusega töid, kuid samal ajal moodustavad need tööd väiksema osa avaldatud teaduspublikatsioonidest. Seetõttu mõjutab nn. massautorluse fenomen enim väiksemaid riike, kellel on proportsionaalselt rohkem taolisi artikleid kui suurtel teadusriikidel. See on viinud olukorrani, kus teadusliku mõju ja riikidevahelise koostöö suundumuste uurimine üksnes autorluse andmete põhjal on muutunud bibliomeetrikute jaoks palju keerulisemaks. Näiteks uurimuses näidatud massautorluse fenomen selgitab, miks väikeriigid nagu Eesti, Küpros või Island edestavad viidete arvus artikli kohta suuremaid teadusriike.

Kolmandaks leitakse uurimuses, et mitte ainult rahastamise maht, vaid ka rahastamise viis on oluline teadustöö mõjukust määrav tegur. Üllatuslikult on projektipõhise rahastamise osakaalul U-kujuline seos viidete arvuga artikli kohta. Seda võib seletada Matteuse efektiga – neile, kel on, antakse juurde. Varasemalt on leitud, et rahastamise killustatus avaldab negatiivset mõju teaduslikule tasemele (Mali et al., 2017). Keskmisest suurema mõjukusega riikides on teadustöö koondunud vähestesse eliitasutustesse (Prathap, 2017). Kõrge projektipõhise rahastuse tingimustes võivad silmapaistvamad uurimisgrupid eliitasutustes saada Matteuse efekti tõttu samas mahus raha uuringuteks kui kõrge baasrahastuse korral.

Neljandaks, ettevõtete ja ülikoolide koostöö on oluline tegur teaduse mõjukuse suurendamisel. Selle põhjuseks võib olla, et rakenduslik fookus suurendab uurimuse aktuaalsust, muutes tõenäolisemaks, et sellele viitab suurem arv osapooli.

Uurimuse viimase faasina koostati kokkuvõtlik nimekiri milliste karakteristikutega riikidel läheb hästi teaduse mõjukuse maksimeerimisel ja kus teised maha jäävad. Näiteks EL-13 riigid on teadus- ja arendustegevuse väheste kulutuste tõttu väga ebasoodsas olukorras, kuid on ka muid tegureid, milles nad peavad järele jõudma. Ettevõtete-ülikoolide koostöö on levinum kõrge elatustaseme ning suurte teadus- ja arendusinvesteeringutega riikides, näiteks Skandinaavia riigid, Šveits ja Belgia. Mikroriigid teevad rohkem rahvusvahelist koostööd, sh.

rahvusvahelistes konsortsiumites, kui suuremad riigid. Ainult üksikud riigid eelistasid selgelt institutsionaalset (Malta, Itaalia) või projektipõhist rahastamist (Läti ja Eesti).

UURIMUS II

Uurimus II on Eesti juhtumuuring, mis keskendub konsortsiumidele ja rahvusvahelisele koostööle. Uurimus toob välja, et rahvusvahelised konsortsiumid mõjutavad oluliselt Eesti teadusuuringute mõjukust. See on ka Eesti teaduse „pusle“ kõige suurem osa. Rahvusvahelistes konsortsiumides osalemine toob kaasa märkimisväärse autorite arvu kasvu ning normaliseeritud viidatavuse mitmekordistumise. See ilmestab, kuidas rahvusvaheliselt koordineeritud teadusuuringud märkimisväärselt mõjutavad väikse uurimissüsteemiga riikide viidatavust, toetades eelmise uurimuse tulemusi (uurimus I).

Vastavalt Web of Science’i (WoS) andmetele, tuleneb suurem osa massautorlusega artiklitest (mis hõlmavad rohkem kui 16 autorit) konsortsiumide raames tehtud koostööst. CERN on selles esikohal 423 artikliga, järgneb IDEFICS CONSORTIUM 62 ning EUROPEAN MALE AGEING STUDY GRP 48 artikliga.

Uuring leiab, et massiivsed rahvusvahelised konsortsiumid mõjutavad oluliselt riikide teadusliku mõjukuse pingerida. Väiksemate uurimissüsteemidega riikide puhul toimuvad massautorluse arvesse võtmisel märkimisväärsed muutused pingereas paiknemisel. Näiteks langeb Island mõjukuses esimeselt kaheteistkümnendale, Peruu kuuendalt kolmekümnendale ning Eesti kaheteistkümnendalt kolmekümne esimesele kohale.

Massautorluse fenomen mõjutab erinevaid uurimisvaldkondi erineval määral. Näiteks molekulaarbioloogias ja geneetikas moodustavad kuni kuueteist kaasautoriga artiklite viited ainult 16% kõigist saadud viidetest. Sellele järgnevad füüsika 27% ja kliiniline meditsiin 30%. Oluline on märkida, et välja toodud uurimisvaldkonnad olid ka kõrgeima teadusliku mõjuga Lauk ja Allik (2018) uurimuses.

Uurimuse teine osa arvas välja massautorlusega publikatsioonid ning tuvastas proportsionaalse seose riikide kodumaiste ja rahvusvahelise koostööpublikatsioonide viitamismäärade vahel. Riikide kodumaiste publikatsioonide viitamise suurenemisel suureneb ka rahvusvahelises koostöös valminud publikatsioonide viitamine, mis on kooskõlas Beckmanni (1993, pp. 12–13) teoreetilise koostöö mudeliga.

Aastal 2005 moodustas ilma massautorluseta rahvusvaheliste koostööartiklite osakaal Eesti publikatsioonidest 50%. Sellest alates on rahvusvaheline koostöö Eestis muutunud domineerivamaks. Siseriiklikud publikatsioonid kasvasid vaatlusperioodil (2008–2015) aastas 5,2 protsenti võrreldes koostööpublikatsioonidega, mille kasv oli 9,3. Eesti teeb rohkem rahvusvaheliselt koostööd kui EL-15 territoorium ning see aitab neile teaduse mõjukuses järele jõuda.

Eesti peamised koostööpartnerid pole oluliselt muutunud võrreldes 90ndatega (Lewison & Must, 2001). Eesti teeb jätkuvalt enim koostööd Soome, Rootsi, Ameerika Ühendriikide, Saksamaa ja Ühendkuningriigiga. Sotsiaalvõrgustiku visualiseerimine näitab, et enim viidatud artiklid hõlmavad koostööd teadlastega väga kõrge teadusliku mõjuga riikidest. Koostöö Venemaa, Ukraina, Leedu ja Lätiga pole mõjutanud Eesti mõjukust nii palju kui koostöö teaduslikult arenenumate riikidega. Lisaks leiti, et partnerlused, mis hõlmavad laiemat riikide arvu, toovad endaga kaasa kõrgema viidete hulga. Eesti peamisteks koostööpartneriteks olevad riigid on sotsiaalvõrgustikus keskmeteks, mille ümber on teised osalised koondunud.

Rahvusvaheline koostöö esineb 72% immunoloogia ning 69% molekulaarbioloogia ja geneetika teadusartiklites. Kõige madalam rahvusvahelise koostööga artiklite osakaal on matemaatikas (32%), millele järgneb majandus ja äri (28%).

Kosmoseteadused saavad rahvusvahelistumisest kõige suuremat kasu ning seal on 29 protsendipunktine erinevus rahvusvaheliste ja kodumaiste artiklite viidatavuses. Kosmoseteadustele järgnevad immunoloogia 21 ja psühhiaatria/psühholoogia 19 protsendipunktiga.

UURIMUS III

Uurimus III keskendus Euroopa Liidu rahastuse mõjule Eesti teadustöös. Uurimuse panus seisneb rahastuse tüüpide ja rahvusvahelise koostöö mõju eristamises. Tulemused näitavad, et Alliku (2015) välja toodud 54% viidatavuse kasv aastatel 2007 kuni 2014 oli osaliselt tingitud ELi (Euroopa Liit) rahastusest. Artiklid, mis olid rahastatud EList, on suurema viidatavusega, valminud kõrgema tõenäosusega rahvusvahelise koostöö tulemusel, on kõrgema autorite arvuga ning avaldatud kõrgema mõjufaktoriga ajakirjades kui need, mis on saanud ainult riiklikku rahastust.

ELi rahastuse mõju oli eriti selgelt märgatav loodusteadustes, kus ELi ja avaliku sektori koosrahastatud publikatsioonid said märkimisväärselt rohkem viiteid kui need, mis olid rahastatud üksnes avaliku sektori vahenditest. Teiseks ja kõige olulisemalt näitas uurimus, et kõige viidatuimad teadusuuringud valmivad ELi rahastuse ja rahvusvahelise koostöö kombinatsioonist. Need leiud näitavad, et EL aitab saavutada Eesti teadlastel paremaid tulemusi rahvusvahelises koostöös kui muidu võimalik.

On üllatav, et tehnika ja inseneriteaduste valdkonnas ei ilmnenud ELi rahastuse positiivset mõju. Lisaks ei mõjutanud rahvusvaheline koostöö selle uurimisvaldkonna teaduslikku mõjukust. Üks võimalik seletus on, et uurimus ei hõlmanud konverentsi ettekandeid ega raamatute peatükke, mis võis tulemusi mõjutada.

POLIITIKASOOVITUSED

Eesti peaks jätkama osalemist riikide vaheliselt koordineeritud teadustöös, et pääseda ligi kõrgetasemelisele teadustaristule ja ekspertteadmistele. Taolised algatused leevendavad rahalist koormust ja aitavad viia uurimisvaldkondade tugevused kooskõlla riiklike strateegiatega. Nendes pidev osalemine aitab pikemas perspektiivis kaasa teadusliku taseme suurendamisele, rahvusvahelise maine tõusule ja jätkusuutlike võrgustike loomisele.

Rahvusvaheliselt koordineeritud teadustöö toob bibliomeetrikutele kaasa katsumuse teadustöö mõjukuse hindamisel. Väikese uurimissüsteemiga riikide puhul võib valesti valitud metoodika anda ebarealistliku kirjelduse teadussüsteemi mõjukusest. Tuleb olla teadlik massautorluse mõjust ja valida või kohandada vastavalt publitseerimisega seotud teadus- ja arendustegevuse näitajate kogumise metoodikat. Kuigi rahvusvaheliselt koordineeritud uurimistöö suurendab märkimisväärselt teaduse mõjukust, peaksid poliitikakujundajad meeles pidama, et suurem osa sellest on näiline.

Rahvusvaheliselt koordineeritud uurimisprojektide publikatsioone peetakse „teaduse moonutuseks“ kõrge kaasautorite arvu tõttu, mis ulatub sageli tuhandetesse (Thelwall, 2020; Cronin, 2001). Arvatakse, et 50 või 100 uurijat ei saa olla kirjutanud, toimetanud ja heaks kiitnud lõplikku visandit (Cronin, 2001). Kõige enam kasutatavad andmebaasid nagu Web of Science (WoS), Google Scholar ja Scopus ei murdosasta publikatsioone (*fractional counting),* mis tähendab, et kõik autorid saavad andmebaasis kirja artikli selle täies mahus, vaatamata kõrgele autorite arvule. See võib viia valede järeldusteni teadusliku võimekuse hindamises nagu näiteks Eesti väga kõrge koht bibliomeetrilistes pingeridades.

Ühtlasema vaate saamiseks peaksid poliitikakujundajad ja sõltumatud bibliomeetrikud, kes koostavad pingeridu, tegema koostööd ning koordineerima üldised põhimõtteid, kuidas mõõta teaduslikku mõju. Vastasel korral saadetakse avalikkusele valesid signaale riigi teadusliku võimekuse kohta. Hea näide sellest on bibliomeetrikute kaks hiljutist uudisartiklit Postimehes, kus esimene artikkel (Allik & Lauk, 2023a) näitas, et viimase 11 aasta jooksul avaldatud tööde põhjal on Eesti saanud teaduse mõjukuses maailma neljandaks riigiks. Teine artikkel (Allik & Lauk, 2023b) väitis, et mõjukuse poolest on Tartu Ülikool ees kõikidest Põhjamaade ülikoolidest. European Innvovation Scoreboardi tulemused, mida Haridus- ja Teadusministeerium (2022) kasutab riiklikus teadus- ja arendustegevuse strateegias, erinevad oluliselt sõltumatute ekspertide poolt avalikkusele esitatust. Scoreboardi (2023) kohaselt on Eesti teaduse mõjukus ligikaudu 83% Euroopa Liidu keskmisest.

Soovitusena võiks Eestit käsitlevad bibliomeetrilised pingeread järgida Riigikogu poolt heaks kiidetud Eesti teadus- ja arendustegevuse asutuste baasfinantseerimise korda (2020). Seal on öeldud, et artiklid, millel on üle 100 autori, arvestatakse koefitsiendiga 0.5 ja artiklid, millel on üle 1000 autori, koefitsiendiga 0.3. On vaieldav, kas need koefitsiendid on optimaalsed, kuid see oleks paremini kooskõlas riiklikus strateegias kasutatava European Innovation Scoreboardi mõõdikuga kui praegune praktika.

Massautorluse levik sunnib Eesti Teadusagentuuri grantide taotlejate bibliomeetriliste ülevaadete koostamise praktikat üle vaatama. Uurimisprojektide rahastamise taotluste hindamise protsessi käigus on laialdaselt levinud, et hinnatakse mitte ainult projekti sisu, vaid võtavad arvesse ka taotleja varasemaid tulemusi (Latour & Woolgar, 1979; García & Sanz-Menéndez, 2005). Sellest tulenvalt kalduvad hindajad kasutama kaudseid näitajaid nagu viitamismäärad ja ajakirjade prestiiž, kus taotleja on varasemalt avaldanud.

Näiteks Eesti Teadusagentuur (2023) lisab iga taotleja kohta täiendavad bilbliomeetrilised andmed, mida saab ekspertpaneel ja hindamisnõukogu kasutada saamaks taotleja teadustegevusest põhjalikumat ülevaadet. Massautorluses publitseerivad taotlejad võivad saada eelise kui seda fenomeni ei võeta arvesse.

Selleks et jõuda järele teaduslikult arenenumatele riikidele, peab Eesti investeerima rohkem teadus- ja arendustegevusse (R&D). Koostöö toimimiseks peavad partnerid võrdväärselt panustama ning sellest tulenevalt võivad kõrged R&D kulutused koos rahvusvahelise koostööga olla efektiivne valem Eesti teaduse mõjukuse suurendamiseks.

Poliitikakujundajad peaksid jätkuvalt tunnustama ELi rahastamise ainulaadset olemust koostöömehhanismina ja julgustama teadlasi aktiivselt osalema. Euroopa Liidu rahastus toimib vahendajana, võimaldades Eesti teadlastel kergemini pääseda ligi rahvusvahelistele võrgustikele ja ressurssidele kui see muidu võimalik oleks. Julgustades ELi koostööd, saavad poliitikakujundajad aidata kaasa keskkonna säilitamisele ja parandamisele, kus Eesti teadlased saavad täielikult ära kasutada rahvusvahelise koostöö eeliseid. See omakorda tõstab riigi teaduslikku pädevust ja soodustab oluliste ühiskondlike väljakutsete lahendamist.

Kuigi ettevõtete-ülikoolide koostöö on seotud kõrgema teadusmõjuga, käib see käsikäes majandusstruktuuriga ja seda ei saa poliitika abil lühikeses perspektiivis muuta. Vähem arenenud riigid jõuavad ettevõtete-ülikoolide koostöös järele, kui majandusstruktuur on piisavalt arenenud teadmispõhisemaks majanduseks.

Kuigi selge baasfinantseerimise või projektipõhise rahastuse eelistamine seostub kõrgema teaduse mõjukusega, ei pruugi see olla kõige parem variant pikemas perspektiivis. Siinkohal on oluline rõhutada, et tasakaalustatud rahastamisstrateegia on näidanud madalamat viidete arvu, kuid selle mõju võib olla positiivne kultuurile, süsteemi jätkusuutlikkusele ja majandusele, mida siin ei käsitletud.

PIIRANGUD JA EDASISED UURINGUD

Esitatud analüüs tunnistab piirangute olemasolu, kuid peab neid töö tulemusi silmas pidades ebaolulisteks. Tööd käsitletavad piirangud on järgmised:

- Taksonoomia muutus: mõiste „mõju“ on muutumas selle traditsioonilisest viitamisel põhinevast mõõtmisest, hakates hõlmama laiemaid ühiskondlikke aspekte nagu kultuur, majandus ja poliitika (Bornmann & Haunschild, 2017).

- Ajalise mõõtme puudus: bibliomeetriline lähenemine mõõdab innovaatilisust praeguste publikatsioonide ja viidete kaudu, arvestamata pikemaid ajalisi perioode ning makroinnovatsioonide arvu.
- Rahvusvahelised vs. riiklikud keskkonnad: jäi lahtiseks, millist kasu (kapital, oskusteave või mõlemad) saavad Eesti teadlased rahvusvahelisest koostööst. Veelgi enam, mil määral panevad need eelised teadlasi eirama kohaliku tähtsusega uurimisprobleeme, eelistades rahvusvahelisi, kus teemad meelitavad rohkem lugejaid (Lancho Barrantes et al., 2012).
- Andmete täielikkus: potentsiaalsed usaldusväärsusprobleemid, mis võivad tekkida ebapiisavatest andmetest. See võib soodustada loodus- ja inseneriteadusi sotsiaalteaduste ja humanitaarteaduste arvelt (Clarivate Plc, 2023).

Võimalike uute uurimisteemade ring on lai. Näiteks murdosalise loendamise mõju publikatsioonide arvule. On täheldatud, et Balti riikide teaduspublikatsioonide arv on ületanud ootusi arvestades nende piiratud ressursse (Allik, 2003). See on oluline teema, mida uurida, sest rahvusvahelistumine võib täieliku loendamise korral võimendada publikatsioonide arvu.

Teiseks, ELi struktuurifonde on aastaid kasutatud infrastruktuuri parandamiseks, koostöövõrgustike loomiseks, palgatoetuseks ja mobiilsuse suurendamiseks. On oluline aru saada, kuidas neid fonde on kasutatud kategooriate lõikes, et mõista struktuurifondide mõju teaduse mõjukusele.

Lisaks eelmainitule oleks täiendavalt vaja uurida, kas Riigikogu poolt (2020) kehtestatud koefitsiendid 0.5 üle 100 ja 0.3 üle 1000 autoriga publikatsioonidele on sobilikud baasrahastuse määramisel. Arvestades massautorluse trendi kasvu võivad need olla liiga kõrged.

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