Participation in the programs of the European Space Agency: Micro- and meso-level effects and additionality
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LIST OF AUTHOR’S PUBLICATIONS AND CONFERENCE PRESENTATIONS

I. Articles in international journals

II. Conference publications

III. Conference presentations
INTRODUCTION

This thesis is based on three original papers listed below, which will hereinafter be referred to as Study 1, Study 2 and Study 3:


Motivation for the research

From the second half of the 20th century, large-scale collaborative efforts that involve shared scientific facilities and other resources have become crucial for the advanced research (Galison, 1992; OECD, 1995). This form of knowledge production is popularly known as 'Big Science' (Weinberg, 1967), clearly distinguishable from investigator-driven research usually performed at universities (Esparza and Yamada, 2007). Big Science projects and programs are undertaken for the production of knowledge located at the state-of-the-art frontier to accomplish a demanding, widely agreed scientific mission, facilitated by cutting-edge instruments and technologies (Jacob and Hallonsten, 2012). They stand out in terms of their unique size, complexity or duration, and require long-term governmental commitment, often through international co-operation (Elzinga, 2012). In Europe, among the best known and most studied examples of Big Science organisations are the European Organization for Nuclear Research (CERN) and the European Space Agency (ESA). However, this mode of research is not confined to nuclear physics and astronomy, it is becoming increasingly common in other branches of science (Meyer, 2009; Autio, 2014).

Deployment of Big Science to address problems of crucial social importance has been considered as a central element of mission-oriented innovation policies (Weinberg, 1967; Ergas, 1987). The mission paradigm of innovation policy assumes that the government sector should be engaged with research and development activities to propose workable solutions addressing the social challenges as public interests are not readily served by private research and development efforts (Bozeman, 2000). National mission-oriented innovation policies were particularly prevalent in the 1960s and 1970s (Mowery et al., 2010; Kattel and Mazzucato, 2018), 'long before innovation policy or even innovation became part of their [policy-makers'] standard vocabulary' (Edler and Fagerberg, 2017: p.5). A classic example of a mission-oriented program in this era is the Project Apollo. This centralised program was oriented to the achievement of a particular, well-defined technological objective, i.e. landing the first humans on the Moon. Public US Federal agency funded the program and was the main customer of its outputs (Nelson, 2011). Similarly, ESA was established by 10 European countries in 1975 (Cogen, 2012) to implement and coordinate European space programs in order to build space infrastructure carrying powerful instruments to advance space science (Bach et al., 2002). There is renewed scholarly interest in mission-oriented innovation policies targeted at present-day grand societal challenges (Mowery et al., 2010; Foray et al., 2012; Edler and Boon, 2018; Kuhlmann and Rip, 2018) to achieve transformative change (Weber and Rohracher, 2012; Schot and Steinmueller, 2018). The new mission-oriented policies are directed towards complex, multi-dimensional and systemic societal problems which also implies decentralised coordination of the policies (Wanzenböck et al., 2019). These aspects clearly differentiate new mission- and challenge-oriented policies from traditional technology- and government-led policies. In this wider context, traditional mission-oriented Big Science organisations such as ESA are under pressure to change and modernise in order to contribute to tackling the contemporary grand societal challenges (Robinson and Mazzucato, 2019).
According to the ESA Convention, one of the high-level objectives of ESA is to improve the global competitiveness of European aerospace industry. To achieve this objective, a complex procurement system has been shaped over the years to purchase products and technologies from the industry. ESA typically procures single products with superior specifications for successful space missions, preferably from companies located in the ESA member states (Petrou, 2008). Such purchases by the public agency correspond to the early definition of public procurement of innovation (PPI): “the purchase of a not-yet existing product or system whose design and production will require further, if not completely novel, technological development work” (Edquist and Hommen, 2000: p.5). It means that mission-oriented public organisations such as ESA constitute an important channel for PPI (Castelnovo and Florio, 2019).

PPI is a demand-side innovation policy instrument (Edler and Georgiou, 2007); it seeks to influence markets for innovative products or services. The capacity of public procurement to create new markets for products and technologies, to lower risks associated with innovative activity, and to provide a testing ground for innovative products has long been recognized by scholars (Rothwell, 1984, Geroski, 1990). Already Geroski (1990) argued that innovative public procurement is more effective than supply-side instruments, such as research and development (R&D) grants, in stimulating private innovation investments. More recent empirical studies confirm a positive effect of PPI on private expenditures in innovation activities (e.g. Guerzoni and Raiteri, 2015). PPI can take place at any level of governance – at the regional, national, or supranational level, or in combinations thereof in multi-level governance (Edler and Georgiou, 2007). The implementation of national space strategies in collaboration with ESA is an example of multi-level governance of PPI. By participating in various ESA programs, the ESA member states delegate the procurement function to the supranational level and provide respective budgetary means to the agency to perform the function.

Through public procurement of high-performance products and technologies, achievement of the specific high-end technological objectives leads to knowledge spillovers spurring industrial innovation (Chiang, 1991). Mazzucato (2013) underlines that many highly impactful innovations have emerged as the result of mission-oriented policies. For example, the internet, a general purpose technology thriving progress in many industrial sectors, is an offspring of the U.S. military R&D programs (Mowery et al., 2010) and the research carried out in CERN (Vuola and Hameri, 2006). Such knowledge spillovers have been extensively studied and quantified in case of mission-oriented space programs in the United States (an overview of early studies in Comstock (2010)) and in Europe (e.g. Cohendet, 1997). Since the early studies, the research on the use and usefulness of mission-oriented space programs as a source and catalyst of industrial innovation has expanded considerably. For example, smaller member states of ESA, such as Norway and Denmark, have reported significant firm-level effects from participation in ESA programs (Erme, 2016). The practical importance of knowledge spillovers from ESA programs is highlighted by the fact that altogether in ten ESA member states, the ministry overseeing issues related to ESA membership is the one in charge of economy, industry, and/or innovation (Adriaansen et al., 2015). This also suggests that the ESA membership is firmly placed among the innovation and economic policy instruments available to the governments of ESA member states.

Borrás and Edquist (2013) emphasise strong contextual nature of innovation policy instruments that affects the design and use of policy tools by policy-makers. The promise of substantial knowledge spillovers has been one of the drivers behind the eastward expansion of ESA, the process that took off in the 1990s. While some of the Central and Eastern European countries actively participated in a cooperative space program Intercosmos, launched in 1967 by the Soviet Union and abandoned in 1991, the number of companies involved in the European space industry value chains in these countries was close to zero when they first approached ESA with the intent to accede the organisation (Sagath et al., 2018). Therefore, ESA membership can be seen as a policy tool for (space) industry creation for these countries. At the same time, ESA membership grants access to the ESA procurement system to companies and research organisations located in a member state. The focal point of the complex industrial policy of ESA is the principle of equitable participation in ESA programs. It means that the financial volume of contracts between companies and research organisations located in a certain member state and ESA should be proportionate to the respective member state’s annual contribution to the ESA budget (Schmidt-Tedd, 2011). A modification of the equitable participation principle is also applied by
CERN (Åberg and Bengtson, 2015). The principle of equitable participation offers incentives to non-space companies in new ESA member states to spin in to the ESA procurement system in the hope of finding new use cases for their products and technologies or boosting their internationalization activities. There are a number of potential micro- (firm-) and meso- (industry-) level effects from the participation in ESA programs. It can be expected that mechanisms behind these effects may exhibit different patterns in case of an economy with limited activity of the conventional space industry, such as Estonia, compared to the countries with different industry structure, i.e. leading ESA members states with the strong presence of large system integrators of space industry (France, Germany, Italy) or mid-sized countries with long traditions in space domain (cf. Petroni et al., 2018), such as Belgium or Norway. However, scholarly studies of the effects from the participation in ESA programs have approached the topic from the perspective of the Big Science organisation itself. This thesis adopts the perspective of a small ESA member state without actors actively involved in the conventional space industry, such as Estonia, to study the micro- and meso- (industry-) level effects from ESA membership. Results of an inquiry into the mechanisms behind the effects enable to understand Big Science affiliation as an innovation policy tool in this distinctive context.

Aim and research tasks

The main aim of this thesis is to add to the current understanding of the nature of various micro- and meso-level effects that are induced by the participation in the programs of the European Space Agency and how these effects unfold in an economy. The thesis is based on three original research papers. Studies 1 and 2 focus on the firm-level effects that is various types of additionalities from doing business with ESA. Study 3 is also concerned with the meso-level effects, i.e. the role of ESA in multi-level institutional change processes that are connected to the market formation processes.

In order to accomplish the overall goal of the thesis, the following research tasks have been set:

- To delineate theory-based rationales for public funding to Big Science mode of knowledge production in different strands of innovation policy literature (Chapter 1.1).
- To provide an overview of usage of different types of additionalities in innovation policy evaluations, and connect the evaluation practices with the theory-based rationales for innovation policy interventions (Chapter 1.2).
- To identify research gaps with respect to the main objective of the thesis in order to raise specific research questions (Chapter 1.3).
- To conduct a meta-analysis of the current evaluation practices used in the country-wide studies on firm-level effects from the participation in the programs of the European Space Agency (Chapter 2).
- To provide a more fine-grained understanding of the internationalisation processes of ESA supplier firms and the role of ESA in market and marketing knowledge acquisition and assimilation (Chapter 2).
- To offer exploratory insights into the institutional dynamics associated with the introduction of ESA as the innovation intermediary to the nascent market of Earth Observation solutions (Chapter 2).
- To discuss empirical results of the three studies and highlight the theoretical contributions from completing the previous research tasks (Chapters 3.1 and 3.2).

Novelty of the thesis

The thesis is based on three research papers that study different aspects related to micro- and meso-level effects from the participation in the programs of ESA, which is one of the most widely known Big Science organisations. The empirical studies are rather heterogeneous in terms of the research gaps that were addressed, theoretical background, and applied research methods. Study 1 is positioned in the literature on evaluations of innovation policy instruments, more specifically evaluations of the ESA
membership from the viewpoint of a small open economy. Study 2 contributes to the international entrepreneurship and international marketing literature, while Study 3 applies the rapidly evolving conceptual framework in the marketing theory – service-dominant logic – to study endogenous institutional change in the emerging service ecosystem. These different theoretical lenses enable to provide new insights into the subject of the thesis, which is the firm- and industry-level effects from membership in Big Science, a new innovation policy tool in the Central and Eastern Europe. In the following paragraphs, the novelty of the research will be discussed against both respective theoretical backgrounds and the extant literature on evaluations of the public investments to international space programs.

International organisations, such as the Organisation for Economic Co-operation and Development, have provided analytical frameworks and methodological guidelines for collecting data on space economy and measuring the impacts of public space programs (e.g. OECD, 2011; OECD, 2012). Also, progress has been made with delineating the full range of economic and social effects from the space programs (e.g. Clark et al., 2014). Despite these efforts, there was still lack of knowledge about the methodological foundations of different country-wide impact assessments that measured firm-level additionalities of public investments to space programs. In case of small and mid-sized European countries, these investments are largely associated with the programs of ESA that funnel the financial payments of ESA member states to the programs to purchase innovative products and services from firms (Petroni et al., 2018). By conducting a meta-analysis of the existing body of academic and grey literature, Study 1 addressed this gap by highlighting the key underpinnings of the existing methodological approaches, identifying various methodological caveats for measuring the firm-level impacts, and discussing issues related to comparability of the existing impact assessments.

Study 2 contributes to the theory on the internationalisation process of the firm investigating the topic from the perspective of resource-constrained companies which are working with new-to-the-world technologies. Two schools of thought have dominated the academic debates on the internationalisation process of the firm. Early theories on the internationalisation process of the firm explained it as being driven by an active but incremental collection of knowledge from preselected markets (Johanson and Vahlne, 1977). Two decades later, research on international new ventures suggested that the process was not accelerated by knowledge created during the process but rather by the active utilisation of knowledge already possessed by key actors before a company’s inception (Oviatt and McDougall, 1994; Knight and Cavusgil, 2004). However, both literature streams assume that internationalising companies hold proprietary assets (including products or technologies) prior to entering foreign markets. Recently, this premise has been questioned (Hewerdine et al., 2014; Kriz and Welch, 2018) with a proposition that internationalisation of small knowledge-intensive firms is driven by constant need for financial and knowledge resources for R&D. Connecting to this emerging literature strand, Study 2 challenges the underlying assumptions of the existing theories on the internationalisation process of the firm. It seeks for a deeper understanding of the role of knowledge acquisition in the non-linear and irregular internationalisation process of resource-constrained companies and how this newly acquired knowledge can be used in exploring and exploiting opportunities in international markets. The study examines how knowledge-intensive firms capitalise on the collaboration with Big Science that offers them an opportunity for acquiring and leveraging knowledge resources.

In the context of Big Science organisations, the extant literature has focused predominantly on various aspects related to technological knowledge, looking at Big Science as a unique environment for inter-organisational learning that is supportive to the development of innovative products and technologies with superior characteristics (Autio et al., 2004) and a source of novel technologies for a wide range of applications (e.g. Byckling et al., 2000; Szalai et al., 2012). Despite acknowledging the collaboration with Big Science as a highly valuable marketing reference (Cohendet, 1997; Florio et al., 2018) and a driving force in the evolution of the business networks (Bach et al., 2002) for their suppliers, there are no studies concentrating on the internationalisation processes of Big Science supplier firms and the role of Big Science, or more specifically ESA, in market and marketing knowledge acquisition and assimilation. Study 2 aimed at addressing this research gap.
Study 3 contributes to the three streams of literature. The paper adopts the service-dominant logic perspective (Vargo and Lusch, 2004; Vargo and Lusch, 2008), which foundational premises postulate that value co-creation is coordinated through actor-generated institutions and institutional arrangements (Vargo and Lusch, 2016). Empirical studies on how actors in service ecosystems challenge prevailing institutional order and are engaged with deliberate actions that lead to institutional change are scarce (e.g. Kleinaltenkamp et al., 2018). Study 3 responds to the calls for more studies to gain better understanding on how changes in micro-level institutions, i.e. at the level of individual actors, endogenously evolve into multi-level shifts within overall service ecosystems.

Study 3 also connects to the theoretical and empirical research on public procurement of innovation. This growing research stream has mostly dealt with the rationales for using public procurement to promote innovation (e.g. Chicot and Matt, 2018) and PPI’s innovation impacts (e.g. Uyarra and Flanagan, 2010), also barriers associated with the implementation of PPI hindering the realization of the impacts (e.g. Uyarra et al., 2014). Rolfstam (2009, 2012) has investigated the role of institutions in PPI and interplay between institutions and innovation outcomes from PPI relying on multi-level institutional analysis. While he discussed micro-level institutions, which evolve within organisations and may change as a result of organisational learning, he downplayed entrepreneurial efforts to reshape the institutional order. Study 3 sets the focus on this overlooked aspect. Also, Uyarra et al. (2017) argued that the extant literature neglects the multi-level dimensions of PPI. Study 3 seeks to address this research gap by identifying additionalities from procuring innovations at the supranational level instead of the national level.

Institutional aspects have recently been addressed in space studies by Wong et al. (2018) and Sagath (2019), who applied the institutional logic perspective (cf. Thornton and Ocasio, 2008) to study how sectoral institutional logics in the space domain enable and constrain entrepreneurial action. As space industry development in mid-sized countries, such as Austria and the Netherlands, largely resides in the hands of ESA (Petroni et al., 2018), then participation in ESA programs transforms the identities of organisations. Various existing stable institutional logics affect the space actors’ behavior. While acknowledging the dynamic nature of the institutions and the role of entrepreneurial behavior in changing the institutional order, the focus of these contributions was rather narrow as the researchers mainly dealt with the embeddedness of firms within prevailing institutional logics. Study 3 adds more dynamic perspective to these works by highlighting the role of institutional entrepreneurship in the absence of stable institutional logics.

The three studies combined contribute to the literature on the evaluations of innovation policy instruments. Study 1 reveals potential problems with data quality in survey-based impact assessments when the total number of beneficiaries of the evaluated innovation policy instrument is low and stable over time. The data quality issues may result in biased estimates of input and output additionality of the policy instrument, thus undermining the value of such concepts in ex ante and ex post evaluations. Interdisciplinary qualitative Studies 2 and 3 illuminate processes that lead to the persistent changes in behaviour of the suppliers to Big Science. This knowledge regarding various impact channels of micro- and meso-level behavioural additionality could be used for elaborating new approaches to the evaluation of demand-side instruments that would encompass a full range of theoretical rationales behind policy intervention.

**Structure of the thesis**

This thesis is structured into three chapters. The first chapter provides a theoretical framework for studying the membership in international Big Science, such as ESA, as an innovation policy tool. The Chapter 1 is further divided into four sub-chapters. The first sub-chapter establishes the connections between theory-based policy rationales in three main framings of innovation policy and the role of Big Science mode of knowledge production in addressing market-, system- and transformative failures pinpointed in these framings. The second sub-chapter discusses the use of input-, output-, and behavioural additionality in evaluations of innovation policy instruments and discusses various approaches to assess the impacts of Big Science organisations focusing on the firm- and industry-level
effects. The third sub-chapter poses the research questions based on the gaps identified in the literature. Finally, the fourth sub-chapter describes the research methods and data used in the thesis.

The second part of the thesis presents three empirical studies, which deal with different aspects of the micro- and meso-level effects from participating in the programs of ESA from the perspective of a country that recently acceded the organisation but is characterised by limited presence in the European space industry value chains (Figure 1). Study 1 is a systematic review of the extant country-level studies on public investments to ESA programmes. Study 2 studies the internationalisation processes of ESA supplier firms and the role of ESA in market and marketing knowledge acquisition and assimilation. Study 3 looks into the institutional change processes linked to the transfer of the innovation procurement function from the national level to the hands of the international organisation – ESA.

![Figure 1. Positioning of the three empirical studies with respect to the studied phenomena (compiled by the author)](image)

The third chapter is composed of four sub-chapter. The first sub-chapter highlights the main empirical findings of the three studies. The main conclusions and theoretical contributions that are drawn from the empirical work are outlined in the following sub-chapter. This thesis emphasises the practical utility of the research results. Therefore, the implications for policy-makers and managers of companies are discussed in the third sub-chapter. The thesis is wrapped up by delineating the limitations of the research and proposing avenues for further research.

**Contributions of individual authors**

Study 1 was authored by Tõnis Eerme.

Studies 2 and 3 were co-authored with Professor Niina Nummela. However, the author of this thesis is the main author of both studies, identifying research gaps and proposing the overall study design to
address the research gaps. In Study 2, the co-author wrote the theoretical part of the paper and contributed with the methodological guidance and improved the manuscript before and during the reviewing process. Tõnis Eerme was responsible for fieldwork for collecting data, data analysis, and writing respective parts of the manuscript.

In Study 3, the co-author mainly contributed with the methodological assistance. The author of the thesis was responsible for all other aspects of the research process and manuscript preparation.

The author is solely responsible for any errors or omissions in this thesis.

Acknowledgements
1. THEORETICAL BACKGROUND

1.1. Rationales for innovation policy intervention

The term ‘innovation policy’ emerged in scholarly debates relatively recently, from the late 1960s onwards (Fagerberg, 2017). However, this does not mean that policies affecting innovation did not exist before. Governments’ activities to promote the production, diffusion, and use of scientific and technical knowledge for economic growth were discussed under labels of ‘science policy’ and ‘technology policy’ before the surge of research on ‘innovation policy’ (Lundvall and Borràs, 2006). The term ‘innovation policy’ may be defined broadly as all policies that have an impact on innovation, or more narrowly as policies (or policy instruments) created with the intent to affect innovation (Edquist, 2004). The narrower definition understands innovation as the first occurrence of a new product, a service, or a process (Fagerberg, 2017). Science policy after the Second World War was based on a narrow understanding of the innovation process. It was guided by the linear model of innovation (cf. Godin, 2006 for historical evolution of the concept), which considered scientific breakthroughs as the starting point and main source of innovation. The broader definitions connect to the view that the ultimate objective of innovation policy is usually not innovation per se; these objectives may be environmental, social, related to health or security (Borràs and Edquist, 2013). Different definitions of ‘innovation policy’ reflect fundamentally different positions about the origins of innovation and its role in economic development, activities that are contributing to innovation, and actors who are actively involved in the innovation processes.

![Diagram of consecutive policy paradigms](image)

**Figure 2.** Consecutive policy paradigms layered upon but not fully replacing each other (based on Gassler et al. (2008) and Diercks et al. (2019)).

Hall (1993) defines a policy paradigm as „a framework of ideas and standards that specifies not only the goals of policy and the kind of instruments that can be used to attain them, but also the very nature of the problems they are meant to be addressing” (p. 279). The development of science, technology, and innovation policy domain since the 1950s has been characterised by shifting dominant paradigms. Diercks et al. (2019) distinguish between three main paradigms on grounds of the core understanding about the innovation process, policy objectives and policy rationales. These innovation policy paradigms are science and technology policy, which relies on the linear model of innovation and refers to market failures as the justification for intervention, innovation systems policy, and transformative innovation policy (Figure 2). Schot and Steinmueller (2018) avoid using the term 'paradigm’ in their paper but they similarly delineate three main 'framings’ that are aligned with the policy paradigms proposed by Diercks et al. (2019). Hekkert et al. (2020) speak of three generations of innovation policies,

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1 ‘Rationales’ are interpreted similarly to Laranja et al. (2008) as more or less formalised models implicitly or explicitly drawing upon academic theories or concepts that could inform policy design, implementation and evaluation.
while Grillitsch et al. (2019) label science and technology policy as innovation policy 1.0 and – respectively – the emergent transformative innovation policy as innovation policy 3.0. Each of the paradigms/framings/generations involves a distinctive model of innovation and defines the roles of engaged actors. The nature of the problems hindering innovation and economic performance – i.e. rationale for public intervention – follows from these theoretical underpinnings. This thesis adheres to the tradition of the so-called public interest theories of regulation (Hertog, 2010); the thesis does not delve into the possible incongruence between public interests and private interests of economic agents and interest groups, such as public agencies with regulatory powers and legislators or their staff, and the effects of the incongruence on the policy-making process. One of the main implications of the chosen perspective is, for example, that the explanatory power of a market failure as a rationale for public intervention does not depend on whether decision making rights have been centralized or decentralized.

In the following chapters, the main premises of the three framings for innovation policy (cf. Schot and Steinmueller, 2018) are discussed. The focus is set on establishing links between policy rationales in each of the framing and the role of Big Science mode of knowledge production in addressing problems identified by economic theories (chapters 1.1.1, 1.1.2, and 1.1.3). Market creation is associated with demand articulation through public procurement in the different framings for innovation policy; this link is elaborated in chapter 1.1.4. Chapter 1.1.5 consolidates the arguments proposed by the theoretical considerations in the three innovation policy framings to clarify the role of participating in the international Big Science organisations in the overall repertoire of national-level innovation policy instruments.

1.1.1. Framing 1 – fixing market failures

According to Schot and Steinmueller (2018), the neoclassical market failure ‘doctrine’ provides the rationale for innovation policy intervention in the framing 1. In their seminal papers, Nelson (1959) and Arrow (1962) put forth the ideas that knowledge and information are not normal economic commodities but possess unique attributes. First, information—the output of knowledge production—has attributes of a pure public good; it is non-rival and non-excludable. Therefore, as the generator of the information is not able to prevent others from using it, the information it cannot be kept proprietary. This means imperfect appropriability of investments aimed at creating knowledge and the existence of positive externalities of knowledge-generating efforts (Arrow, 1962). Consequently, private benefits from knowledge production are smaller than social benefits and an economic agent has insufficient incentives to engage with knowledge generation. Also, outputs of knowledge production activities are uncertain. Nelson (1959) points at the very large variance of the profit probability distribution from a basic research project that causes a risk-avoiding agent to value a basic-research project at significantly less than its social value. Due to the gap between private and social value of new information, markets fail to efficiently allocate socially optimal resources to knowledge production and governments need to intervene as a remedy to market failures (Steinmueller, 2010). Smith (2000) notes that the market failure doctrine prescribes a rather limited range of policy interventions. The most straightforward policy option available to governments is to encourage discovery-oriented activities by increasing investments in knowledge production in the economy towards the socially ‘optimal’ level. Mapping of innovation policy instruments shows that direct financial support for innovation activities is a dominant policy measure (for Europe, Edler et al., 2012) and governments tend to prefer research and development intensity indicators in policy goal setting (Carvalho, 2018). Public investments to research should be complemented with the creation of property rights to protect intellectual property in order to alleviate the appropriability problem.

The market failure argument has been very influential but prone to criticism. The market failure approach implies a comparison between an existing state and an optimal steady-state (Edquist, 2011; Mazzucato, 2016). For evolutionary economists, to consider competition as a state of equilibrium rather than a restless evolutionary process that characterises capitalism is fundamentally flawed (Metcalfe, 2005). Evolutionary economists see references to the idealized static state as manifestations of algebraicism, i.e. a belief that true understanding of economics must be based on formal mathematical logic (cf. Dopfer et al., 2004). The purpose of algebraicism is to provide clarity of social mechanics but
often it strongly limits to the scope of economic analysis. Following the neoclassical line of thinking, the essential task of policy-makers is to calculate what is the amount of public investment that corresponds to the gap between the sub-optimal and the optimal allocation of resources (Edler and Fagerberg, 2017) keeping in mind a boundary condition that policy intervention must be the least costly way to produce the desired level of additional investment to knowledge-generating activities (Lipsy and Carlaw, 1998).

Evolutionary economists also stress the difference between information and knowledge. Information is codified and articulated, while knowledge is always tacit and owner-specific (Metcalfe, 2005). Therefore, knowledge is not a homogeneous good. While discoveries about how nature works resulting from basic research share the features of a public good (Foray, 2004), the same cannot be said about firm-level knowledge. Such knowledge can be rather ‘sticky’ (von Hippel, 1994) and may not be applied by others without considerable investments in absorptive capability (Cohen and Levinthal, 1990). These properties impede the full realization of social benefits from public investments to knowledge production. In the realm of neoclassical theory, heterogeneity of knowledge implies that not only knowledge production effort is important but the internal composition of this effort as well. This in turn leads to a theoretical proposition that there are optimal allocations of research and development efforts in terms of the proportions of industrial research and basic research (cf. Cohen and Klepper, 1996), which adds to the complexity of the underlying optimization problem.

The market failure argument does not answer to the question where should be the social loci of the public investment to knowledge production (Smith, 2000; Clò and Florio, 2019). The market failures can be compensated with different types of public funding to research, e.g. provided to universities, technology institutes, research and technology organisations, or international governmental organisations. In case of Big Science, explanations regarding the selection of the particular social locus refer to political processes of governance. The innovation policy agenda in the framing 1 was a combination of economic objectives, economic growth and competitiveness, and societal objectives, such as national pride or strategically important societal challenges (Diercks et al., 2019). Promoting government-sponsored mission-oriented research – Big Science – in 1950s and 1960s offered an opportunity to exert top-down centralized control over knowledge production (Mowery et al., 2010). Bundling together public investments to knowledge production to pursue a well-defined technological mission enabled not only to lower transaction costs related to political processes of resource reallocation but also provide insurance against uncertainties arising from these processes as funding of basic scientific research could be justified in terms of its contribution to specific objectives rather than relying solely on the somewhat vaguer promises about science’s long run benefits” (Schot and Steinmueller, 2018, p. 1557). This implies that market failure doctrine needs to be enriched with ideas from other theories, e.g. neo-institutional theory (cf. Coase, 1937; Williamson, 1981), in order to explain the particular social locus of knowledge production.

1.1.2. Framing 2 – systems of innovation

The emergence of the framing 2 is seen as a response to the perceived inadequacy of the framing 1 to explain innovation processes (Lundvall, 1992; Sharif, 2006). Studying the economic growth rates of countries, researchers started to question the public good nature, or ‘fluidity’ (cf. Fagerberg, 2017), of knowledge and, thus, the extent of externalities. If knowledge is a public good, then the source of cross-country differences in GDP per capita cannot be explained by knowledge argument in the traditional neoclassical theory (Fagerberg, 1994). Accumulating evidence from economic history made scholars theorize of a spectrum of capabilities (Gerschenkron, 1962) such as ‘technological capability’ that determine economic growth rates of nations. These capabilities can be consciously promoted in a less-developed economy to catch up (e.g. Kim, 1997). The observation that technological and social factors interact in the process of economic development led during the 1980s to the emergence of the so-called ‘national systems of innovation’ (NSI) approach to the study of countries’ abilities to generate and benefit from technology. Lundvall (1992) defined NSI as comprised of “the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge” (p. 2).
This definition highlights the economic importance of diffusion and assimilation of new knowledge generated in research organisations by industry, e.g. in the form of technology transfer.

Early contributions to the systems of innovation literature stressed the role of institutions (regulations, culture) and deliberate state coordination (Freeman, 1987) in the creation and coordination of knowledge, and interactive learning processes in which categories of agents (e.g. government, firms, universities, inventors, banks, users, etc.) are involved (Lundvall, 1992). Rationales for innovation policy intervention stem from the notion that the basic structural elements of NSI and multiple links that connect these may not function efficiently serving their purpose with respect to knowledge generation and diffusion. A range of ‘systemic failures’ provide rationales for policy intervention in NSI approach (Klein Woolthuis et al., 2005; Chaminade and Edquist, 2010). The widely cited list of systemic failures consolidated by Klein Woolthuis et al. (2005) is comprised of imperfections, such as infrastructural failures, transition failures, path dependency failures, hard and soft institutional failures, strong and weak network failures, and capabilities failure that should be tackled with various policy instruments. From this repertoire of the systemic failures, weak network failure marks the lack of linkages between actors in an innovation system which hinders interactive learning, productive use of complementarities, and creating new ideas. Innovation intermediation is proposed as one of the fixes to the weak network failure. Innovation intermediaries establish or facilitate the links between different agents in order to support the generation and diffusion of knowledge in an economy (Howells, 2006; Edler and Yeow, 2016). Already Braun (1993) noted that publicly funded mission-oriented research organisations act as innovation intermediaries. They seek to connect various agents in their partner network with the goal to combine their complementary capabilities to create innovations in order to solve technological challenges that Big Science faces. This intermediation is supported by high-level of technical expertise in Big Science organisations and their market power (Fernandez et al., 2014; Landoni, 2017), as well as their reputation (Leyden and Link, 1999). Infrastructure failure draws attention to missing elements in science technology infrastructure, such as underdeveloped channels for knowledge transfer (Klein Woolthuis et al., 2005). The extant literature on knowledge transfer from Big Science is diverse and covers different modes of knowledge transfer (e.g. Autio et al., 2004; Lauto and Valentín, 2013; Venturini and Verbano, 2014; Nilsen and Anelli, 2016). The empirical studies demonstrate that Big Science organisations are involved in activities aimed at overcoming the systemic failures to contribute to the diffusion of knowledge. Therefore, it is claimed that contemporary mission-oriented policies embodied in Big Science organisations exhibit diffusion-oriented policy characteristics too (Bach et al., 2002; Robinson and Mazzucato, 2019).

The systemic view on technological changes led to the concept of technological innovation systems (TIS). TIS is defined as a dynamic socio-technical system of agents that, by interacting within a particular institutional infrastructure, are involved in the development, diffusion, and use of a specific technology (Carlsson and Stankiewicz, 1991). Many Big Science organisations (including ESA) are distributed facilities (Jacob and Hallonsten, 2012) – multi-located and multi-disciplinary –, which potentially embeds them in a number of different TIS. The TIS approach offers a functional perspective to innovation system paying attention to the key activities and processes that contribute to the main objective of the innovation system, which is the generation and diffusion of innovations (Hekkert et al., 2007; Bergek et al., 2008; Markard and Truffer, 2008). On top of the structural elements of innovation systems (actors, networks, institutions), there are generic key functions that an effective innovation system should perform. Functions are the basis for TIS evaluation, identification of system weaknesses and suggestions for policy actions to remove these barriers. The sets of functions and models of their interaction vary in the literature. Both Hekkert et al. (2007) and Bergek et al. (2008) distilled seven basic system functions out of a review of many years of innovation systems literature. These two key papers in the TIS literature consider research and development and knowledge development to be prerequisites within the TIS (function ‘knowledge development’). Big Science organisations are important contributors to this function. Activities of entrepreneurs are essential to reduce the uncertainty intrinsic in technological and industrial development (function ‘entrepreneurial experimentation’). The TIS needs

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2 The contributors to the early NSI literature tried to avoid the term ‘failure’ using ‘problem’ instead “to avoid the connotations that the traditional economics notion of ‘market failure’ has” (e.g. Edquist, 2011, p. 1726).
to be able to consolidate human, financial, and other types of resources for development of new technologies (function ‘resource mobilization’). International Big Science is a vehicle to pool together resources to build and equip scientific facilities and implement ambitious long-term programs that lie beyond the means of any single nation. A well-functioning innovation system should offer institutional support to new technologies (function ‘legitimation’). Encouraging new niche markets is required for diffusing new technologies (function ‘market formation’). For better use of limited resources, a system has to support selection between alternative technologies by affecting visibility and clarity of specific wants and needs among technology users (function ‘guidance/direction of search’). The functions interact and may reinforce each other (Suurs and Hekkert, 2009). Different system building and evolution processes are characterised by different interaction patterns.

According to Smits and Kuhlmann (2004), the formulation of innovation policy has reached to a stage where policy instruments need to become systemic in order to support innovation processes. Systemic instruments function at system level and, thus, can be differentiated from traditional supply-side measures targeting individual beneficiaries, such as research and development subsidies to companies. In Smits and Kuhlmann (2004) approach, systemic instruments provide interfaces for interaction across sub-system border, help to establish and organise innovation systems, provide a platform for various types of learning, and stimulate demand articulation. Despite being originally theoretically weakly elaborated (cf. Wieczorek and Hekkert, 2012), the concept of systemic instruments has drawn scholars’ attention. van Lente et al. (2003) combine the idea of systemic instruments with innovation intermediation to delineate ‘systemic intermediaries’ that have three main functions in an innovation system:

- **Articulation of demand** – establishing a dialogue between actors in the innovation system is the key function of an innovation intermediary (Klerkx and Leeuwis, 2008). This function is closely related to the TIS functions ‘market formation’ and ‘guidance/direction of search’ that both stress the importance of articulation of demand from competent ‘lead users’ who are capable of anticipating user needs that will eventually prevail in an economy (Von Hippel, 1986). Big Science organisations can be viewed as lead users even though with quite distinctive characteristics in terms of technology demands and motivations in interactions with other actors (Andersen and Åberg, 2017). Big Science may be too subsumed in their own scientific challenges, which may be in conflict with the innovation intermediation role. It is argued that the diffusion speed of the innovative solutions developed to meet the lead user’s needs depends on the attributes of the solution (Uyarra and Flanagan, 2010); too narrow specifications hamper the adoption of the solution by other users.

- **Alignment of actors and possibilities**, which corresponds to the activities that are necessary to overcome the weak network failure in Klein Wootlishuis et al. (2005).

- **Support of learning processes**, which is in line with the activities that address the infrastructure failure in Klein Wootlishuis et al. (2005).

Compared to the framing 1, the different theoretical strands of the systems of innovation perspective offer much wider assortment of justifications for public funding to Big Science organisations. Public investments to Big Science contribute to the technological capability of the country. But they also enable to overcome the systemic failures and provide a ‘treatment’ channel to have a systemic effect on the core functions and processes of the innovation system. While in the framing 1, a current state is benchmarked against an idealized optimal state, the framing 2 demonstrates how different systemic configurations can deliver similar results regarding innovation performance. Policy makers should focus their attention to the missing structural components or blocking functional mechanisms hindering the overall performance of the innovation system (Wieczorek and Hekkert, 2012).

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3 It must be noted that the ‘equifinality’ property of innovation systems – a view that different systemic configurations can deliver similar results regarding innovation performance – has recently been challenged. For example, Cirillo et al. (2019) conclude that the structure of the innovation system is so tightly interrelated that the system’s properties cannot be characterized in terms of relatively independent sub-components.
1.1.3. Framing 3 – transformative change

The framing 3 of innovation policy has emerged over the past decade. The first two framings implicitly assume that stimulating innovation is positive per se and “the only bad innovation is an innovation that did not come about” (Diercks et al., 2019, p. 882). This understanding has been increasingly challenged (e.g. Soete, 2013; Giuliani, 2018). The point of departure of the framing 3 is the need to cope with a wide range of so-called grand societal challenges plaguing the mankind (Foray et al., 2012; Kuhlmann and Rip, 2018). Tackling the grand societal challenges implies a system-wide change not incremental changes in the structure of the innovation system (Lindner et al., 2016). The innovation policy should push for transformations that involve changes in technological, institutional, political, economic, organisational, and socio-cultural dimensions (Markard et al., 2012; Steward, 2012). The question of directionality – or “what future citizens want?” – has become central for the innovation policy formulation. The framing 3 can be viewed as the ‘normative turn’ in innovation policy (Kattel and Mazzucato, 2018; Uyarru et al., 2019). The ‘extra-economic’ goals (cf. Cantner and Vannucini, 2018), such as climate change mitigation, are of inherently political and normative nature (Boon and Edler, 2018). In addition to directionality, other fundamental issues, such as legitimacy (why do we want this future and who defines it?) and responsibility (transformation by and for whom?), must be addressed (Schlaile et al., 2017).

To complement market and system failures, Weber and Rohracher (2012) proposed new types of failures. The transformative system failures that have "emerged as new reference points for innovation policy" ( Wanzenböck et al., 2019, p.5) are comprised of directionality failure, policy coordination failure, demand articulation failure, and reflexivity failure. The directionality failure refers to the current innovation system’s inability to steer innovations towards a particular direction of transformative change (Weber and Rohracher, 2012; Schot and Steinmueller, 2018). The transformative innovation processes are understood as collective experimentation processes involving multiple technology domains – some of them emerging and others declining (Kivimaa and Kern, 2016) – and multiple actors. The policy coordination failure denotes a lack of alignment between innovation policy and sectoral policy fields (e.g. transport, energy, and space), public policy and private sector institutions, or policies at supranational, national, regional and local levels (Weber and Rohracher, 2012). As innovation goals are not identified centrally, a spectrum of new actors (e.g. non-governmental organisations) are more engaged in the innovation policy making. All this points at the need for holistic, multi-level policy coordination, extending from local communities to global scale, potentially entailing considerable or even prohibitive transaction costs (Schot and Steinmueller, 2018). Transformative policy is selective as it pursues specific socio-technical pathways (Janssen, 2019). The transformative innovation processes are also subject to continuous policy adaptations. Reflexivity failure refers to the system’s inability to monitor, to anticipate and to involve actors in long-term processes of self-governance (Weber and Rohracher, 2012). Transformative change implies experimenting along different technology trajectories and appropriate continuous evaluation function enables to make timely decisions to suppress some of the trajectories if their performance falls below expectations. Demand articulation failure reflects a deficit in anticipating and learning about societal needs, which has an adverse effect on market uptake of socially desirable innovations. Therefore, innovation policy must devise mechanisms for iterative interactions between various economic agents to translate latent needs into increasingly concrete and explicit users’ requirements (Boon and Edler, 2018).

Diercks et al. (2019) argue that the emerging framing 3 is still in its infancy. Its apparent discontent with the existing knowledge base (i.e. framings 1 and 2) can be challenged (e.g. Fagerberg, 2018). For example, already the TIS literature has paid attention to the directionality of technological innovation. One of the TIS functions in both Hekkert et al. (2007) and Bergek et al. (2008) – guidance of the search – refers to the activities that may generate a momentum for change in a specific direction. Similarly, counteracting the demand articulation failure corresponds to the development of the TIS function ‘market formation’ (Raven and Walrave, 2018). However, there are concerns that TIS framework is not analytically suitable for capturing the interactions between multiple technologies and devise mechanisms to address the policy coordination failure (Kern, 2015; Markard et al., 2015) and this necessitates radically new thinking about innovation policy.
The contemporary grand societal challenges are fundamentally different from the early mission-oriented programs, such as the Project Apollo. This was already highlighted by Nelson (1974) who asked the famous question: “If we can land a man on the moon, why can’t we solve the problems of the ghetto?” (p.376). The Project Apollo had relatively well-defined goals and technological solutions; it was run top-down with a limited number of stakeholders actively involved. Present-day societal problems are complex, multi-dimensional, systemic, and ill-defined, therefore these must be first translated into concrete and solvable technological problems that are combined into missions (Mazzucato, 2018). Kattel and Mazzucato (2018) see Big Science instrumental in attempts to find solutions to actionable technological problems in this new mission-oriented policy while governments have a task to establish suitable conditions for inducing knowledge spillovers from Big Science in the form of new markets. For example, European Space Agency is the European Commission’s partner in developing the Copernicus constellation of Earth Observation satellites and instruments to collect data on geophysical variables, including over areas of the globe that are difficult to access otherwise (Robinson and Mazzucato, 2019). Such data provides insights about geographic patterns and their variability, and underpins public policies for tackling climate change (Tassa, 2019). Dedicated mission-oriented public funding for such field of science and technology could help in addressing grand societal challenges resulting in radically new technologies and formation of new markets. This places Big Science in the wider policy mix targeting the transition of the society in a pre-defined direction (cf. Kivimaa, 2014; Kern et al., 2019).

### 1.1.4. Demand articulation through public procurement

In the framings 2 and 3, demand articulation and public demand for creating and supporting markets have emerged among the key functions and core processes of a well-working innovation system (e.g. Bergek et al., 2008; Hekkert et al., 2007; Weber and Rohracher, 2012; Schot and Steinmueller, 2018). Issues related to public demand are addressed through public procurement. The primary objective of public procurement is to provide public administrations with the goods and services required for the performance and delivery of public services. However, public procurement may also serve the needs outside government domain; such procurement type is denoted with a term ‘catalytic procurement’ (Edquist and Hommen, 1998; Edquist and Zabala-Iturriagagoitia, 2012). According to the broadest definition, public procurement of innovation (PPI) constitute such “purchasing activities carried out by public agencies that lead to innovation” (Rolfstam, 2012, p. 303). While some PPI initiatives are aimed directly and explicitly, i.e. intentionally, at promoting innovation and its diffusion, Cave and Frinking (2003) pointed at random nature of innovations; they may easily be unintentional by-products of purchasing activities.

Demand articulation through public procurement was already discussed within the theoretical boundaries of framing 1 (Edler and Georghiou, 2007; Bleda and Chicot, 2019). In their classic paper about the role of demand-side policies to facilitate the diffusion of innovations, Edler and Georghiou (2007) focus on information problems that can be addressed with PPI: those wishing to supply innovative products may be unaware of unsatisfied needs in the markets beyond their traditional customer base. Fontana and Guerzoni (2008) label this information asymmetry problem the ‘uncertainty effect’ of demand in innovation. The intrinsic uncertainties associated with introducing innovative products can be relieved through channelling useful market information to supply side (Von Hippel, 1978). In other words, user-supplier interaction and communication is necessary to compensate the market failure. Therefore, Chicot and Matt (2018) speak of user-supplier interaction failures as a rationale for PPI.

Chicot and Matt (2018) bring out another user-supplier interaction failure – lack of an interactive learning space – that is consistent with framing 2. The systemic perspective stresses the importance of knowledge and inter-organisational learning of agents in markets (Edler and Georghiou, 2007, Hommen and Rolfstam, 2008) to tackle the systemic failures hindering innovation (see Ch. 1.1.2). In knowledge-

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4 Uyarra (2016) notes that this broad definition incorporates all kinds of Schumpeterian innovations, including new ways to organize business.
based view, procuring agents possess tacit knowledge about (often latent) needs for which innovative solutions could be developed. PPI is applicable as an instrument to address poor interaction between supply and demand through communication of this tacit knowledge to other economic actors (for products, e.g. Edquist and Zabala-Iturriagagoitia, 2012; for services, e.g. Pelkonen and Valovirta, 2015). At the same time, the interaction is expected to bring into conversation tacit knowledge of potential bidders. Georgiou et al. (2014) point at a widely shared belief that an increase in the number of potential bidders can increase the potential for innovation. Various authors have argued in favour of gearing public procurement towards small-and medium-sized companies (SME) referring to a range of gains to the procuring agency, such as increased innovativeness and encouraged entrepreneurship (cf. Karjalainen and Kemppainen, 2008). Similarly, framing 3 points at the lack of interaction spaces where economic actors could signal about their needs and wants, often because relevant markets have not emerged (Frenken, 2017; Grillitsch et al., 2019). Some authors stress the importance of the interaction spaces that promote crossovers between unrelated technologies to facilitate the emergence of radical recombinant innovations as a source of long-term growth (Castaldi et al., 2015; Edler, 2016; Frenken, 2017).

Lember et al. (2015) note that the interaction mechanisms and even project level technical skills related to effective cooperation between procurement stakeholders have received a lot of scholarly attention in PPI literature. Even though public procurement is assigned with a role to connect demand and supply, the actual conduct of PPI often fails to deliver appropriate interaction (Uyarra et al., 2014). Lack of procurement capabilities, and managerial and technical skills at demand side are considered the main reasons for that (Loader, 2013; Georgiou et al., 2014; Kattel and Mazzucato, 2018). The capability problem is claimed to be more severe in smaller countries (for Latvia, see Cepilovs, 2014) and at lower (e.g. regional and municipal) levels of governance. Applying PPI to create new markets in order to promptly react to the urgency of the grand societal challenges requires new types of dynamic capabilities in public sector as well as new structures and institutions to accommodate these capabilities (Mazzucato, 2016; Kattel and Mazzucato, 2018; Uyarra et al., 2020).

Demand articulation has also other effects on innovative behaviour. Schmookler (1962) argued that demand is a source of economic incentive for invention due to increased profits as the fixed cost of producing an item of knowledge can be spread over a greater volume of output. Fontana and Guerzoni (2008) call this the ‘incentive effect’ of demand in innovation. Edler and Georgiou (2007) indicate that the incentive effect can be leveraged by setting sufficiently generic requirements to new products during procurement process to allow for agile expansion into international markets with innovations. Positive impact on internationalisation activities of companies supplying innovations to public bodies is an implicitly assumed by-product of PPI. The results of surveys conducted among public sector suppliers (e.g. Edler et al., 2015) have provided evidence of this capacity of PPI to help to increase exports of the companies that benefit from PPI. Guerzoni (2010) suggests that in addition to the size of the potential demand also the sophistication of the potential demand affects a firm’s decision to introduce a new product or service. The empirical results by Pickernell et al. (2011) and Slavtchev and Wiederhold (2016) indicate that the sophistication of demand determines the effectiveness of the use of public procurement as a tool for inducing additional private investments to knowledge production. For example, an econometric analysis of the US federal procurement in the period 1999–2009 showed that a shift of $1 in government purchases from low-tech to high-tech industries was associated with an average increase in company-funded research and development of $0.21 (Slavtchev and Wiederhold, 2016).

1.1.5. Policy rationales for procuring innovations through Big Science

Flanagan et al. (2011) note that the innovation policy literature tends to treat theory-based rationales as the main driver of innovation policy development. The policy process is usually viewed as consisting of

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5 At the same time, increasing returns to knowledge diffusion can be the main driver of ‘technology lock-in’ type of systemic failure in an innovation system as accompanying learning by doing effects and accumulation of specific capabilities render switching costs prohibitively high (Foxon & Pearson, 2008).
linear discrete stages and policy instruments emerging through this process should correspond to the theory-backed rationales. The previous chapters (p.1.1.1, p.1.1.2, and p.1.1.3) connected the rationales for policy intervention in the three framings of innovation policy to the roles that Big Science could play in an innovation policy toolbox to address various problems hindering knowledge generation and diffusion. Inspired by the integrated framework of market, systemic, and transformational failures by Weber and Rohracher (2012), Table 1 summarises how various failure types could be addressed through Big Science organisations.

<table>
<thead>
<tr>
<th>Type of failure</th>
<th>Failure mechanism in Weber and Rohracher (2012)</th>
<th>Big Science’s role in tackling the failure mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market failure</td>
<td>Information asymmetries: Uncertainty about outcomes and short time horizon of private investors lead to undersupply of funding for R&amp;D.</td>
<td>Knowledge production to advance single or multiple scientific disciplines, such as nuclear physics and astronomy, and channelling market information to other economic agents to overcome the effects of information asymmetries.</td>
</tr>
<tr>
<td></td>
<td>Knowledge spillovers: Public good character of knowledge and leakage of knowledge lead to socially sub-optimal investment in research and development.</td>
<td>Knowledge production towards socially optimal level.</td>
</tr>
<tr>
<td>Systemic failure</td>
<td>Network failure: Too limited interaction and knowledge exchange with other actors inhibits exploitation of complementary sources of knowledge and processes of interactive learning.</td>
<td>(Systemic) innovation intermediary that connects economic actors with complementary capabilities and facilitates inter-organisational learning.</td>
</tr>
<tr>
<td></td>
<td>Infrastructure failure: Lack of knowledge infrastructures due to large scale, long time horizon of operation and ultimately too low return on investment for private investors.</td>
<td>Big Science consolidates and makes available resources, such as scientific and applied knowledge and skills, or dedicated testing facilities, and establishes possibilities for knowledge transfer.</td>
</tr>
<tr>
<td>Transformational system failures</td>
<td>Directionality failure: Lack of shared vision regarding the goal and direction of the transformation process; Lack of targeted funding for research, development and demonstration projects and infrastructures to establish corridors of acceptable development paths.</td>
<td>Big Science consolidates targeted funding for demonstrating technologies that potentially assist socio-economic transitions.</td>
</tr>
<tr>
<td></td>
<td>Demand articulation failure: Insufficient spaces for anticipating and learning about user needs to enable the uptake of innovations by users. Absence of orienting and stimulating signals from public demand. Lack of demand-articulating competencies.</td>
<td>Big Science organisations possess high-level of technical expertise, market knowledge, and procurement capabilities enabling to anticipate future user needs.</td>
</tr>
</tbody>
</table>


If policy-makers base their intervention logic on market failure doctrine, Big Science is a specific knowledge production locus in the society to narrow the gap between the sub-optimal and optimal allocation of resources to knowledge creation, either in one specific technology domain (e.g. particle physics in case of CERN) or multiple domains (in case of space missions executed by ESA). Peculiar nature of information and various information problems rooted in demand and supply interactions in unregulated markets cause this gap. If publicly funded Big Science procures goods and services to produce new knowledge from other economic actors, it can address information asymmetries that cripple
knowledge production by these actors by channelling useful market information to other agents. This latter role – already noted in framing 1 – is one of the main tasks of innovation intermediaries in framing 2 (Howells, 2006).

In framing 2, Big Science is a structural element in the innovation system. Big Science is a junction that seeks to combine complementary capabilities of and facilitate inter-organisational learning between agents in its partner network to create and also diffuse new knowledge. These roles of Big Science can be performed by establishing interaction spaces for economic agents in the process of demand articulation through public procurement. If Big Science is engaged with all these activities – connecting actors, facilitating mutual learning and articulating demand – it fits to the definition of systemic intermediaries (van Lente et al., 2003) that support innovation at higher system level (Klerkx and Leeuwis, 2009). Big Science as a systemic intermediary is the focal element in the network of firms and private and public institutes coping with uncertainties, interdependencies, and diverging interests in the long term change processes (van Lente et al., 2020) that characterise a (nascent) TIS (cf. Suurs et al., 2009). For example, the central role of ESA in the evolution of emerging space downstream industries has been comprehensively discussed in Mazzucato and Robinson (2017).

Gassler et al. (2008) and Diercks et al. (2019) argue that the innovation policy paradigms do not substitute each other but an emerging policy paradigm is seen as layered upon earlier innovation policy paradigms. Bleda and del Río (2013) lend support to this sentiment by noting that even though the systemic failure rationale has toppled the market failure rationale as the most dominant theoretical justification for innovation policy intervention in recent years, both rationales are still often used in combination. For example, Barge-Gil and Modrego-Rico (2008) who discuss the role of public technology institutes in innovation policy toolbox conclude that the institutes “are helping to reduce market failures in the area of technology and to foster relationships among innovation-system actors” (p. 808). In other words, they view public funding to organisations, which core task is knowledge production as a policy instrument addressing both the market and systemic failures simultaneously. This is in line with Weber and Rohracher (2012) who see systemic failures to be partly compatible with market failures.

In framing 3, governments do not merely intervene to fix market and systemic failures, but rather they do actively create new markets to support socio-economic transitions and tackle so-called ‘wicked problems’. Demand articulation through public procurement stimulates the formation of new markets (Edler and Georgiou, 2007; Cagnin et al., 2012; Borrás and Edquist, 2013; Mazzucato, 2016; Frenken, 2017), thus having a positive effect on innovation. Therefore, Kattel and Mazzucato (2018) regard mission-oriented policies, the policy layer that translates ill-defined contemporary grand societal challenges into concrete and actionable problems, as “a market-shaping public investment and policy framework” (p. 789) and envisage Big Science to be an important contributor in this context. For example, Robinson and Mazzucato (2019) discuss how ESA responds to global societal challenges, such as climate change, by articulating demand for the growth of downstream utility of space technologies and services, which are connected to the space infrastructure and missions around what the core activities of the organisation revolve. Needs that are targeted with such activities reside often outside ESA (cf. Eerme and Nummela, 2019a).

Bleda and Chicot (2019) appreciate the scholarly attention to the idea that markets7 can be created by public procurement but argue that the extant literature fails to develop this idea nor provide explanations

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6 Interestingly, as Laranja et al. (2008) point out, the territorial implications of different economic theories are often debatable. For example, could ESA as an international Big Science organisation be considered as a structural element of the Estonian national system of innovation at all? Such question does not arise in the TIS perspective, where TIS overlaps with parts of various national innovation systems and with various sectoral innovation systems (cf. Hekkert et al., 2007).

7 In this thesis, market is not understood as merely an abstract price forming mechanism coordinating economic exchanges between firms and customers. The comprehensive definition of markets by Nenonen et al. (2019) as “complex adaptive socio-technical-material systems, consisting of institutions, actors, practices, and discourses
how PPI contributes to the market creation process. Influenced by the works by evolutionary economists (e.g. Dopfer et al., 2004), Bleda and Chicot (2019) elaborate that procurement instruments can be used to support different types of knowledge coordination processes that take place both at the company-level (micro) and agent population level (meso). According to their view, market forms when certain new knowledge (e.g. new technology embodied in a new product) with all its associated technical, social, cognitive and behavioural knowledge components is ‘institutionalised’, i.e. repeatedly used by a population of agents in their economic exchange practices and other market practices (cf. Kjellberg and Helgesson, 2007). Economic transformation means that many new technologies must become institutionalised and some other obsolete (Kivimaa and Kern, 2016) and there is the need for adjacent social, institutional and behavioural changes to complement technological innovation as participative social innovation is indispensable for actual transformation (Diercks et al., 2019).

Some authors (e.g. Mazzucato, 2016; Boon and Edler, 2018) stress that to succeed in implementing mission-oriented and transformative policies, which poses a variety of operational challenges, new skills and capabilities must be developed. As was discussed in p.1.1.4, the lack of capabilities enabling effective user-supplier interactions at procuring side has been a factor that limits innovation performance of PPI (Georghiou et al., 2014). Hence, the emergence of transformative policies may worsen the problem of insufficient procurement capabilities. The problem is shown to be scope-dependant. Therefore, centralisation, i.e. concentration of expertise and budgets – is a possible remedy to this problem. It can be expected that procuring sophisticated products and services to solve societal problems at the highest possible governance level by a competent supranational body, such as a Big Science organisation, may have positive effects in terms of innovation outcomes from PPI compared to procurement conducted at national level or lower levels. Autio et al. (2004) argued that Big Science organisations possess skills and capabilities that enable their industrial supplier companies to deal with higher levels of technical complexity than would otherwise be possible. However, Georghiou et al. (2014) note that in case of PPI, economies of scale can be offset by creating a distance between the procurement function and the users. Outsourcing public procurement processes by allocating funds from national budgets to the procurement programs of the international organisations creates an agency relationship, where the principal (the nation state) and the agent (the supranational organisation) may have conflicting policy goals and interests. There is a trade-off between related agency and transaction costs and innovation benefits that are attributable to the interaction between suppliers and a Big Science organisation that has capabilities to expect what future citizens want and communicate these requirements effectively to other actors.

Viewing different innovation policy paradigms as complementing each other, public support to Big Science can be regarded as a systemic policy instrument helping to address the market, systemic, and transformational failures. The objectives of and rationales for policy interventions are not limited to the failures identified in the economic literature (Borrás and Edquist, 2013). Therefore, it crucial to differentiate between rationales derived from theories and the specific rationales adopted by policy-makers to justify the design, selection and use of a particular policy instrument or mix of policy instruments (Laranja, Uyarra, and Flanagan, 2008). Also, it has argued that policy-makers often rationalise policy interventions retrospectively (cf. Gök and Edler, 2012). Nevertheless, explaining the theoretically elaborated rationales behind policy intervention is essential for meaningful evaluation.

*that organize particular economised exchanges” (p.252) covers the important elements beyond the relationship between firms and customers.*
1.2. Evaluation of innovation policy instruments

Scholars have acknowledged the rapid diversification and increasing sophistication of available innovation policy instruments (Borrás, 2009; Flanagan et al., 2011; Edler et al., 2012), even if the instruments are to be treated purely as functional, ‘technical devices’, to address certain types of failures. However, it is observed that innovation policy instruments are context-specific (Borrás and Edquist, 2013; Edler et al., 2016), i.e. policy instruments are devices of both technical and social nature (Lascoumes and Gales, 2007). One instrument with a similar delivery structure, tackling a problem of the similar nature, might perform very differently in different contexts. Flanagan et al. (2011) illustrate this with the example of innovation voucher schemes in different European countries. For policy-makers, such variation adds to the complexity related to the choice of policy instruments.

The design of innovation policy requires a broad knowledge base, starting from theoretical and political rationales, understanding of the capabilities of targeted groups of actors, linkages and interactions between these actors and other stakeholders, the interplay with other existing policy instruments (‘policy mix’), meso- and macro-level framework conditions (context), and policy effects. The evaluations of policy interventions inform policy-makers about the effectiveness, efficiency, appropriateness and impact of policy instruments. Evaluation refers to ‘a process that seeks to determine as systematically and objectively as possible the relevance, efficiency and effect of an activity in terms of its objectives, including the analysis of the implementation and administrative management of such activities’ (Papastavrou and Polit, 1999, p. 10). Evaluations are carried out to assess past performance (summative evaluations) to understand if the intervention met its obligations in socio-economic terms and/or to assist policy-makers in the design, implementation and re-adjustment of policies (formative evaluations) (Edler et al., 2008). Evaluations combine summative and formative aspects; roughly half of the evaluations in the repository of 171 evaluation reports of national innovation policies of EU25 countries studied by Edler et al. (2012) were combining both elements. Learning processes entailed in formative evaluations, labelled ‘the most positive dimension of evaluations’ (Georghiou, 1999, p. 524), are important in addressing the reflexivity failure put forward by Weber and Rohracher (2012).

Evaluations seek to identify and quantify the impacts induced by the policy instrument. A key dimension for the measurement of impact is additionality, which involves comparing the absence of policy instruments with the impacts in the presence of policy instruments (Georghiou, 2002). Additionality is differentiated into input additionality (how much additional resources are allocated to innovation activities than would have been without the instrument), output additionality (how much additional output would not have been foregone without the instrument), and behavioural additionality (persistent change of actor behaviour due to the instrument that is conducive to better innovation performance) (Georghiou, 2002; Gök and Edler, 2012). Evaluations that consider additionality aspects rely on quantitative methods and a counterfactual approach (Edler et al., 2012). However, evaluations should also provide inputs for understanding processes related to the diffusion of innovations and pertinent inter-organisational learning. Therefore, in evaluation practice, qualitative methods are used in combination with quantitative methods to extract a more holistic picture of the impacts policy instrument (Edler et al., 2012).

Majority of evaluations and impact analyses still apply a single instrument perspective and functional approach, which treats policy instruments as technical devices (Edler et al., 2016). With the emergence of the framings 2 and 3, systemic interactions between policy instruments are more stressed. Scholars are increasingly arguing that conventional evaluation methods are not appropriate to investigate the impacts of policy mixes, particularly in the context of transformative change (e.g. Magro and Wilson, 2013; Mazzucato, 2016). Nevertheless, empirical evidence shows that system oriented innovation policy evaluations are still rare (Borrás and Laatsit, 2019).

A good literature review on the development of the concept of policy mixes in innovation studies is provided by Kern et al. (2019). The emergence of the term is associated with the contributions by Nauwelaers and Wintjes (2002), Laranja et al. (2008) and Flanagan et al. (2011).
The following chapters discuss the use of all three types of additionalities in evaluations of supply- and demand-side innovation policy instruments. Chapter 1.2.1 is dedicated to input additionality and output additionality, while chapter 1.2.2 focuses on a very diverse field of behavioural additionality assessments. Sowing the seeds of new markets is one of the key roles of demand-side instruments, therefore, chapter 1.2.3 examines how information on market formation processes is embedded to policy evaluations. Chapter 1.2.4 reviews the extant academic and grey literature on the socio-economic impact assessments of Big Science.

1.2.1. Input and output additionality in innovation policy evaluations

Government-funded research and direct R&D subsidies and tax incentives for providing additional inputs to knowledge generation processes of companies are the dominant supply-side innovation policy instruments implied by the market failure argument in the framing 1. There is a literature stream trying to measure the spillover effects of publicly funded basic research and science. The research findings consolidated by Salter and Martin (2001) in an early review and by Georgiou (2015) in a more recent summary endorse the core rationale for public support for R&D, that the social rate of return to publicly funded R&D is significant and exceeds the private rate of return. The topics of social returns to R&D and knowledge spillovers are closely intertwined. Hall et al. (2009) identify public research organisations such Big Science as important sources of knowledge spillovers from R&D from the perspective of firms. Results by Mansfield (1991, 1998) demonstrated that a considerable share of new products and processes could not have been developed by industrial companies without the government-funded basic research.

Due to various methodological problems related to measuring knowledge spillovers and externalities and, consequently, estimating the net social benefits of the direct R&D subsidies (Papaconstantinou and Polt, 1999; Salter and Martin, 2001), scholarly studies on the effectiveness of direct R&D subsidies to companies have traditionally focused on input additionality, which seeks to capture whether the incremental investments in R&D by treated agents were greater than or equal to the amount of direct R&D subsidies (Georgiou and Roessner, 2000). Researchers are concerned with the possible ‘crowding out’ effect of R&D subsidies. Crowding out occurs because any firm has always an incentive to apply for the direct R&D subsidy to substitute private research investment with public funding in order to increase the expected private returns from the R&D investment. There is mixed evidence regarding crowding out or crowding in (input additionality) effects of direct R&D subsidy programmes (e.g. Sziucs, 2020; Czarnecki and Hussinger, 2018; Dimos and Pugh, 2016; Zúñiga-Vicente et al., 2014; Cerulli, 2010; David et al., 2000). For example, the meta-regression analysis of 52 micro-level studies published since 2000 performed by Dimos and Pugh (2016) rejected crowding out of private investment by public subsidy but did not show evidence of substantial input additionality. Interestingly, the empirical results by Montmartin and Herrera (2015) point towards the possibility that the effects of national R&D subsidy programmes on national private R&D intensity can be offset by the effects of R&D subsidy programmes of other countries. This means that the effects of a policy intervention do not only depend on the interactions between various elements of a policy mix at the national level but also on the systemic effects of foreign innovation policy instruments.

In the context of this thesis, empirical evidence regarding a few specific aspects of the effects are of interest. First, are direct R&D subsidies associated with input additionality in sectors with an above-average level of R&D intensity, such as aerospace? Second, as in a number of ESA programs research on technologies at lower maturity level is purchased, it is relevant to ask whether the relationship between R&D subsidies and input additionality is affected by the R&D stage at which funding occurs, comparing far from market ‘research’ to close to market ‘development’. With respect to the R&D intensity of sectors, as subsidies are mainly awarded to firms that would perform R&D anyway, then some authors have found that R&D subsidies are more effective in terms of input additionality for companies operating in sectors with below-average level of R&D intensity (e.g. González and Pazó, 2008; Becker and Hall, 2013). Consistent with a notion of knowledge as semi-public good, studies by Clausen (2009) and Hottenrott et al. (2017) have shown that R&D subsidies to far from market
’research’ projects result in input additionality, while subsidies to close to market ’development’ projects are less effective or even crowd out private R&D investment (Clausen, 2009).

Compared to literature on input additionality of direct R&D subsidies, the scholarly studies about the effect of direct R&D subsidies on R&D output are less frequent. Dimos and Pugh (2016) connect it to methodological problems; if the R&D subsidy leads to a higher level of R&D output (measured in numbers of patents or sales arising from innovation) than the counterfactual situation, it cannot be determined whether additionality, no effect or partial crowding out takes place, because output indicators are not commensurable with the value of subsidies and the presence of many unobserved determinants that might have contributed to the output induced by the given R&D project (the project fallacy problem, cf. Georghiou and Clarysse, 2006). Recent studies (e.g. Cin et al., 2017; Vanino et al., 2019) have established the positive effect of R&D subsidies on the business performance of the recipients. Vanino et al. (2019) showed this effect to be stronger in R&D intensive sectors. An interesting direction is to apply the Crépon–Duguet–Mairesse (CDM) framework (Crepon et al., 1998; Lööf et al., 2017) to estimate input additionality and then whether the public R&D subsidy and induced private R&D investment lead to output additionality, that is, more innovation. Using a modified CDM framework, Czarnitzki and Delanote (2017) found evidence of both input additionality and output additionality, which means that subsidy-induced R&D increases companies’ sales from new products.

While measuring input additionality is common for supply-side financial instruments, it is problematic to deal with input additionality in the evaluations of demand-side policy instruments (Edler et al., 2012). For example, it is often challenging to distinguish the specific intervention from other demand-side instruments, thus the specific financial expenditure on the policy in the promoting agency’s budget (Uyarrat, 2016; Edler et al., 2012). Empirical studies on the effects of public procurement on the private sector suppliers’ innovative behaviour and innovation outcome are scarce, with a few notable exceptions. Aschhoff and Sofka’s (2009) results highlighted that public procurement contracts are associated with the better innovation performance of suppliers expressed as the share of turnover of products new to the market as a whole. Guerzoni and Raiteri (2015) conclude that innovative public procurement has a robust impact on private expenses in innovation activities. This holds when this policy instrument is considered in isolation as well as in combination with supply side instruments – direct R&D subsidies and R&D tax credits.

In practice, the borders between supply-side and demand-side instruments are blurred. There are instruments such as pre-commercial procurement (PCP) that are located on this borderline. PCP involves the purchase of research by a contracting authority and usually the development of a prototype with the objective of stimulating innovation (Rigby, 2016); the benefits from the resulting innovations, such as intellectual property rights, are shared between the procuring authority and the firm which supplies the solution (Iossa at al., 2018). The European Space Agency often procures R&D works from its industrial partners and such contracts correspond to the definition of PCP (Bedin et al., 2015). Majority of authors (e.g. Edler and Georghiou, 2007; Lember et al., 2014; Rigby, 2016) view PCP as a form of PPI. This view is strongly challenged by Edquist and Zabala-Iturriagagoitia (2015) who consider PCP as a specific type of public R&D funding subsidy. Scholarly papers on the impacts of PCP programs are scarce, the Small Business Innovation Research program in the United States being the most studied program (e.g. Audretsch et al., 2002; Link and Scott, 2010). In Lerner (2000), the ‘certification effect’ modulates input additionality, i.e. participation in pre-commercial procurement provides legitimising signals about the suitability of small firms for equity investment by institutional investors. Colombo et al. (2011) found evidence of the certification effect also in case of selective R&D subsidy schemes.

9 The CDM model is structural model that describes the link between (i) R&D expenditure, which depends on the characteristics of a firm and industry, such as size, internationalisation patterns, or institutional environment, (ii) innovation output, which is a function of the R&D input, and (iii) productivity, which is a function of innovation output. The CDM widely used in the empirical literature on innovation and productivity and has been applied to micro data of over 40 countries (Lööf, Mairesse, & Mohnen, 2017).
1.2.2. Behavioural additionality in innovation policy evaluations

Evaluators’ focus on the concepts of input additionality and output additionality has been considered to be emblematic for the framing 1, which is based on the linear model of innovation and uses the neoclassical market failure rationale as a justification for policy intervention. Evaluations that concentrate on input additionality and output additionality treat the firm as a ‘black box’. Input additionality perspective assumes that there is a clear link between inputs (more R&D investments) and outputs (higher turnover), even though this assumption is debatable (Georghiou and Clarysse, 2006). According to this line of thinking, if a public instrument designed to compensate market failures does not induce more inputs than would have been generated in the absence of this instrument, there is a ground to regard this instrument as ineffective (Gök and Edler, 2012). Buissere et al. (1995) who introduced the concept of ‘behavioural additionality’ noted that the traditional concepts of additionality did not capture comprehensively the effects of R&D support programmes on large firms. They argued that the effects on the firms are more nuanced ranging from changing patterns of their R&D collaborations to strategic and organisational dimensions. Behavioural additionality was conceived to illuminate the internal processes within the ‘black box’ that converts inputs into outputs. Behavioural additionality is based on evolutionary and structuralist ideas about innovation (Gök, 2010) that stress the centrality of the interactions between agents and different forms of learning, thus being compatible with the framing 2, which builds on a process oriented non-linear model of innovation. Gök and Edler (2012) divide various definitions and understandings of behavioural additionality into four categories to illustrate lingering theoretical vagueness of the concept (Table 2). Rather narrow understanding of behavioural additionality as the scale, scope, and acceleration additionalities represents one end of the continuum (Georghiou, 2002; Falk, 2007). Scale additionality refers to possible economies of scale induced by public intervention leading to R&D projects that are larger than they would otherwise have been. Scope additionality means that new objectives or even new research domains that are beyond the existing competence bases of firms are added to projects. While the narrow understanding of the concept basically focuses on R&D project portfolios of treated firms, the broadest view (Category D in Table 2) seeks to identify persistent changes in the general conduct of the firm across all strategic dimensions (Gök and Edler, 2012). Different definitional categories of behavioural additionality are the embodiments of different theoretical underpinnings. Approaches that build on the resource-based theory and dynamic capabilities (e.g. Georghiou and Clarysse, 2006), theory of organisational learning (e.g. Clarysse et al., 2009) or evolutionary economics (e.g. Gök, 2010) tend to emphasize the temporal scope of the concept, i.e. the persistence of the changes associated with a policy intervention.

Table 2. Comparison of different definitions of behavioural additionality

<table>
<thead>
<tr>
<th>Definition</th>
<th>Category A</th>
<th>Category B</th>
<th>Category C</th>
<th>Category D</th>
</tr>
</thead>
<tbody>
<tr>
<td>An extension of input additionality covering scale, scope, and acceleration additionality and like</td>
<td>The one off change in the behaviour related to R&amp;D and innovation activities</td>
<td>The change in the persistent behaviour related to R&amp;D and innovation activities</td>
<td>The change in of the general conduct of the firm</td>
<td></td>
</tr>
<tr>
<td>Functional coverage</td>
<td>Only R&amp;D and innovation</td>
<td>Only R&amp;D and innovation</td>
<td>Only R&amp;D and innovation</td>
<td>Beyond R&amp;D and innovation</td>
</tr>
<tr>
<td>Time dimension</td>
<td>One-off, no persistence</td>
<td>One-off, no persistence or Rather mid-term than long-term and rather less persistent</td>
<td>Persistent or Rather long-term than short-term and rather more persistent</td>
<td>Persistent</td>
</tr>
</tbody>
</table>

Source: Gök and Edler (2012)

This conceptual heterogeneity is reflected in the diversity of measurement practices in the empirical studies on behavioural additionality of innovation policy instruments. If the focus of a study is on project additionality, then researchers have collected survey-based data attempting to create hypothetical,
counterfactual situations (for example, by asking questions “Would the project have been conducted without public support without changes or cancelled?” as in Falk (2007)). Such approach entails a possibility that the respondents over-exaggerate the positive effects of the policy instrument or downplay unanticipated changes in behaviour (Pérez, 2016). The occurrence of scope or scale additionality can be then used as a binary dependent variable to study associations with firm-level characteristics, such as firm size, exporting activity, and R&D intensity (Wanzenböck et al., 2013). Empirical studies on behavioural additionality often study the effects of innovation instruments on a firm’s propensity to cooperate with external partners (e.g. Fier et al., 2006; Busom and Fernández-Ribas, 2008; Afcha Chávez, 2011; Teirlinck and Spithoven, 2012; Chapman et al., 2018; Bianchi et al., 2019). Generally, the results of these studies point in one direction – firms receiving R&D support tend to collaborate with a larger number of external partners, such as publicly funded research organisations and universities. The second stream of empirical literature focuses on cognitive capacity additionality as the firm’s management capabilities are positively affected by project management guidelines that are imposed by the R&D subsidy (Buisseret et al., 1995), more elaborated and formalised innovation management processes (Clarysse et al., 2009), inter-organisational learning resulting from extended R&D collaborations and new partnerships (Falk, 2007; Clarysse et al., 2009), ‘systematization’ of R&D activities (Magro et al., 2010), and, at level of individuals, changes in senior managers’ innovation-oriented attitudes (Chapman and Hewitt-Dundas, 2018). In the model of Clarysse et al. (2009), the dependent variable was the change in the way the firms operationally manage their innovation process. They used Likert scale to capture the respondents’ opinions about the degree to which the R&D subsidy allowed the firm to ‘formalize the innovation management process within the firm’ and ‘increase the innovation management capabilities’. Measures of the independent variables such as the number of R&D projects funded by the funding agency, the number of other organizations involved in these projects, and R&D intensity of the firms represented different types of organisational learning. The study identified behavioural additionality from R&D subsidies, which was realised simultaneously with input additionality. The empirical studies tend to agree that behavioural additionality is an antecedent of output additionality (e.g. Falk, 2007; Cerulli et al., 2016) and the changes in R&D collaborations and cognitive capacity should ultimately lead to better performance.

Due to ambiguities regarding the concept, Gök and Edler (2012) and Pérez (2016) note there is the tendency to label input additionality as behavioural additionality. There are studies that view the increase in scientific personnel induced by the R&D subsidy as the occurrence of behavioural additionality (Madsen and Brastad, 2006). Meuleman and De Maeseneire (2012) associate behavioural additionality with the SMEs’ improved access to external financing thanks to legitimising effect of R&D subsidies, which results in more inputs to ‘black box’. Such studies indicate frequent misuse of the concept of behavioural additionality in evaluations (Gök and Edler, 2012). Gök (2010) concluded that behavioural additionality does not have a consistent unit of analysis as behaviour cannot be easily operationalised. Collaboration is the most studied aspect of behavioural additionality. However, the finding that direct R&D subsidies induce measurable increase in the number of partners involved in R&D collaboration is not really informative about the processes that take place within the ‘black box’. Researchers merely open the ‘black box’ to find a smaller ‘black box’ inside the company (Amanatidou et al., 2014). The current evaluation practices that rely on survey-based data are unsuitable to unfold the dynamics of the internal processes of the treated firms (Gök and Edler, 2012). According to Gök (2010), the comparative static perspective of these studies basically examines two stationary snapshots of the firm’s input or output indicators characterising certain behaviour (i.e. level of R&D cooperation) and attribute the difference to behavioural additionality. It is obvious that such an approach does not inform the evaluators about links between the intervention and the company’s innovation process nor grasp the entire spectrum of behavioural and strategic effects.

Within the past ten years, a couple of doctoral theses defended at the University of Manchester (Gök, 2010; Pérez, 2016) have sought to address these limitations related to the concept of behavioural additionality and its evaluation. Inspired by Nelson and Winter (2004) seminal contribution to evolutionary economics, Gök (2010) proposes organisational routines as a unit of analysis for
behavioural additionality. Organisational routines are defined as ‘repetitive\(^{10}\), recognizable patterns of interdependent actions, carried out by multiple actors’ (Feldman and Pentland, 2003, p. 95), such as adopting new approach to purchases of components or standard product testing methods for implementing a R&D project. Gök (2010) also assimilated the evolutionary micro-meso-macro framework of Dopfer and Potts (cf. Dopfer et al., 2004) to his approach. The micro level refers to the evolution of particular organisational routines in particular firms by government action, the meso level refers to the evolution of particular organisational routines within a population of firms, such as industry, and the macro level refers to the evolution of widely practiced and institutionalized organisational routines. Empirically, both doctoral theses employed multiple case study approach with the aim to test if the methodology is capable of observing complex organisational processes over time in order to identify behavioural additiounality through changes in routines, e.g. Gök (2010) detected in case companies a new routine of collaborating internationally to perform R&D. However, the studies remained at firm-level; the methodology was left empirically untested at the meso-level.

### 1.2.3. Evaluating market formation processes

The Gök’s (2010) approach to evaluation of behavioural additionality echoes the conceptual focus of the Dopfer and Potts framework, which stresses that evolutionary meso-economics stands at the core of evolutionary economic analysis. Meso is the analytical domain that deals with populations of agents. The evolution of the economic system, such as the market, is a process driven by the origination, adoption, adaptation and diffusion of novel ideas in a population of interacting agents (Dopfer et al., 2004). Market formation starts when new technical knowledge, created through entrepreneurial effort of an economic agent, connects to the cognitive, social and behavioural context in a way, which turns this novelty understandable and communicable to other agents (Bleda and del Río, 2013), which is the pre-requisite for further adoption. In the Dopfer and Potts framework, the processes of origination and adoption at the meso-level are the most essential to capitalism. Evolution at the meso-level is ‘evidenced in transformed market and industrial organisational structures’ (Dopfer et al., 2004, p. 272) and may involve new markets as ‘any new product can always be defined as the basis of a new market’ (p. 274). Creating new markets through public demand is one of the main tasks of demand-side innovation policy instruments in the framings 2 and 3. Therefore, the evaluation of demand-side policies has to go beyond firm-level perspective and cover also meso-level, combining qualitative and quantitative methods (Edler et al., 2012).

If the aim of demand-side instruments is to guide existing markets towards new consumption and investment patterns, which is often the case for the demand-side interventions (particularly in energy markets), then evaluators have to select indicators that appropriately describe changes in core themes addressed with the policies. With that respect, Edler et al. (2012) refers to pioneering market transformation programs, such as the Swedish market transformation program (cf. Neij, 2001; Neij and Åstrand, 2006), as the demand-side policies with the most elaborated evaluation designs. Neij (2001) highlights that such evaluations have both summative and formative roles and should monitor the changes in actors’ behaviour, market development, and technology development. In the long term, the dynamics of various parameters, such as changes in available products and engaged actors, changes in market share of products and actors, changes in product performance and price, and formal and informal standards, describe the persistence of market transformation. Neij and Åstrand (2006) discuss this bundle of outcome indicators in the context of impact assessment of the transformational policy on a complex socio-economic system, which, in essence, is basically a combination of multiple technological innovation systems (see chapter 1.1.2).

Bleda and del Río (2013) emphasize the usefulness of the TIS functional perspective in capturing the dynamics of markets in an innovation system. Both theoretically and empirically, the TIS perspective has been mostly dealing with emerging technologies that are the important building blocks in the formation of new markets. Early literature identified two phases of market creation – a formative phase and a growth phase (Bergek et al., 2008). The empirical work on the build-up of a TIS has used a

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\(^{10}\) In this context, repetitiveness implies persistence.
diversity of indicators to characterise the performance of market formation function of a TIS (a few examples are given in Table 3). The indicators can be grouped into several categories that connect to the three key analytical dimensions characterising a TIS. These dimensions are: (1) actors who are involved in the TIS, (2) institutions that affect the actions of these actors and (3) dynamically evolving technology (Markard, 2020). Indicators such as sales figures, number of sold units, market size, or market shares can be derived from aggregated firm level data of relevant actors. The firm-level data can be gathered through the prevailing subject-centric data collection approach. However, the build-up of a TIS can be a decades-long process, but even in such case market formation may remain insignificant (Suurs et al., 2009; Bento and Wilson, 2016). Therefore, delineating relevant actors may be challenging in practice because new markets involve loosely connected, emerging populations of interacting agents, which sales figures are often low or close to zero. Uyarra (2016) notes that problems with defining the target groups of the demand-side interventions is one of the reasons why such instruments in general and PPI in particular are greatly under-evaluated.

**Table 3. Market formation indicators in empirical studies on the build-up of a TIS**

<table>
<thead>
<tr>
<th>Study</th>
<th>TIS</th>
<th>Market formation indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gosens and Lu (2013)</td>
<td>Wind power (China)</td>
<td>• Size of markets formed&lt;br&gt;• Drivers of market formation (e.g. support scheme)&lt;br&gt;• Competitiveness of domestic and foreign firms in global markets;&lt;br&gt;• Relevance of domestic and international support schemes</td>
</tr>
<tr>
<td>Bento and Fontes (2015)</td>
<td>Energy technologies (Portugal)</td>
<td>• Events of tariff stimuli&lt;br&gt;• Installed capacity&lt;br&gt;• Market shares</td>
</tr>
<tr>
<td>Bento and Wilson (2016)</td>
<td>Energy technologies</td>
<td>• Sales figures (incl. subjective assessments if sales growth is permanent and represents take-off),&lt;br&gt;• Sold unit numbers&lt;br&gt;• Installed capacity</td>
</tr>
<tr>
<td>Chou et al. (2019)</td>
<td>Fuel cells (Taiwan)</td>
<td>• Events of market regulations&lt;br&gt;• Events of tax exemptions</td>
</tr>
<tr>
<td>Sawulski et al. (2019)</td>
<td>Offshore wind (Poland)</td>
<td>• Size of markets formed&lt;br&gt;• Subjective assessments of expected future market size</td>
</tr>
<tr>
<td>Kushnir et al. (2020)</td>
<td>Hydrogen reduction (Sweden)</td>
<td>• Descriptions of customer groups&lt;br&gt;• Descriptions of application types&lt;br&gt;• Sales information</td>
</tr>
</tbody>
</table>

Source: the author’s compilation

Some of the market formation indicators in Table 3 represent the institutional aspects of the functional performance of a TIS, such as events of tariff stimuli in Bento and Fontes (2015) and events of market regulations in Chou et al. (2019). From the perspective of sociological neo-institutional theory (cf. Scott, 2014), these indicators fall under regulative institutional pillar. According to sociological neo-institutional theory, regulative institutions such as laws and rules make sure that actors behave according to certain regulated standards out of fear of sanctions. The normative pillar consists of norms and values that allow actors to perceive the social implications of a certain behaviour. It represents assumptions and expectations about what is appropriate or expected in social interactions (Scott, 2014). Cognitive institutions refer to “ways, perceptions, and descriptions, theories and models, empirical data about reality and thus, the understanding of a business reality as a basis for operating as a successful business” (Edvardsson et al., 2014, p. 302). In the Markard’s (2020) TIS life cycle model, cognitive institutions have an influential role in the formative phase. Wirth et al. (2013) show that the effects of

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11 The ‘subject-based’ approach that is in line with the Oslo Manual (OECD, 2005) looks at the innovative behaviour and activities of the firm, while data collection with a focus on specific innovations, embodiments of new technical knowledge (‘object-oriented’ measurement), could be better suited for tracing the impact of demand-side policies (Appelt & Galindo-Rueda, 2016).
the regulative pillar on the meso-level dynamics depend on the normative and cognitive institutions that modulate the effects. Actors are often engaged with the purposive action to create and disrupt institutions. This institutional work (cf. Lawrence and Suddaby, 2006), even by a single market actor (Kukk et al., 2016), is instrumental in market formation. In the absence of other quantifiable indicators enabling to capture weak signals of market formation, tracing institutional change along all institutional pillars, not only in regulative pillar, could be useful to understand if demand-side interventions are sufficiently effective in triggering expected meso-level changes. However, measuring institutional change is challenging because of problems with theoretically sound operationalisation of the concept – “articulating institutions along three encompassing pillars may encourage the view that everything is an institution” (Abdelnour et al., 2017, p.1779). Another problem is how to deal with proto-institutions, which are defined as weakly embedded and less persistent institutions (Lawrence et al., 2002). Commonly used measurement approaches such as surveys to detect changes in market actors’ behaviour or preferences convey valuable information about the meso-level changes. Cost and effectiveness considerations of monitoring institutional change over the market gestation period limit their practical applicability, though.

1.2.4. Evaluating the impacts of Big Science organisations

A comprehensive review by Reid et al. (2018) concludes that there is no unified framework for the socio-economic impact assessment of public investments in Big Science and, more broadly, in large scale research infrastructures12. They offered a typology of approaches that have been applied by evaluators. This list included:

1) Socio-economic assessments based on impact multipliers that are used to estimate the effect of an additional investment to Big Science in a pre-defined industrial sector or economic activity (direct impact) or on the whole economy (indirect and induced impacts); the latter macro-level approach is more appropriate for ESA as its programmes are generally involving a variety of industrial players in a broad range of industrial activities (Teirlinck and Khoshnevis, 2020); this stream of evaluations applies the analytical input-output framework that dates back to the works of Leontief in the 1930s (cf. Miller and Blair, 2009);

2) Methodologies grounded in the knowledge production function approach, based on seminal contributions of Griliches (Griliches, 1979; Pakes and Griliches, 1980), that connect the inputs, the outputs, and the rules according to which inputs are transformed into the outputs;

3) Cost-benefit analysis;

4) Approaches based on multi-methods, such as the approach developed mostly by Ben Martin at the Science Policy Research Unit (SPRU) of the University of Sussex (Martin, 1996; Martin and Tang, 2007) and adaptations of the BETA method, originally developed in the 1970s by the Bureau d’Economic Théorique et Appliquée at the University of Strasbourg to study the economic impacts of ESA and CERN (Bach and Matt, 2005; Bach and Wolff, 2017), and

5) Case studies.

Reid et al. (2018) also discussed theory-based evaluations (cf. Weiss, 1997) that focus on causal change processes induced by policy interventions but in the context of Big Science these are very rarely considered (Simmonds et al., 2013). In the following paragraphs, multi-method approaches, case studies, the production function approach, and cost-benefit analyses that are consistent with the micro- and meso-level perspective of the thesis are discussed in more detail.

12 Partial overlaps between these two terms – Big Science and research infrastructures – are well addressed in Hallonsten (2020). While “the most physically imposing (and expensive) research infrastructures, accelerators and reactors, are also archetypal examples of Big Science” (p. 7), the roadmap issued by the European Strategy Forum for Research Infrastructures (ESFRI, 2018) contains also distributed data repositories and vessels (icebreaker ships or aircraft) as the research infrastructures of Pan-European importance. Such heterogeneity, due to various political reasons, undermines the analytical value of the construct of large-scale research infrastructures.
Multi-method approaches seek to capture the multidimensional nature of the socio-economic impacts of Big Science. The SPRU approach combined various indicators for measuring scientific activity, production and progress, indicators for tracking record of publications and citations and their quality and importance, and other indicators to measure other factors, such as contributions to the development of new or improved technologies and include new products, processes and services (for CERN, Irvine and Martin, 1984). The BETA method has been extensively used to study the so-called indirect industrial effects from ESA contractors’ involvement in ESA programs, both at European level (Cohendet, 1997; Bach et al., 2002) and, in a modified and reduced form, at national level (e.g. Ramboll Management, 2008; Norsk Romsenter, 2018). The BETA method emphasises the importance of the knowledge creation and diffusion processes associated with the collaboration between ESA contractors and ESA. The indirect industrial effects are the firm-level effects that go beyond the scope of the objectives of the contract between ESA and its suppliers. They are defined through the acquisition of new knowledge that increases the capacity of the contractor. The incumbent firm exploits this extra capacity for purposes not related to the collaboration with the Big Science. The indirect industrial effects are quantified ex post using, wherever possible, standard sales, added value and cost-savings figures (or proxies) and always following the principle of minimum estimate. The data is collected through interviews with the top management or R&D managers of companies (Bach and Matt, 2005). While the BETA approach sees its theoretical roots in evolutionary theory of innovation and the resource-based view of the firm, Reid et al. (2018) consider both the SPRU approach and the BETA methodology ‘largely atheoretical’ (p. 26). The BETA methodology has been applied in smaller ESA member states, where the total population of ESA suppliers is measured in tens of companies (Eerme, 2016), and used for international comparison (OECD, 2012), despite the claims that without the well-established connection to a widely accepted theory, the reliability of the assessment method and comparability of different studies are questionable (Reid et al., 2018).

In addition to the more traditional quantitative approaches in impact assessments, case studies provide valuable insights about the impact-generating mechanisms activated by Big Science-supplier interactions. Based on the cases of 14 Swedish CERN suppliers, Åberg and Bengtson (2015) investigated the connection between innovation outcomes and the complexity of Big Science-supplier interaction. Two dimensions of the interaction were highlighted - mutual involvement in a dyadic relationship and continuity of the relationship. The cases provided evidence that the level of mutual involvement modulates the innovation outcomes from Big Science-supplier interaction but continuity of the relationship does not have a similar effect. Autio et al. (2004) developed a theoretical framework that describes how Big Science organisations operate as sources of learning for their industrial suppliers relying on three in-depth case studies of projects implemented by companies in collaboration with Big Science. The framework stresses the important role of relational social capital but also learning potential nested in the access to the wider community around Big Science. The two detailed case histories in Szalai et al., (2012) trace trajectories how space technologies developed for the purposes of ESA missions reach non-space markets to shed light on the processes behind the indirect industrial effects. Reid et al. (2018) argue that the existence of standardised implementation rules has a positive effect on the reliability of the case study approach. Case studies, with their context specific narratives, are unavoidably heterogeneous in method, which means that research results are hardly reproducible and, thus, there is an issue with the generalisability of the results. At the same time, the ability to account for the context in which Big Science organisation operate is the main advantage of this stream of impact assessments.

The production-function approach can be applied to estimate impacts at macro-level and at micro-level. According to Reid et al. (2018), studies based on the production-function approach that look into the firm-level effects from the collaboration with Big Science organisations are scarce. The most elaborate study was performed by Castelnovo et al. (2018) using a sample of 365 CERN suppliers. The firm-level data contained detailed information about procurement contracts with CERN and accounting data of the

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13 Dyad denotes a relationship between two organisations.

14 A good example is Matt et al. (2017), who on the basis of 32 standardised case studies of innovation from a single agricultural research organization, develop a typology of impact-generating pathways for such innovations.
companies for the period 1996-2007. Its empirical strategy was based on the Crépon–Duguet–Mairesse framework. The following sequence of events was tested as a system of simultaneous equations using a three-stage least squares procedure for the estimation: (1) if procurement relation with CERN leads to increase in R&D effort (proxied by the yearly variation of intangible fixed assets per employee in the model), which (2) results in more innovations as measured in a number of patents, which (3) leads to higher productivity (in the model, the yearly change in sales normalised by the number of employees is used as a proxy for labour productivity) and, ultimately, (4) to change in revenues and profitability (using different financial performance indicators, such as EBIT). For high-tech companies, the estimation results underscored the direct “CERN effect” on R&D investments as well as its mediated impact on company innovation output, productivity and economic performance. In other words, the study provided evidence of input additionality and output additionality from offering sophisticated products to Big Science. One of the main strengths of the study is usage of accounting data instead of survey-based data. In principle, the methodology could be replicated to identify the direct “ESA effect” on ESA suppliers. However, applying this methodology to investigate “ESA effect” on ESA suppliers in small ESA member states, such as Estonia, is constrained by a lack of relevant data. As of June 2020, there were only 24 ESA suppliers among Estonian companies. Two Estonian companies that were awarded an ESA contract before 2015 have ceased to exist and another four did not create any turnover in the most recent available financial year. This relates to one shortcoming of the Castelnovo et al. (2018) approach – it did not account for the survival of CERN suppliers, which may result in biased estimators. The same research group at the Università degli Studi di Milano recently published another work on the relationship between the public procurement by Big Science and its suppliers’ performance (Florio et al., 2018). As discussed in the previous paragraph, several case studies have provided evidence about the positive association between the relational governance of Big Science’s procurement and innovation outcomes for its suppliers. By using survey-based data of 669 CERN suppliers in 33 countries and Bayesian network analysis, such association was confirmed. Moreover, the empirical results indicated that better economic performance of Big Science suppliers is linked to their ability to exploit CERN as an important marketing reference. This finding resonates with the results of an earlier survey on the technological learning and innovation benefits derived from CERN’s procurement activity – 42 % of the respondents of the survey claimed that CERN’S procurement helped to increase their international exposure during the period 1997–2001 (Autio et al., 2003).

Cost-benefit analysis aims at appraising the Big Science’s full contribution to social welfare by evaluating non-market impacts and using shadow prices that reflect the social opportunity cost of goods and services. Therefore, applicability of cost-benefit analysis for the impact assessment of Big Science has been hindered by the methodological complexity and, consequently, costs of accounting for all relevant benefits (for ESA programs, cf. Clark et al., 2014). However, Florio and Sirtori (2016) developed a specific framework for Big Science organisations, empirically tested by Florio et al. (2016) for CERN. The empirical study identified four classes of direct benefits related to the knowledge output of scientists, human capital formation, technological spillovers, and direct cultural effects for the general public. It must be noted that an array of methodological issues must be solved for assigning values to different parameters to calculate the monetary values of social benefits. For example, while the number of scientific publications in peer-reviewed journals is a reasonably good proxy for the scientific production of Big Science (Martin, 1996), it may be difficult and time-consuming to trace a particular publication back to a particular Big Science organisation (cf. Hallonsten, 2016). In the Florio et al. (2016) study, the largest component of the benefit side was related to human capital formation, i.e. benefits to students and post-docs, calculated on the basis of expected wage premiums attributed to the involvement with Big Science. Technological spillovers, computed as the estimated incremental profits of the Big Science suppliers in adjacent markets, were almost at the same level with the benefits to students and post-docs. Interestingly, the estimation procedure of technological spillovers used the published multipliers of various studies based on multi-method approaches as inputs without paying attention to the incommensurable nature of these indicators. The Estonian scientific production is strongly impacted by involvement in Big Science, and CERN in particular (Hirv, 2019). This calls for

\[25\] In the model the relational governance was a binary variable taking the value 1 if suppliers, according to their own opinion, processed CERN orders with frequent and intense interaction with CERN staff.
assessing the Big Science's full contribution to social welfare at national level. However, as was argued before, the empirical data, expressed in terms of increased sales and cost savings, or increased profits, is insufficiently available to assess the technological spillover component of the social benefits of ESA.

1.3. Research questions

This thesis explores the firm-level and industry-level effects from the participation in international Big Science organisations, focusing on the involvement of Estonian companies in the programs of ESA. Different strands of literature on innovation policy converge to an understanding of the public funding to the membership in international Big Science organisations as a systemic innovation policy instrument helping to target the market, systemic, and transformational failures. The theory-based rationales behind this policy instrument form a starting point for the assessment of its effects and impacts. The previous section discussed the compatibility of different types of impact assessments of public investments in Big Science with different framings for innovation policy (cf. Schot and Steinmueller, 2018). For example, methodologies grounded in the knowledge production function are theoretically consistent with the linear model of innovation in the framing 1, while the theoretical reasoning behind the BETA methodology, a multi-method approach, is in line with the innovation model in the framing 2.

The main limiting factor hindering application of different impact assessment approaches is availability of data. The total number of Estonian companies that have supplied technologies, products, and services to ESA between 2011 and June 2020 is 24, insufficient to apply rigorous large-N econometric methods on data from governmental repositories and the ESA Procurement Department, and survey-based data. At the same time, multi-method approaches (e.g. for Denmark, Ramboll Management, 2008) and case based approaches (e.g. for Sweden, Åberg, 2013) have been deployed in academic and grey literature to assess the firm-level effects of the participation in Big Science organisations in its smaller member states.

In space domain, various country-level studies have collected primary data through interviews and surveys to establish the magnitude of the firm-level effects accrued to ESA suppliers thanks to technology transfer and learning benefits from the collaboration with the agency (OECD, 2012). Edler et al. (2008) suggests that evaluation results of specific individual policy instruments, such as the membership in ESA, should be used more systematically to disclose regularities in the evaluations. They propose secondary analyses – systematic reviews and syntheses of evaluations – to determine the quality of their processes and findings. One of the purposes for conducting a meta-analysis of a set of evaluations is to identify strengths and weaknesses in evaluation practice. The expected outcome of evaluation syntheses is to reach to more generalised conclusions about a policy instrument (Cooksy and Caracelli, 2005). A secondary analysis carries a potential to enhance policy-makers’ understanding of the policy instrument and therefore it encompasses formative aspects. Against this backdrop, Study 1 responds to the call by Edler et al. (2008) and reviews systematically the existing country-level studies of the firm-level effects and additionality from the participation in the programs of the European Space Agency. The study asks the following research question – how methodologically trustworthy are the processes and findings of the available country-level studies on public investments to ESA programmes? Each study has a specific context shaped by the prevailing evaluation practices (e.g. guidelines of the best practices at national level, regularity of evaluations), industry structure, or data sources for data triangulation. The answer to the first research question enables to appraise the value of the current evaluation practices for policy-makers at both national and supranational level, and determine the reliability of reported indicators for international benchmarking purposes (cf. OECD, 2012).

Extant literature has paid considerable attention to the different learning processes that happen in the supplier firms during their collaboration with Big Science organisations. In particular, the focus has been on the technological learning taking place not only in this mutual relationship but also between Big Science suppliers and actors in the Big Science organisations’ wider R&D network (Bach et al., 2002; Nordberg et al., 2003; Autio et al., 2004; Åberg and Bengtson, 2015; Florio et al., 2018). Learning is cumulative; the learning processes are supported by the amount of dyad-specific resources brought into
the collaboration. Readiness to build up such resources depends on the congruence between organisational goals of the parties (Autio et al., 2004). Accumulation of market and marketing knowledge in this learning environment has also been acknowledged by researchers (Cohendet, 1997). A contract with ESA is a case of direct exports for its suppliers from countries where ESA as a Big Science organisation with distributed facilities does not operate technology units. Exporting entails ‘learning by exporting’ effects, i.e. exposure to foreign customers enhances the firms’ technological, market, and marketing knowledge, which in turn forms the basis for the development of further innovations (cf. Love and Ganotakis, 2013). To add to the learning effects, both quantitative analysis in academic research (e.g. Florio et al., 2018) and quotes from the interviews with Big Science suppliers in grey literature (e.g. Ramboll Management, 2008) have highlighted the importance of collaboration with Big Science as a marketing reference. Being selected for delivery of novel products or services by ESA certifies the quality of the supplier to uninformed third parties (Lerner, 2000), thus, it is a major event in the process of legitimation of an actor. Legitimacy is viewed as a resource, which is facilitating the acquisition of other tangible and intangible resources (Zimmerman and Zeitz, 2002). However, in literature, the emphasis has been on measuring the monetary value (Cohendet, 1997) or determinants (Florio et al., 2018) of the reputation effects. There is a research gap concerning the understanding of the processes of market and marketing knowledge acquisition, assimilation and integration associated with the collaboration with Big Science. Therefore, the second research question of the thesis asks how firms capitalise on knowledge from collaboration with Big Science organisations. More specifically, Study 2 focuses on the internationalisation processes of resource-constrained, knowledge-intensive companies to answer this question.

Contributions by various authors suggest that procuring sophisticated products and services at the highest possible governance level by a competent supranational body, such as a Big Science organisation, positively affects firm-level innovation outcomes from PPI/PCP compared to procurement conducted at lower levels of governance (Guerzoni, 2010; Georgiou et al., 2014). Big Science organisation is an innovation intermediary, which activities in an innovations system are leveraged by their high-level of technical expertise, procurement skills, reputation, and market power (Leyden and Link, 1999; Landoni, 2017). These properties enable them to identify latent needs and to convert them into concrete and explicit users’ requirements (Boon and Edler, 2018). Innovations developed to satisfy these requirements form the basis for new markets. Actions of Big Science organisations are affected by prevailing institutional order but given the multitude of roles prescribed to Big Science by its member states (Robinson and Mazzucato, 2019), they are also acting as change agents that induce institutional development potentially supportive to market formation processes (Battilana and D’Aunno, 2009). This facet of Big Science has not been discussed in the academic literature. Against such a background, the third research question of the thesis asks: how PPI/PCP implemented at supranational level by Big Science organisations leads to the meso-level institutional change? Study 3 seeks answer to this question from the perspective of ESA contractors involved in the emerging market of Earth Observation applications.

Both Study 2 and Study 3 deal with different aspects of behavioural additiveness from participation in Big Science. The studies seek to contribute to the understanding of mechanisms how did this innovation policy instrument alter behaviour of its suppliers and how persistent are those new behaviours.

1.4. Data and methods used in the thesis

The focus of the research was set on the efficiency and industrial policy considerations regarding a small country’s participation in the programmes of the European Space Agency. The research aimed at finding associations between various micro-economic parameters, such as the size and financial indicators of ESA suppliers, and their position in value chain, and different types of additiveness attributable to ESA membership. Therefore, the first research task was to elaborate a data collection methodology for identifying different types of firm-level effects from collaboration with ESA.
For that purpose, a meta-analysis of the existing country-wide impact assessments focused on measuring firm-level additionalities of public investments to space programs was carried out. The meta-analysis covered the existing body of academic and grey literature. A set of studies subjected to the analysis was identified by re-examining earlier reviews (e.g. Hof et al., 2012; Simmonds et al., 2012; OECD, 2014). An additional search was performed in electronic journal databases (Web of Science, Scopus) and publication repositories of national space agencies and space offices in Europe. The final sample comprised of the country-wide impact assessments of five countries: Belgium, Denmark, Ireland, Norway, and Portugal. In each case, the coverage of the study was described along with the methodological steps taken by study teams. In order to collect data on the methodological considerations of the reviewed studies, the author conducted seven interviews with the representatives of space offices and research teams who implemented the impact assessments (see Table 4). In case of Norway, the assessment was performed by the space agency itself. In Portugal, the company that performed the study was dissolved. Collecting the additional primary qualitative data from parties involved in the impact assessment process enabled to tackle the common problem of limited information in situations, when formal reports are the only sources used meta-evaluations (Cooksy and Caracelli, 2005). The detailed description of each study in the sample contained information about the total population of ESA suppliers in the respective countries, the concentration levels of ESA contracts, data collection methods, characteristics of collected quantitative and qualitative data, applied data triangulation approaches, key indicators, and theoretical foundations and political arguments behind the selection of the indicators. The main findings of the meta-analysis were reported in Study 1.

Table 4. Interviews regarding the methodological aspects of the country-wide impact assessments

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Represented organisation</th>
<th>Impact assessment</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian Landbo</td>
<td>Ramboll Management</td>
<td></td>
<td>November 12th, 2013</td>
</tr>
<tr>
<td>Didier Baudewyns</td>
<td>Université Libre de Bruxelles</td>
<td></td>
<td>January 8th, 2014</td>
</tr>
<tr>
<td>Luís Serina</td>
<td>Fundação para a Ciência e a Tecnologia</td>
<td>Clama Consulting (2011)</td>
<td>February 19th, 2014</td>
</tr>
</tbody>
</table>

The results of the meta-analysis were used to develop guidelines for semi-structured interviews to collect data on the firm-level effects from the collaboration with ESA in two new ESA member states – the Czech Republic16 and Estonia17. The interview guidelines can be regarded as a modification of the original BETA methodology (Cohendet, 1997; see Ch. 1.2.4). Face-to-face interviews with 25 ESA suppliers were conducted by the author of the thesis between February 2015 and April 2015. The companies in the study sample accounted for 91% and 88% of the total financial value of ESA contracts with the Czech and Estonian industry, respectively. These interviews revealed that a time lag between the beginning of an ESA assignment and additional output attributed to this contract by interviewees was five years on average (Eerme et al., 2015). Consequently, most of the Estonian suppliers to ESA were in the development phase during the fieldwork, where ESA-derived products and services weren’t still ready for markets. The initial research idea was discarded because the lack of quantitative data.

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16 Full member state of ESA since 2008.
17 Full member state of ESA since 2015.
The author of the thesis worked as a consultant assisting the Estonian Space Office and Estonian small- and medium sized companies (SMEs) in matters related to ESA industrial policy and ESA procurement system since 2010. He could closely follow the activities of the ESA suppliers in Estonia without the direct involvement in the internal processes of the companies and, hence, had an observer role (cf. Piekkari et al., 2013). Two witnessed phenomena drew the researcher’s attention – the role of ESA in the internationalisation processes of its suppliers and in the formation of new markets for innovations developed during R&D projects procured by ESA. The interviews with the Czech and Estonian companies provided evidence that the collaboration with ESA considerably affects the internal processes of the ESA contractors as well as interactions between the firms and other actors in their business networks. Persistent changes in the collaboration patterns with cross-border partners and entrepreneurial activities to induce change in institutional environment steering the behaviour of actors in the focal firms’ networks fall under the concept of ‘behavioural additionality’ (Gök and Edler, 2012), an antecedent of output additionality from the collaboration with ESA. In the longer run, output additionality could be identified and measured with the methods elaborated for the fieldwork in the Czech Republic and Estonia.

While the details of the employed research methods and data collection approaches are presented more thoroughly in the Studies 2 and 3, two overarching themes are discussed in the following paragraphs. First, the adoption of the qualitative research design. Both phenomena of interest are understudied in the extant literature. There is still little known about associations between constructs that constitute building blocks of the nascent theories on internationalisation of knowledge-intensive firms for resource seeking and innovation intermediation for multi-level institutional change. Also, there are knowledge gaps regarding how ESA is connected to the sequence of events and activities that take place within the firms and in their external environments. In case of nascent theories, (Edmondson and Mcmanus, 2007) argue that qualitative inquiry has a value for inductively generating new theories or refining the existing theories on the basis of fieldwork: observations, interviews, and archival data. Hence, there is a good methodological fit with the research tasks of this thesis as qualitative methods facilitate the emergence of rich, context specific, in-depth description of the phenomenon (Ghauri, 2004). Both Studies 2 and 3 are multiple-case studies because of the ability of case studies to illustrate the process logic and establish links between constructs (Siggelkow, 2007).

Table 5. Major rounds of data gathering in Estonia

<table>
<thead>
<tr>
<th>Period</th>
<th>Method</th>
<th>Number of ESA suppliers involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 2014</td>
<td>Self-reported survey covering capabilities of companies and applications of their space technologies</td>
<td>11 companies</td>
</tr>
<tr>
<td>February-March 2015</td>
<td>Semi-structured interviews covering different aspects of how knowledge and technologies acquired through collaboration with ESA are used in business practices</td>
<td>10 companies</td>
</tr>
<tr>
<td>December 2016 – January 2017</td>
<td>Semi-structured interviews covering the acquisition and assimilation of market and marketing knowledge and other resources through collaboration with ESA and the impact of these activities on the evolution of business networks</td>
<td>6 companies</td>
</tr>
<tr>
<td>June 2017</td>
<td>Self-reported survey covering the characteristics of ESA-derived products and services and their commercialisation routes</td>
<td>11 companies</td>
</tr>
<tr>
<td>March 2018</td>
<td>Semi-structured interviews covering different aspects of how knowledge and technologies acquired through collaboration with ESA are used in business practices</td>
<td>6 companies</td>
</tr>
<tr>
<td>May 2018</td>
<td>Self-reported survey about the outputs, outcomes and impacts of all ESA contracts</td>
<td>10 companies</td>
</tr>
<tr>
<td>January - March 2019</td>
<td>Semi-structured interviews covering the institutional change in the evolving service ecosystems</td>
<td>4 companies</td>
</tr>
</tbody>
</table>

Source: author’s compilation
Second, ESA suppliers in Estonia were examined over an extended period of time in order to identify and explain patterns of change in its context. Longitudinal case studies are useful to provide the details of how dynamic processes actually play out (Pettigrew, 1990). The data about the Estonian firms were collected in several rounds of semi-structured interviews and surveys, which were conducted for different purposes (Table 5). The nature of the indirect industrial effects, their magnitude and individual trajectories how ESA-derived products and services were taken to market were the central themes that were repeatedly covered over time during these data collection rounds. The author of the thesis was in constant contact with the managers of the ESA suppliers through electronic communication channels, such as Skype. The Skype sessions were informal, mainly focusing on different events related to R&D and internationalisation and the managerial reasoning behind them. The Skype sessions provided supplementary information and allowed for the tracking of the development process. In order to increase the validity of the research findings, secondary data from several publicly available and internal documents were obtained for data triangulation. Company websites, newsletters, professional magazines and newspapers supplemented the understanding of the companies. Utilisation of other types of internal documents such as reports related to the projects funded under various EU level or national support schemes or internal memos also allowed for the validation of the views of the informants and a better capturing of the phenomenon over time. Reliance on multiple data sources over a longer period of time enabled to create a “thick description” (Geertz, 1973) of the cases for the analysis.
2. EMPIRICAL STUDIES
3. DISCUSSION

3.1. Empirical findings of the thesis

The thesis opens different aspects of firm- and industry-level effects and additionalities from the membership in the European Space Agency. Three research questions presented in the chapter 1.3 were derived on the basis of the theory-based rationales in three innovation policy framings studied in the chapter 1.1 and the extant practices of evaluations and impact assessments examined the chapter 1.2. The thesis is based on three research papers; each research paper addresses one research question. Therefore, the discussion of the empirical findings pertaining to the formulated research questions is structured along to the individual Studies.

The Study 1 sought an answer to the question how methodologically trustworthy are the processes and findings of the available country-level studies on public investments to ESA programmes? The Study 1 published the results of the systematic review of the extant academic and grey literature on this topic. In the following paragraphs, four key findings that emerged from the Study 1 are highlighted.

First, the low number of ESA partners in smaller ESA member states narrows down the set of available impact assessment approaches in these countries. In ESA member states with population less than 10 million people, the total number of ESA suppliers is usually less than 100. Even more importantly, the ESA contracts are concentrated in the hands of a few main partners. For example, the 10 largest beneficiaries of ESA contracts in Danish private sector were awarded 98% of the total value of ESA contracts in the period from 2000 to 2007 (Ramboll Management, 2008). While larger European countries apply quantitative methods to study the impacts of public space investments, such as impact multipliers based on the analytical input-output framework in UK (e.g. London Economics, 2014) or the production-function approach in Italy (Graziola and Cristini, 2013), the smaller ESA member states resort to the so-called multi-method approaches, measuring aggregated firm-level additionalities of ESA contracts. There were four smaller ESA member states in Europe – Denmark, Norway, Portugal and Ireland – that had performed country-wide ex post analyses measuring the so-called indirect industrial effects that are defined similarly to the BETA impact assessment methodology (Cohendet, 1997; Bach and Matt, 2005).

Second, the reviewed country-level impact assessments focused on firm-level outcomes from the collaboration between ESA contractors and ESA but various knowledge transfer and diffusion pathways that drive those outcomes received very limited attention in these studies. The original BETA methodology takes on an evolutionary perspective and is theoretically grounded in resource-based view of the firm (Bach and Matt, 2005). Consistent with the view that behavioural additionality is an antecedent of output additionality (Ch.1.2.2), the BETA methodology disentangles the indirect industrial effects into different types of inter- and intra-organisational learning effects that are manifested in the improvement in an ESA supplier’s performance into four impact channels (Cohendet, 1997):

- Technological effects relate to learning processes and intra-firm knowledge transfer that results in widening of scientific and technical knowledge but, ultimately, in product and process innovations;
- Commercial effects, such as the impact of ESA programs on the accumulation of market and marketing knowledge thanks to the new research and business connections of the participants involved; similarly to the framework of Clarysse et al. (2009), these new connections provide access to different forms of knowledge, such as business practices and market strategies of other actors, and this knowledge is transferred to the recipient organisation;
- Organisation and method effects, such as inter- and intra-organisational learning that leads to the adoption of novel management procedures and methods and, potentially, to changes in the organisational structure to accommodate these new ways of conducting business, and
- Work factor effects, such as heightened qualifications and skills acquired by the personnel employed in ESA projects.
While the original BETA methodology attempts to look inside a ‘black box’ by studying the effects from participating in ESA programs on different strategic and organisational dimensions of the firms, the reviewed country-level impact assessments collected primary information about inputs (quantity and financial value of ESA contracts) and outputs (additional turnover from technologies and products developed during the implementation of the ESA contracts). The BETA methodology is addressing both behavioural and output additivity, but the reviewed country-level impact assessments essentially dealt with output additivity. In addition to this fundamental difference, there are a few other major differences between the BETA methodology and the reviewed studies that are summarised in Table 6.

Table 6. Comparison between the BETA methodology and the existing country-wide assessments of the firm-level impacts from participation in ESA programs

<table>
<thead>
<tr>
<th>Identified additionalities</th>
<th>Original BETA methodology</th>
<th>Country-level impact assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Behavioural additivity</td>
<td>Output additivity</td>
</tr>
<tr>
<td></td>
<td>Output additivity</td>
<td></td>
</tr>
<tr>
<td>Unit measurement of</td>
<td>Effects measured in value-added units</td>
<td>Effects measured in additional sales</td>
</tr>
<tr>
<td>Counterfactual</td>
<td>The interview protocol takes into account the counterfactual logic, i.e. <em>what if</em> without the participation in the space programmes, whenever possible.</td>
<td>The assessments focus on ESA-generated additional turnover. The counterfactual logic is not explicitly addressed.</td>
</tr>
<tr>
<td>Data collection</td>
<td>Interviews</td>
<td>Mail and online surveys, interviews</td>
</tr>
</tbody>
</table>

Sources: compiled by the author on the basis of Cohendet (1997), Bach and Wolff (2017), and Eerme (2016)

Third, several methodological issues make it difficult to transform the indicators reported in the reviewed country-wide assessments of the firm-level impacts from participation in ESA programs into a standardized indicator for a cross-country comparison. These problems are related to the differences in underlying data collection approaches, such as differences in sampling interval or time series length. There are also certain peculiarities stemming from national contexts, such as the usage of a tax distortion coefficient in the Danish study in order to correct for allocative inefficiency in the calculations of output additivity. Therefore, any cross-country comparisons on the basis of reported indicators should be treated with due care. This resounds with the concerns voiced by Reid et al. (2018), who consider the indicators of multi-method approaches not as a measure of socio-economic impacts but rather markers of periodic change along the impact pathways. Therefore, Reid et al. (2018) argue that multi-method approaches tend to be useful for benchmarking progress towards strategic goals from the perspective of decision makers and managers of Big Science. Study 1 provided evidence to support this understanding. Norway is the only country among the reviewed studies measuring the indirect effects on a regular basis – annually since 1992 – and the responsible ministry applies the indicator to trace the efficiency of public investments to ESA. If the indicator is above the pre-defined threshold, then this signals to decision-makers that the public investments to ESA lead to a sufficient level of indirect effects from the ESA contracts. In other countries, the impact assessment of the membership in ESA remained an *ad hoc* analysis for summative purposes and its usefulness from policy-making perspective was limited.

Fourth, the published results of the country-wide *ex post* analyses of output additivity from public investments to ESA programs raise several questions about the quality of data. The weighted average ratio of the additional turnover from ESA-derived products and technologies to the financial value of the ESA contracts (often called ‘spin-off multipliers’) that ESA contractors self-reported in Norway was above 4, or even higher depending on the length of the time series for calculating the indicator or preset time lags between the contracts and derived effects used in the calculations. Moreover, the histogram of the individual output additionalities of the companies in the study sample of the Norwegian impact assessment showed that there were multiple companies with the ratios of the additional turnover from new products and technologies to the financial value of the ESA contracts to the respective firms exceeding 20. The result that, on average, each Euro invested in companies’ ESA projects results in at least 4 Euros in additional turnover of the companies is in contrast with what is known about private rates of return to R&D (cf. reviews in Hall et al., 2009; Salter and Martin, 2001). The distribution of private rates of return is skewed (Scherer and Harhoff, 2000) but just a small proportion of investments
in R&D yield positive returns while other R&D investments yield very low or even negative rates of return. This implies that the individual output additionalities of the companies in the study sample of the Norwegian study were anomalously high.

If the self-reported data behind the very high values of the individual output additionalities in Norway represented adequately the firm-level effects from the participation in ESA programs, then the access to the ESA procurement system granted to companies through the ESA membership can be viewed as a distinctive, highly-selective policy instrument that is geared towards high-growth firms. The implementation of such instrument (‘picking the winners’ initiative) also requires strong hands-on, capacity-boosting support from ESA to companies. However, the results of the studies on high-growth entrepreneurship (e.g. Coad et al., 2014) point to the difficulties in predicting which firms will grow and the fieldwork of the Studies 2 and 3 does not provide evidence of the unique capacity-enhancing support from ESA to its suppliers. A possible explanation for the high level of output additionality in the Norwegian study is the effect of the project fallacy problem (cf. Georghiou and Clarysse, 2006). It means that the respondents associate the collaboration with ESA with most of the effects of a number of unknown and unobserved factors that might have contributed to the additional output and performance improvements. Another possible explanation is that the respondents deliberately reported inflated data about the effects (the so-called ‘strategic answering’ problem). The high concentration level of ESA contracts with companies in all smaller ESA member states indicates that these companies have incentives to provide such answers to evaluation surveys that help to continue and increase funding to ESA. For example, Archibald and Finifter (2003) argued that high response rate in a survey distributed to the participants in the NASA small business innovation research program was a result of ‘a desire to keep the option open to apply for additional support from NASA’ (p. 608). Due to the research methodology of the Study 1 and lack of available data, none of the explanations cannot be rigorously analysed in order to confirm or reject them.

Study 1 concluded that the results of the existing ex post national level evaluations of public investments to the programs of ESA deserve cautious handling. Despite being intuitive and easy to understand in debates on funding allocations to different innovation policy measures, the usefulness of the spin-off multiplier for international benchmarking or policy-making purposes is limited. The indicator is used for summative evaluations to justify public spending to the ESA membership but its reliability is undermined by the problems with the quality of survey-based data, such as the project fallacy problem or the respondents’ inclination to provide such answers that correlate with the sustained or increased funding level. The latter problem is more acute if the population of ESA contractors is stable over the years. Analysing the evaluation practice in Europe, Edler et al. (2012) highlights that evaluations using methods based on survey data are perceived to be of higher quality. Study 1 points out that there are pitfalls undermining the usefulness of survey-based methods in the evaluations of the membership to ESA that call for careful data triangulation approaches.

The secondary analysis of the existing assessments of firm-level effects from the participation in the ESA programs in Study 1 showed that collaboration with ESA may play an important role in the internationalisation processes of its suppliers. However, the extant literature has focused predominantly on the technological inter-organisational learning and knowledge transfer, overlooking the internationalisation processes of ESA supplier firms and the role of ESA in market and marketing knowledge acquisition and assimilation. Study 2 addressed this research gap and searched for answers to the second research question – how firms capitalise on knowledge from collaboration with Big Science organisations? The main empirical findings of the Study 2 are discussed in the following paragraphs.

Two cases in Study 2 scrutinised the internationalisation processes of knowledge-intensive ESA suppliers in Estonia over a three year period. Study 2 adopted a holistic view of internationalisation delving into both inward cross-border links – understood as the inter-organisational relationships, which add resources to a company’s internal processes – and outward cross-border links that seek to exploit the internal resources (Rilla, 2016). The internationalisation process of the case companies was non-linear and irregular – their activities on various some markets were characterised by transient activity bursts, often confined to inward or outward dimension only, and subsequent withdrawal from the
market. For resource-constrained firms followed in Study 2, the main motive for internationalisation was the need for additional resources to support further R&D activities in order to exploit an entrepreneurial opportunity, similarly to Hewerdine et al. (2014). The perception of the nature of this entrepreneurial opportunity, such as the appropriateness of the value proposition of the company, benefits from the possible first-mover advantage, or features of the competitive environment, is founded on the grounds of the existing knowledge stock of the company. However, a closer look at the internationalisation process implied that some elements of the initial knowledge stock were of value for internationalisation, while other existing knowledge may hinder the firms from adapting to the foreign market environment and should be ‘unlearned’.

Study 2 proposed a new theoretical framework to describe the cyclical internationalisation process of knowledge-intensive, research-constrained firms (see Figure 3). Recursive ‘learning loops’ are the main engines of this process; the firm continuously learns about the technology, market and customers, as well as the competencies required to operate in international markets. The knowledge acquisition and assimilation loop reveals new opportunities and pushes companies to acquire new resources to go after these new opportunities make efforts to reconfigure their existing resource base for improved flexibility. There is an interplay between a company’s resource base, the ‘learning loop,’ and the timing of internationalisation activities. Collaboration with ESA connects inward and outward activities of the firm. The collaboration can be seen as ‘a triggering event’ (cf. Hedaa and Tornroos, 2008) in this non-linear internationalisation process. It is crucial in two simultaneous processes of learning and unlearning of market and marketing knowledge.

Figure 3. The framework for knowledge acquisition and assimilation from collaboration with Big Science organisations, the author’s elaboration on the basis of Eerme and Nummela (2019b)

The execution of the ESA contract involves co-creation between the purchasing agency and the supplier: an immature technology is developed jointly into a more scalable and marketable product. The ESA contractor benefits from temporary access to the high-level of technical expertise concentrated at ESA due to long-term collaboration with companies in its wide partner network with similar technological capabilities as the supplier. This co-creation channels not only useful technical knowledge to the ESA supplier but also specific market and marketing knowledge, such as improved understandings of preferences of various end-user groups or viable business strategies. Moreover, the case companies established contacts with their peers during industry events organised by the ESA, gatherings of
incumbent industry actors along the full value chain, and by extracting and using relevant information from ESA supplier databases. All this resulted in better awareness about the structure of and actors in the relevant value chains in Europe. Based on the leveraged market knowledge, it was possible to approach the ESA and ask its staff to act as brokers for new business ties. In line with the notion by Hameri (1997), Study 2 provided evidence demonstrating that collaboration with Big Science offers diverse opportunities for its suppliers even from geographically peripheral areas to expand and improve their business networks and become more engaged in inward and outward cross-border collaboration.

Study 2 contributed to the understanding of the role of ESA contracts as a powerful marketing reference. It would be more appropriate to label this phenomenon as a 'legitimising signal’ as a word 'marketing’ implies that ESA’s role is restricted to only outward links. In fact, ESA has a strong impact on both inward and outward internationalisation activities of its suppliers even without direct involvement in these processes. The cases provided evidence that entering new business networks would not have been feasible to the extent that was experienced without a strong legitimising signal provided by the relationship with a highly esteemed organisation such as the ESA. Without the ESA’s facilitating role, it would have been unthinkable for the Estonian companies to reach out to leading multinational companies. Heavy reliance on this legitimising signal as a centrepiece of resource-access strategy is what Rawhouser et al. (2017) called a ‘strategy of projective associations’ – high-quality relationships can often indicate the viability of a company and enable to overcome the liability of newness, thus opening up paths to necessary tangible and intangible resources. Collaboration with ESA enables its suppliers to improve their network position, which is associated with elevated level of inflow of market and marketing knowledge. Even though most of the established business ties with large multinationals were short-lived, highly specific knowledge about the market conditions in different countries was channelled to the case companies in these temporary networks of actors.

The organisational learning loop that feeds new market and marketing knowledge into a firm’s decision processes may also imply the need to cyclically unlearn, discard existing business strategies and adopt new ones. The cases demonstrated how market and marketing knowledge collected from the large number of long-lasting and temporary cross-border links that were created by virtue of a single contract with the ESA caused the companies to continuously reassess its business strategy. There was continuous refinement of the firms’ business models over the course of the data collection period. Building on the empirical part of Study 2 and Gök and Edler’s (2012) definition of behavioural additonal as the persistent change in what the target group of the innovation policy instrument is doing and how they are doing it, the Freel et al. (2019) position that "exporting may be an important behavioural additonal of innovation policy" (p. 2) can be re-phrased in the context of this thesis: 'internationalisation is the important behavioural additonal from participation in Big Science programs’.

The case companies’ internationalisation processes affected by the collaboration with ESA illustrated how impactful can be rather temporary linkages to leading multinational companies in terms of strategy creation and development due to inter-organisational learning. The extant literature on the econometric estimation of behavioural additonal that was discussed in Ch. 1.2.2 often relies on the comparative static perspective focusing on the change in the number of partners at different points of time and attributing the difference to behavioural additonal. The results of Study 2 challenge the usefulness of such approach as it neglects the duration of the linkages and, more importantly, their impact on the knowledge acquisition and assimilation processes of companies.

Study 2 demonstrated that the ESA suppliers capitalise on knowledge from the collaboration with ESA both directly through knowledge acquisition and knowledge transfer during co-creation of new products and services, expansion of business networks through involvement in ESA events and benefitting from intermediation by ESA staff, and indirectly through the strong legitimising signal provided by the collaboration with reputable organisation. The collaboration leads to persistent changes in the suppliers’ business strategy.

18 Understood as a “hypothesis about what customers want, and how an enterprise can best meet those needs, and get paid for doing so” (Teece, 2007, p. 1,329).
For its member states, the membership in ESA and involvement in its various programs means that the procurement of new technologies and innovative products and services is handed over to the supranational level. ESA is engaged with both direct and catalytic procurement. From the economic standpoint, transferring the procurement function to the supranational level implies that the member state’s policy-makers expect higher level of additionalities from such approach compared to the procurement carried out at the national level. As was discussed in chapters 1.2.3 and 1.2.4, in case of innovation policy instruments, which are targeted at infant markets where commonly used indicators often fail to provide reliable input data for evaluators – e.g. sales figures are negligible – monitoring institutional change could be an alternative solution for capturing weak signals of market formation.

Therefore, Study 3 aimed at answering the third research question: how PPI/PCP implemented at supranational level by Big Science organisations leads to the meso-level institutional change? In the following paragraphs, the key findings of Study 3 are discussed.

Eight case companies from three Central- and Eastern European countries (Estonia, Latvia, and Slovakia) are ESA suppliers, which operate in the nascent market of Earth Observation solutions, developing and offering knowledge-intensive business services that are based on processing of satellite imagery. Study 3 showed that without the involvement of ESA as an innovation intermediary, the interaction between the case companies – suppliers – and customers, such as national and regional level public agencies, for mutual value co-creation was impeded by the uneven distribution of knowledge resources. For creating value, suppliers’ knowledge resources, such as accumulated specialist domain knowledge or technological capabilities, must be integrated with customers’ knowledge resources that include different types of contextual knowledge. In addition to high-level of technical expertise, ESA holds deep knowledge about existing markets and emerging market opportunities. By adding ESA as the intermediary in the nascent service ecosystem, a triad emerges which consists of the three dyadic relationships between the ESA, a supplier of Earth Observation applications, and its customers. The empirical findings showed that the emergence of the triad was linked to more intense interaction between the Earth Observation companies and (potential) end-users in the service ecosystem. In line with the theoretical arguments clarifying the role of innovation intermediaries (Howells, 2006), ESA was found to facilitate more productive use of complementarities of the knowledge base of the suppliers and the end-users.

Quite surprisingly, value-generating exchange of knowledge between ESA and the suppliers was held back by certain micro-level normative institutions framing the relationships, such as the norms and values that guide ESA’s behaviour in the procurement process. ESA was engaged with the value co-creation but the intensity of the interaction was below the level expected by the suppliers. Despite this, the influence of the involvement of ESA in the emerging ecosystem was substantial. The evidence showed that the suppliers held certain normative expectations about the role of ESA. Therefore, the suppliers tended to attribute meanings to the actions of ESA, e.g. the ESA contract was perceived to validate the company’s assumptions about the context in which value is created. The adoption of new mental models about business reality in connection to the interactions with ESA – process known as the cognitive disposition mechanism (Siltaloppi and Vargo, 2017) – started to steer the behaviour of the suppliers in the dyadic relationships with other actors in the service ecosystem. It became evident that the reputation of Big Science is not only a source of ‘legitimising signals’ to uninformed third parties that were observed in Study 2 but the reputation also moderates the emergence of new micro-level cognitive proto-institutions, such as beliefs about the appropriateness of certain mental schemas about how to convert new technologies and other resources into desired market outcomes. Historically, reputation has been an important assessment criterion for the performance of Big Science (Braun, 1993). Through the lens of the institutional analysis, Study 3 provides more fine-grained understanding of the interplay between the firm-level effects from the collaboration with Big Science organisation and the reputation of such organisations.

The assimilated understandings about their business context, largely shaped by the cognitive disposition mechanism, guided the activities of the case companies regarding resource integration with the end-users. It turned out that despite the involvement of the intermediary in the service ecosystem that brought
along new configurations of knowledge and competences, disparities in knowledge still persisted hindering the integration of knowledge resources for value co-creation. The case companies gathered new knowledge about the complexities related to the systemic nature of value co-creation through interaction with other actors in the service ecosystem. The expanding knowledge base made clear that actors in the service ecosystem differ in their beliefs and values. To create value, the case companies needed to make entrepreneurial efforts aimed at overcoming the identified differences in micro-level normative and cognitive institutional pillars in order to remove obstacles to effective knowledge resource integration in the dyadic relationships. New proto-institutions emerge as a result of this institutional work (cf. Lawrence and Suddaby, 2006). After several ‘recursive loops’ of deliberate actions by the case companies to change the prevalent institutional order, these proto-institutions either institutionalise to support value co-creation activities of actors in the service ecosystem or fade away. In the first case, new normative and cognitive institutions shared by a population of actors emerge. For example, in the cognitive institutional pillar, this process is manifested in the evolution of shared understandings of the capabilities of the technology and viable business models (cf. Doganova and Eyquem-Renault, 2009). This contributes to the readiness of the end-users in the triad to purchase Earth Observation applications directly from suppliers without the catalytic intervention by ESA. The Estonian data showed that the described meso-level institutional convergence process took more than seven years in some service ecosystems in which there were no additional public policy interventions to accelerate the process. Some service ecosystems may exhibit even stronger institutional inertia due to the deeply rooted assumptions about the roles and ways of working of different actors in the ecosystem.

Study 3 revealed that there are subtle processes of market formation that take place before the nascent market takes off in terms of the continuous growth of annual sales of involved actors. The ‘recursive loops’ of institutional change had a persistent effect on the behaviour of the case companies. Public intervention by integrating ESA as the innovation intermediary to the embryonic service ecosystem did not create immediate output additiveness but did generate micro-level behavioural additiveness. One example of the latter is institutional work, i.e. entrepreneurial behaviour by the case companies to break the institutional barriers impeding value co-creation. The cross case comparison revealed that the meso-level institutional convergence process would not have happened without involving ESA in the ecosystem. Therefore, micro-level behavioural additiveness can be, at least partly, attributed to the ESA membership as an innovation policy instrument. Study 3 examined the triad and institutional change from the viewpoint of the supplier. Therefore, the study did not provide sufficient amount of qualitative data to offer a more comprehensive understanding of processes leading to meso-level behavioural additiveness – the emergence of new persistent shared normative and cognitive institutions.

While the role of ESA in institutional change was important, these processes were also affected by other major changes in macro-level regulative institutional pillar, the emergence of the European Union’s Copernicus program’s19 data policy in particular. The Copernicus program is the most ambitious Earth Observation program worldwide. The Copernicus data policy ensures full, free, and open access to space-based data and information. Also, ESA and the European Union have jointly invested in terrestrial data dissemination platforms to make the data accessible (Aschbacher, 2017). For the case companies, this macro-level regulative institution implied access to resources that enable them to offer new value propositions to multiple other actors without paying for the usage of satellite data with global coverage. Any attempts to isolate the effects of these two major regulative institutional disruptions – accession to ESA and the establishment Copernicus program’s data policy – on actors involved in the service ecosystem in impact assessments inevitably result in the attribution problem and biased estimates of the effects. In practice, the micro-level effects of these two policies are so closely connected that it renders a single instrument perspective in policy evaluation inadequate.

The three papers offered new insights on how the collaboration with internationally reputable Big Science organisation such as ESA activates various impact channels that are associated with the persistent changes in the behaviour of the Big Science suppliers. The firm-level behavioural

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19 The Copernicus program’s space component features a new family of dedicated satellites, called Sentinels, which were specifically developed and commissioned for the operational needs of the Copernicus program.
additionality is linked to the inter-organisational learning between the ESA supplier and ESA, which possesses high-level of technical knowledge in multiple technological domains and up-to-date market and marketing information. It also comes from the supplier’s access to new but sometimes temporary business networks enabled by the legitimising strategy of projective associations (Study 2). The behavioural changes also relate to the cognitive disposition mechanism deeply affecting the micro-level institutional foundations that shape the conduct of the ESA supplier (Study 3). Participation in ESA programs may trigger micro- and meso-level changes that are important from the perspective of the long-term development of innovation systems. If impact assessments rely only on more traditional concepts, such as ex post output additionality derived from survey-based quantitative data (reviewed in Study 1), such changes that take place in early market formation phases may remain unnoticed.

3.2. Theoretical contributions

This chapter summarizes the main theoretical contributions of the thesis. Corley and Gioia (2011) have proposed two dimensions of what constitutes a theoretical contribution – originality and utility. According to this approach, the theoretical contribution of research has to provide new, sometimes revelatory and even surprising, connections among (previously known) concepts and, also, explore the practical implications of these connections. The author of the thesis was the prime investigator in a series of impact assessments related to collaboration with ESA commissioned by the Estonian and Latvian governmental agencies, and the European Space Agency. These assessments combined both summative (ex post) and formative (ex ante) aspects of evaluations. Given this role of the author, the thesis is an example of problem-driven research (Ployhart and Bartunek, 2019) and the main results of the study have imminent practical utility. This thesis is motivated by real-life needs of smaller European countries which have established formalized ties with ESA since mid-1990s. The recently acceded ESA member states and would-be member states need to understand better how to manage the national contributions to ESA programs as effectively and efficiently as possible in order to transform the public funding into different types of additionality.

Study 1 – the meta-analysis of the existing country-wide impact assessments dealing with the firm-level additionalities of public investments to space programs – enabled to identify various methodological caveats related to measuring the firm-level effects in similar studies. The current evaluation practice in smaller European countries tends to apply the so-called multi-method approach focusing on the indirect industrial effects, i.e. the firm-level effects that go beyond the scope of the objectives of the contract between ESA and its suppliers. The usefulness of this approach is dependent on the regularity of assessments, which enables policy-makers to benchmark progress towards pre-defined strategic goals. However, in practice this approach is applied in an ad hoc basis for summative purposes, which does not allow for capturing the full range of inter-organisational learning effects. Also, survey-based studies were found to suffer from the project fallacy and the strategic answering problems. In order to mitigate the respondent bias problems, this thesis suggests that survey-based data should be combined with case-based methods. The conclusions of Study 1 can be directly applied to solving the problems of practicing managers of space offices and policy-makers responsible for space policies in new and prospective ESA member states enabling them to conceive and implement sound impact assessments methodologies.

Study 1 pooled together information about possible impact pathways for realising different types of effects from the collaboration with ESA. The originality of the thesis is mostly associated with Studies 2 and 3, which extend and refine the current understanding about how the collaboration with ESA affects the internal processes and behavioural patterns of the collaborating firms. Study 2 advanced theoretical thinking on the role of ESA as a procuring agency and innovation intermediary in the internationalisation processes of its suppliers. The study proposed a new theoretical framework reflecting the cyclical nature of the internationalisation process of knowledge-intensive, research-constrained firms. The suggestive model connects to the emerging theoretical thinking of internationalisation as a non-linear and irregular process (Hewerdine et al., 2014; Kriz and Welch, 2018). The entrepreneurial activities of such firms are driven by constant need for financial and knowledge resources for research and development. Involvement with ESA plays a crucial role in acquisition and assimilation of new market and marketing
knowledge by suppliers. Due to the changes in the knowledge stock of the ESA suppliers, new entrepreneurial opportunities are revealed to them. The firms are committed to acquire additional resources and adjust their strategies to go after these new opportunities. There is an interplay between the continuous ‘learning loop,’ and the resource base and internationalisation pattern of the company. In the context of this thesis, another important theoretical contribution of Study 2 concerns the role of ESA contracts as a legitimising signal that enables to extend the ESA suppliers’ business networks and granting access to new market and marketing knowledge. There are social expectations of actors in an economy at large that ESA as a reputable organisation purchasing cutting-edge innovations manages the relationships with its suppliers in a certain way. Therefore, the ESA contract certifies its supplier in the eyes of third parties.

Study 3 provided new insights about the role of ESA in the formation of new markets for technologies and innovative products procured by ESA. Study 3 offered a new model of the multi-level institutional change towards a stable institutional order at the meso-level. This process, which involves an emerging population of connected actors, is endogenous and driven by activities (institutional work) of the ESA suppliers. The suppliers become institutional entrepreneurs in a bid to alter the existing institutional order that is perceived to suppress interactions between actors for co-creating value in the emerging service ecosystem. ESA has a multi-faceted role in the process of institutional change. On one hand, ESA as the innovation intermediary facilitates more intense interaction between the suppliers and (potential) end-users in the nascent market. On the other hand, Study 3 showed that the ESA suppliers adopted new mental models about business reality as a result of interactions with ESA, because the companies held certain expectations about the ESA’s *modus operandi*. This change process is labelled as the cognitive disposition mechanism (cf. Siltaloppi and Vargo, 2017). The institutional origins of the legitimising signal effect in Study 2 and cognitive disposition mechanism in Study 3 both lie in the normative institutional pillar. Actor populations rely on normative institutions as a guide to how to behave appropriately in the market. Therefore, introducing ESA as an innovation intermediary to an emerging population of reciprocally involved actors may have strong effects on the dynamics of the population even when the ESA’s direct interaction with the actors in the ecosystem is not intense.

The thesis sought to add to the current understanding of the nature of various micro- and meso-level effects that are induced by the participation in the programs of the European Space Agency and how these effects unfold in an economy. The thesis showed that behavioural additionality of an innovation policy instrument is a multi-faceted concept that deserves more attention in evaluation practice. The cyclical internationalisation process model in Study 2 implied persistent changes in ESA suppliers’ general conduct, such as changes in business model or in research and development strategy. These changes are embodiments of the firm-level behavioural additionality by definition (Gök and Edler, 2012). At the firm-level, the cognitive disposition mechanism and other institutional change mechanisms are origins of behavioural additionality. The model of the multi-level institutional change in Study 3 indicates that the change does not occur merely at the firm-level but also at the agent population level. The appearance of new institutions along all institutional pillars, such as the emergence of shared understandings of the capabilities of a new technology and viable business models exploiting the technology, is the source of meso-level behavioural additionality. The formation of new markets and industries is the hallmark of the meso-level behavioural additionality. From the perspective of the ongoing ‘normative turn’ in innovation policy thinking (Kattel and Mazzucato, 2018), meso-level behavioural additionality may be the most desired effect of an innovation policy instrument. This study insinuates that achieving meso-level behavioural additionality requires meticulously planned and implemented multi-level policy-mixes that pay special attention to the changes in the normative institutional pillar.

### 3.3. Managerial and policy implications

This thesis has assigned considerable importance to the practical utility of the research results. Membership to Big Science organisations is a relatively new innovation policy instrument in the overall policy-mix of smaller European countries, mostly located in the Central and Eastern Europe. Distinctive
features of ESA – complex industrial policy creating opportunities for firms in its member states with relatively lower levels of industrial capabilities to win orders from a reputable international customer, procurement of beyond state of the art solutions, and possibilities to interact with the organisation in possession of a unique set of knowledge resources – are expectedly leading to knowledge spillovers inductive to industrial innovation. The empirical findings and theoretical contribution of the thesis offer several significant public policy and managerial implications by delineating theoretical rationales for the innovation policy instrument, describing current approaches to evaluating the impacts of Big Science and their applicability in the context of smaller countries, and offering novel insights into the impact channels from the collaboration with Big Science. These implications are described in this chapter.

Several prominent publications by the OECD and ESA on the space economy (e.g. OECD, 2012; OECD, 2014) have reported strong firm-level effects from the participation in ESA programs. These publications constitute a point of reference for policy-makers in the countries that have recently acceded ESA or established formalized ties with ESA with an ambition to join the organisation in the discernible future. The meta-analysis of the existing body of country-wide impact assessments that deal with firm-level additionalities from public investments to ESA programs in Study 1 enabled to identify strengths and weaknesses of the current evaluation practice and discuss the usefulness of the country-wide assessments for international benchmarking. The smaller ESA member states apply multi-method approaches (Reid et al., 2018) making use of survey-based data as small study samples in these countries would not allow for applying large-N econometric methods. The thesis argues that the output indicators of multi-method approaches should be viewed merely as markers of periodic change along the impact pathways in a given country. To capture the dynamics of the firm-level effects over time, such evaluations should be conducted regularly. However, most of the existing country-wide studies were one-off exercises claiming that each Euro invested in ESA programs result in up to 4.75 Euros in additional turnover for ESA suppliers (OECD, 2014). Due to lack of information about the assumptions regarding time dimension in these studies or whether the results of the evaluation were compared to the counterfactual situation, such studies deserve cautious handling by policy-makers in other countries.

The case studies in Study 2 provided novel insights into mutual interactions between complex processes of innovation, internationalisation, and knowledge acquisition and assimilation. While the systematic analysis of evaluation practice in national innovation policy across Europe by Edler et al. (2012) showed that assessments based on primary data gathered through surveys are considered by policy-makers to be a hallmark of good evaluation practice, this thesis suggests that survey-based data should be combined with case studies to study the effects induced by ESA contracts. The existing country-wide studies revealed that the population of ESA contractors in smaller ESA member states is rather stable over time. The high concentration level of ESA contracts may correlate to the risk and severity of the strategic answering problem. The steady group of beneficiaries is motivated to report higher level of additional output from the ESA procurement contracts, downplaying the importance of other private and public funding sources and presenting the collaboration with ESA as the main contributor to the growth of the company. Combination of two different data collection approaches is a data triangulation strategy enabling to reduce this respondent bias. If the rationale behind ESA membership as a policy intervention derives from the theoretical thinking of the framings 2 and 3, emphasising demand articulation and market creation functions of public procurement, then case studies are more suitable for detecting what were labelled as ‘weak signals of market formation’ in the thesis.

When the catalytic effect of involving ESA, an systemic innovation intermediary, unfolds according to the expectations of policy-makers and nascent markets pass the formative phase of development, then it becomes relevant for policymakers to re-consider the benefits and costs of continuing with public procurement of innovation at the supranational level. Outsourcing entails agency and transaction costs from using this procurement approach as ESA as an international organisation and its member states and cooperating states may have conflicting policy goals and interests. These costs have to be weighted against input-, output- and behavioral additionalities of this governance mode of national space investments and compared to other available alternatives.
Majority of policy evaluations and impact analyses still apply a single instrument perspective (Edler et al., 2016). Study 3 provided evidence to argue against such approach. For example, the micro-level effects of two policies – accession to ESA and the European Union Copernicus program’s data policy – are closely intertwined and assessing these policies separately would result in biased estimates of the effects because of the attribution problem. Similarly, the thesis pointed at opportunities to leverage the firm-level effects from the collaboration with ESA by introducing supportive policy instruments. For example, concurrent implementation of national-level policies aimed at overcoming the institutional inertia that exerts counterforce to the process of market formation could accelerate institutional change towards a stable institutional order that affects the interactions of actors that are involved in the emergent market. In other words, the interplay of policy instruments implemented at different levels of multi-level governance would lead to acceleration additionality, a sub-type of behavioural additionality (Georghiou, 2002), as value-adding activities of the target group of the policies would significantly brought forward in time. Even though such interacting policies are context specific (Flanagan et al., 2011), the similarities in institutional dynamics in three different countries captured in Study 3 hints at a possibility that there are policy instruments, which are inherently complementary to the ESA membership.

The thesis has also managerial implications. Earlier contributions have demonstrated that the inter-organisational learning effects from Big Science, a highly diverse knowledge environment, increase the potential of new knowledge creation by Big Science suppliers (e.g. Autio et al., 2004). This thesis throws light on the processes how firms from geographically remote areas, such as Estonia, are able to capitalise on the ‘strategy of projective associations’ (Rawhouser et al., 2017) in order to close the distance to other actors in the international business networks (cf. Covielo, 2006). The strategy of projective associations is a tool to extend to new markets and new business directions. Therefore, Big Science membership can be viewed as a deliberate policy instrument enabling target group to reach out to leading multinational companies. Better network position achieved with the help of the legitimising signal from the collaboration with ESA correlates to the intensity of inflows of highly specific market and marketing knowledge, even if the new network ties facilitated by reputation of ESA are often short-lived. Learning new knowledge and the simultaneous process of unlearning some of the existing knowledge that hinders the ESA suppliers from adapting to the foreign market environment may boost business development of the ESA contractor and lead to a persistent change in of the general conduct of the firm.

This study indicated that the ESA suppliers have a tendency of being over-reverent about the collaboration with ESA and adjust their perceptions about the business realities on target markets as a result of interactions with ESA. The direction of the impact of the cognitive disposition mechanism (cf. Siltaloppi and Vargo, 2017) on the ESA supplier is ambiguous. Service-dominant logic argues that knowledge about context guides the firm’s sense-making about the value of resources and, consequently, resource integration activities (Koskela-Huotari and Vargo, 2016). A commonly used word by the case companies in Study 3 to describe the mental models that were embraced through cognitive disposition was “naïve”. Through interaction with other actors in the evolving business networks, the nuances and complexities related to pursuing a chosen business model are learned. The case histories provided evidence that some elements of the initial understanding of the context of value co-creation were reinstated as a result of organisational learning processes. If experiential learning steers an actor back to its initial business strategy, then it may imply negative acceleration additionality from the cognitive disposition mechanism. Firms aspiring to become ESA suppliers should be aware of this possibility and concentrate on the development and constant improvement of internal processes that enable to absorb new technical, market and marketing knowledge accessible due to the collaboration with ESA.

### 3.4. Suggestions for future research

The original studies that form the backbone of this thesis contributed to the literature with two suggestive process models emerging from multiple case studies. This approach to theorising has its merits. It enables to delineate sequences of events and activities that represent the underlying pattern of a studied process (Van de Ven, 1992), and also capture the nuances of the economic and institutional dimensions of the context where the process of interest unravels. These merits are more pronounced in case of processes that play out over time and call for longitudinal research, such as internationalisation processes
of knowledge-intensive firms in Study 2, and novel research questions when little is known about the relevant constructs and associations between them, such as the role of innovation intermediation in multi-level institutional change in Study 3 (Siggelkow, 2007; Edmondson and Mcmanus, 2007). However, studies adopting multiple case study approach and the narrative style of theorising (Cornelissen, 2017) are also exposed to the risk that the suggested process models may be too descriptive or tightly connected to the peculiarities of the specific context. These issues ultimately may show themselves in idiosyncratic labels for constructs and processes, which undermine the generalisability of the findings of research.

To illustrate this concern, it is appropriate to raise a question if the important role of normative institutions in the processes behind both micro- and meso-level behavioural additionality is unique to a certain type of companies – knowledge-intensive firms in nascent industries – in the remote corners of the European economic area (i.e. in Estonia and other smaller Central- and Eastern-European countries) or is it more universal? Future research could provide an answer to this question. Inquiries into the subject could experiment with different strategies of purposeful sampling, such as criterion-based case selection with a wider geographical scope or maximum variation sampling to deal with the context-specificity issue, in order to increase the external validity of case study research (Gibbert et al., 2008; Patton, 2015). Such follow on studies would enable to come up with propositions – possible cause-effect relationships between constructs inferred from the field data – that are testable with quantitative research methods. However, the shift from the purely qualitative research design to a mixed-method research design assumes close access to ESA (or any other Big Science organisation's) suppliers in multiple countries to manage the variance between institutional environments and a larger research team to conduct such study.

Similarly, dedicated data collection effort must be undertaken in close cooperation with the ESA Procurement Department to replicate the approach of Castelnovo et al. (2018) to estimate the ‘ESA effect’ on the innovation output and financial performance of its suppliers. The study of Castelnovo et al. (2018) on the CERN suppliers serves as the current best practice in the production-function based quantitative studies of the firm-level effects from the collaboration with Big Science. However, the dataset of this study was heavily unbalanced towards companies from a few larger countries. The suppliers from France, Italy, the United Kingdom, Spain, and Germany constituted nearly 90% of the total sample. It would be illuminating to estimate the ESA effect separately for the new ESA member states (the Czech Republic, Poland, Romania, Hungary, and Estonia) and for the ‘old’ ESA member states, and compare the estimated coefficients of impact. Possible differences in the estimators, such as different signs of coefficients, could be then linked to the institutional aspects that differentiate the ‘old’ from the ‘new’ member states.

Several directions for future research could be based upon the existing case study database consisting of a number of transcribed interviews and different types of archival data, which for several Estonian firms that are ESA contractors are spanning over a decade. In the context of the collaboration with Big Science, the time span of associated effects is long (Florio and Sirtori, 2016) and, respectively, any study of change affected by the collaboration should take this time dimension duly into consideration. Regarding an ESA supplier company as a unit of analysis, extending the case study database with interviews conducted over regular intervals20, and pertinent internal documents and publicly available information would enable to capture within-unit change (e.g. of internationalisation process or, more specifically, relationships between inward cross-border links and outward cross-border links) across time in high fidelity. However, follow on studies face their own methodological pitfalls that could result in mismatch between theorising efforts and the fieldwork. For example, Edmondson and Mcmanus (2007, p.1158) warn against ‘opportunistic aspect of field research’ in longitudinal studies, an obvious temptation to reanalyse earlier interview data focusing on novel constructs emerging from fieldwork, which basically means using data collected for one purpose for another reason.

20 For example, Ployhart and Vandenberg (2010) suggest at minimum three repeated observations in longitudinal studies.
There is abundant room for further progress regarding the construct of meso-level behavioural addi-
tionality. Two major avenues for future research deserve a mention in this concluding chapter. The
first direction is to address the main limitation of Study 3. The study took a single-sided look at the
multi-level institutional change settling on the perspective offered by ESA suppliers. For a more
comprehensive picture, and therefore theoretically more rigorous understanding of the processes related
to the phenomenon, informants representing other actors in the nascent service ecosystem have to be
included in the study sample of follow on studies. Also, the inherently dynamic nature of the process
of institutional change that involves the emergence of transient proto-institutions and their disappearance
or maturing into new institutions (e.g. Kleinaltenkamp et al., 2018) calls for longitudinal research design.
The existing case study database is a valuable starting point for future research endeavours in this
direction.

The second direction for future research on meso-level behavioural additionality is to blend in the ideas
from the literature stream on market shaping and market change. Instead of viewing markets as given
structures exogenous to firms, this emerging strand considers markets as malleable socio-technical-
material systems (Storbacka and Nenonen, 2015; Vargo and Lusch, 2016). Study 3 provided evidence
that firms, which benefit from public space programmes and develop new-to-the-world technologies,
are engaged with a specific kind of institutional work, also labelled ‘market work’, defined as purposeful
efforts by a focal actor to perform and transform markets (Harrison and Kjellberg, 2016). Market work
encompasses market-shaping activities in pursuit of sustainable competitive advantage. Recent advances
in this theoretical field have offered new insights about the institutional work mechanisms that public
actors are using to shape markets and, similarly to Study 3, the interplay between market-shaping actions
of agents and the dynamics of the multiple levels (micro, meso, macro) of market systems (Kaartemo et
al., 2020). Potential follow on studies of this thesis could build on these results but offer more fine-
grained understanding of the roles of different public sector actors, such as supranational organisations
and national level governmental agencies, in market formation process by applying a longitudinal
multiple case study methodology. Also, this line of inquiry have an opportunity to enrich case study
approach with quantitative empirical data by linking market work processes with the dynamics of market
change indicators that have been recently proposed by Nenonen et al. (2019). The latter study has come
up with a set of 25 indicators, which cover the main elements of market change, such as norms,
representations, supply-side network, channels, customers, and products. Introducing these novel
theoretical perspectives provide a new angle from which to look at the phenomena of multi-level
institutional change and market formation. Mazzucato (2016) has called for new dynamic indicators and
evaluation tools for proper evaluation of public investments and their effects consistent with the
theoretical underpinnings of the framings 2 and 3. The proposed future research direction on meso-level
behavioural additionality holds a potential to contribute to the development of impact assessment
methodologies that are able to better capture and trace weak signals of market formation compared to
the state of art approaches.
References


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Appendices

Appendix 1. Cooperation between the European Space Agency and Estonia

All thirteen European countries that have joined the European Union since 2004 (EU-13) have also established formalized ties with ESA (Klock and Aliberti, 2014; Sagath et al., 2018). There are five full member states and two associate member states among the EU-13. The cooperation between the remaining six EU-13 countries is governed by the international agreements that ESA concludes with its external partners: four countries have signed the European Cooperating State agreement, while two countries have concluded Cooperation Agreements. The summary of ESA and EU-13 cooperation is provided in Table 7. There are currently twenty-two full member states of ESA (ESA, 2020b); Estonia is the 21st ESA member state.

<table>
<thead>
<tr>
<th>Country</th>
<th>Cooperation Agreement</th>
<th>European Cooperating State</th>
<th>Associate Member</th>
<th>Full Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Romania</td>
<td>1992</td>
<td>2006</td>
<td></td>
<td>2011</td>
</tr>
<tr>
<td>Poland</td>
<td>1994</td>
<td>2007</td>
<td></td>
<td>2012</td>
</tr>
<tr>
<td>Estonia</td>
<td>2007</td>
<td>2009</td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Slovenia</td>
<td>2008</td>
<td>2010</td>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>2009</td>
<td>2013</td>
<td></td>
<td>2020</td>
</tr>
<tr>
<td>Lithuania</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyprus</td>
<td>2009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malta</td>
<td>2012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Croatia</td>
<td>2018</td>
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</tr>
</tbody>
</table>

Sources: Sagath et al. (2018); Klock and Aliberti (2014)

The astrophysics research has rich history in Estonia that dates back to the 19th century. Since 1960s, Estonian researchers also designed scientific instruments for the Soviet space program. In the early 1970s, the first Soviet Salyut-type space station was equipped with the Estonian built Mikron, a device to measure the brightness of distant objects in the near-infrared spectral region. Later, in the 1980s, a series of teleradiometers FAZA were constructed in Estonia for experiments on the Soviet orbital space stations Salyut 7 and Mir (Viik, 2014). In mid-2000s, Enterprise Estonia, the Estonian public foundation that promotes foreign trade, investments, entrepreneurship and innovation, took the leading role in the process towards the full integration of Estonia to the European space community. The cooperation between the ESA and Estonia evolved quickly since the first contacts were established in 2005. In June 2007, Estonia signed a five-year cooperation agreement with the ESA (Mathieu, 2007). The purpose of the cooperation agreement was to establish a legal framework for initial cooperation and for the exchange of information and people. Estonia adopted its first Green Paper on national space policy „Towards Estonian space policy and strategy“ in 2008, prepared by a special working group convened by the Estonian Ministry of Education and Research in 2006 (Kolk & Võõras, 2009).

In March 2001, the ESA created a new European Cooperating State (ECS) status which opened up opportunities for the Central and Eastern European (CEE) countries to participate more closely in the ESA programs. ECS countries also subscribe to the PECS Charter, describing the projects to be undertaken and their funding, usually around one year after the signature of the ECS agreement (Klock & Aliberti, 2014). In September 2008, ESA conducted a technology audit in Estonia to assess the technological capabilities of Estonian firms and research establishments. As an outcome of this exercise, Estonia was proposed to enter into an ECS agreement with ESA. The agreement came into effect in November 2009 and Estonia signed the PECS Charter in September 2010. In 2011-2012, the first „Strategy for Estonian space affairs 2011–2013“ was developed and adopted. The vision of this strategy
stated that by year 2020, „Estonia is a respected full member of ESA with positive industrial return“. In this strategy, the ESA membership was seen as a measure for supporting enterprises in entering chains of supply with high added value (MKM, 2012).

The total contribution of Estonia to the PECS program during 5 years was nearly 6.4 million Euros and altogether 27 R&D projects at relatively low technological maturity level, corresponding to the pre-commercial procurement in the context of this thesis, were successfully completed by early 2017. The positive results of the Estonian PECS program pushed Estonia rapidly towards the full membership. The agreement between the ESA and Estonia regarding the accession to the ESA Convention was signed in February 2015. Estonia became the 21st ESA member state as from September 2015. The period between the Cooperation Framework Agreement and the full ESA membership was the shortest among the CEE countries (Eerme & Lillestik, 2019).

In Estonia, the Ministry of Economic Affairs and Communications is responsible for developing the Estonian space policy and supervising its implementation. The Space Affairs Council (SAC), an inter-ministerial body established in 2010, offers high-level guidance for policy-making. The main tasks of the SAC are initiation and governance of space related activities at national and international (regional) level and coordination of resource allocations to space technology R&D. The SAC is supported by secretariat, comprised of representatives of Enterprise Estonia and Estonian Research Council. The Estonian Space Office, a dedicated unit within the Enterprise Estonia, is engaged with the daily management of the implementation of the Estonian space policy. The Estonian Space Office stimulates the uptake of space technologies by the public sector and acts as an intermediary between Estonian companies and the ESA (European Space Agency, 2018).

The main strategic goals related to the full ESA membership were defined in Estonian National Space Action Plan for the period 2016-2020 that was ratified by the Government of Estonia in 2015. This action plan defined a set of measures and key performance indicators regarding the competitiveness of firms in the field of space and development of entrepreneurship related to space affairs. The two key performance indicators of the plan were (HTM, 2015):

- Estonia's overall geographical return coefficient in the ESA, an indicator of a country's historical performance in the ESA procurement system (Eerme, 2016), with a threshold value 0.85 to be achieved by 2019 and
- The so-called spin-off multiplier associated with the ESA investments that was expected to be at least 1.5 by 2019.

The Estonian Space Action Plan for the period 2016-2020 defined the spin-off multiplier similarly to the BETA methodology (cf. Cohendet, 1997) as the ratio of indirect industrial effects arising from the public contracts of ESA with private sector enterprises to the total value of contracts during a particular period. The indirect industrial effects include all benefits arising from technology, know-how, enterprise image and business contacts, which are obtained through contractual relationships with the ESA and result in increased sales and/or added value when applied to other activities of an enterprise. As of June 2020, the impact assessment to measure the value of the spin-off multiplier has not yet been conducted in Estonia. In order to achieve such level of output additionality from the ESA full membership, several supportive policy measures were foreseen by the strategy, such as (HTM, 2015):

- Supporting enterprises in entering the international value chains of the space industry through Estonia's participation in the optional programs of the ESA.
- Systematic efforts to raise the awareness of entrepreneurs regarding the developments and opportunities in the space industry.
- Facilitating utilisation of applications based on space technologies in the terrestrial economy.
- Facilitating cooperation between enterprises and research institutions in developing, utilisation and export of solutions based on space technologies.

In November 2017, an ESA business incubator was launched in Estonia to support entrepreneurship based on space technologies.
Each ESA member state’s mandatory annual contribution to the ESA budget is calculated on the basis of the national income (Cogen, 2012). Estonia’s share in the total annual budget of ESA is below 0.1 per cent (ESA, 2020a). While the Estonia’s annual contribution to the ESA budget is the lowest among the member states in absolute terms, the contribution per capita is the second highest among the recently acceded CEE countries (Figure 4). Between 2015 and 2018, Estonia participated in the mandatory programs of ESA and in two optional programs in total amount of 2.6 million Euros annually (Eerme, 2018):

- Earth Observation Envelope Programme (EOEP), which is a key program of the ESA. Among its multiple objectives, two objectives were the most relevant for Estonia. The program is committed to:
  - maximise scientific impact of ESA, European missions and national missions and;
  - Engage the users and pioneer new Earth Observation applications, including via the use of Earth Observation exploitation platforms.
- General Support Technology Programme (GSTP), which has five major objectives – enable missions of ESA and national programs by developing technology, foster innovation by creating new products, strengthen the competitiveness of European industry, improve European technological non-dependence and the availability of European sources for critical technologies, and facilitate spin-in from outside the space sector. Estonia contributed to GSTP in a bid to activate the so-called ‘Earth-Space-Earth’ technology transfer pathway (Petroni, Venturini, & Santini, 2010), i.e. ESA suppliers adopt terrestrial innovations for space purposes and the upgraded technologies are later commercialized on the main target markets of the suppliers.

Estonia as a new ESA Member State is undergoing its transitional arrangement with ESA, which entails specific objectives, measures and conditions for overall geographical return statistics, such as the implementation of a dedicated Industry Incentive Scheme.

Figure 4. The ESA member states’ national contributions to ESA per capita (in Euros) in comparison to the countries’ Gross Domestic Product per capita (in thousands of Euros) in 2019, the author’s calculations

In April 2020, the new Estonian Space Policy and Programme for 2020–2027 was adopted. According to this strategic document, Estonia implements its space policy through the ESA optional programs and the European Union Space Programme. The strategic vision of the policy document is: „Estonia is a strong partner in European space programmes by helping to strengthen Europe’s leading role in developing space systems in an autonomous, safe and secure manner, and operating in outer space and managing decision-making processes on the ground.” In the ESA Ministerial Council – Space19+ –
which took place in Seville, Spain in November 2019, Estonia decided to continue to subscribe to the GSTP program, but substituted EOEP program with two new ESA optional programs: ARTES Business Applications and Space Solutions and InCubed+. In these programs, ESA acts as the lead-user for close to market products and services, involving satellite telecommunications and Earth Observation technologies, respectively (MKM, 2020). While in 2020, Estonia’s contribution to the ESA programs is still 2.6 million Euros, the new Programme aims at increasing this funding to 10 million Euros annually by 2027.

The Estonian Space Policy Programme for 2020–2027 has introduced a more comprehensive assortment of the Programme’s performance indicators. While the Estonian National Space Action Plan for the period 2016-2020 focused on the output additionality, the new Programme has set ambitious target values for (MKM, 2020):

- The spin-off multiplier – the indicator for output additionality will be measured annually and its target value is 2.8 in 2027.
- Private investments to space-related R&D – the new Programme expects substantial input additionality as ESA suppliers’ additional financing to their space-related R&D should be at least equal to the monetary value of ESA contracts by 2027.

The Programme also expects behavioural additionality from implementing the Estonian space policy through the ESA. Firms winning ESA contracts are expected to reach out to the so-called large system integrators that dominate the European space sector and win at least one contract from these multinational companies a year. ESA suppliers are also expected to change patterns of their R&D collaborations and establish linkages with publicly funded research organisations and universities.
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