Exploitation of public sector R&D and the open invitation paradigm: Governance of knowledge transfer within public research organisations (PROs)

"Exploitation of public sector R&D and the open innovation paradigm: Governance of knowledge transfer within public research organisations (PROs)"

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Title: "Exploitation of public sector R&D and the open innovation paradigm: Governance of knowledge transfer within public research organisations (PROs)"

Abstract

In the current challenging business environment, where firms need to rapidly seize new technological and business opportunities in order to stay competitive, public sector research and development (henceforth: R&D) can provide an important source of frontier knowledge. The determinants, effects and impacts of firms' use of public R&D have been studied in the context of firms' collaborations with universities, while the role of public research organisations (henceforth: PROs) (use PROs as non-university public research institute Cruz-Castro et al. 2015) in knowledge transfer (henceforth: KT) remains under-researched. In light of the efforts of governments and PROs to seek new strategies and approaches to boost the effectiveness of their R&D, and in light of the increasingly 'open' nature of innovation processes, PROs' engagement in KT with businesses and other external partners is encouraged.

This doctoral thesis aims to investigate what organisational approaches and managerial practices PROs use in order to engage in the transfer of their knowledge and R&D outcomes, including the commercial exploitation of their research output.

Particularly, this doctoral thesis intends to fill this important research gap by investigating three key research questions:

(i) How do PROs organise their KT activities? in particular, what factors are associated with different ways to organise their KT management functions?

(ii) What managerial practices are associated with PROs' KT activities within the open innovation paradigm?

(iii) How well do PROs' performance measurements reflect the specificities of their heterogeneous missions and KT engagement?

This thesis is structured using a three-paper format, with each question being addressed in a different paper; the three papers constitute chapters 3, 4 and 5 of the thesis.

In particular, the first research question is addressed in Chapter 3 'Intrinsic and strategic complementarity of research and knowledge transfer activities as determinants of knowledge transfer governance in public research organisations'. A version of this chapter has already been published as an academic article in *The Journal of Technology Transfer*. The full

citation of the paper is: Ghorbankhani, M. and Rossi, F. (2022) Intrinsic and strategic complementarity of research and knowledge transfer activities as determinants of knowledge transfer management: evidence from public research organisations. *The Journal of Technology Transfer*, ISSN 0892-9912.

The second research question is addressed in Chapter 4 'Organisational capabilities and outbound open innovation in public research organisations'. This chapter has been submitted to a journal in the form of an academic article, and it is currently under review.

The third research question is addressed in Chapter 5, 'Measuring the performance of public research organisations: the impact of mission heterogeneity". An academic article based on this paper is in the process of being developed.

The thesis also includes two introductory chapters and a conclusions chapter:

Chapter 1: This chapter introduces the main objective of this PhD thesis, exploring knowledge transfer (KT) in public research organisations (PROs) in the UK, different institutional structure of public research sector, motivation of this study, main research questions and the methodology used to address them in three research papers.

Chapter 2: This chapter focuses on the historical evolution of PROs in the UK and their structure, governance and missions.

Chapter 6: This chapter provides a summary of the main results, conclusion and the key contributions to management literature, policy and related fields referring to main research questions. The chapter also includes limitations of the research and methodological reflections, and raises a number of questions for future research to stimulate thoughts on a few under-researched areas about PROs' KT activities and their potential to actively transfer and commercialise public research for further contributions to innovation, and economic and societal well-being.

CHAPTER 1. Introduction

1.1 Introduction

Knowledge transfer (henceforth: KT) from the public research system, including universities and government-funded research institutes, the latter hereafter called public research organisations (henceforth: PROs), is particularly important in a business environment where firms seek knowledge-based competitive advantage, and societies thrive to improve long-term dynamic innovation and economic competitiveness. Many governments spend heavily on the public research system, including universities and PROs, as sources of generating frontier science. The effectiveness of public expenditure on the public research system in terms of maximising opportunities for KT and commercial exploitation of research output has raised particular interest among policymakers, academia, and industry.

In recent years, the significant role of research in driving economic productivity and public welfare in general, and the importance of science in securing the UK's long-term economic achievements, have been recognised by successive governments (Nurse, 2015). As a result of this recognition, a corresponding safeguard of research and science funds and budget has been outlined against any competing priorities in related government departments and any short-term pressure within governments. Without such protections, many government departments in recent years witnessed difficulties in delivering their policy objectives in their respective departments (ibid.).

In the same vein, attempts should be made by PROs to secure the delivery of their research output and safeguard the most efficient mechanism to transfer and commercialise the produced research output.

Thus, understanding the governance and processes through which knowledge is transferred from the public research system is critical for developing more effective knowledge management systems. In addition, increasing pressure on universities and PROs to generate income and supplement public investment in research, and demonstrate the value they create requires these organisations to engage more effectively with external stakeholders, including the public and private sectors and society in general (OECD, 2013). In doing so, a solid KT governance is required to

manage the knowledge created and effectively transfer it to the relevant markets, for example, by commercialisation of research outputs.

This research focuses on PROs in the UK and seeks to examine the organisational approaches and managerial practices of PROs to transfer knowledge and exploit research outcomes. Since the UK demonstrates high performance in creating knowledge and scientific excellence compared with other countries[1], KT becomes exceptionally significant, particularly from PROs equipped with invaluable assets of the government budget, scientists, and state-of-the-art infrastructure.

Conceptually, this research draws upon: governance theories and theories of outsourcing to analyse PROs' choice of KT management approach (outsourcing vs. vertical integration of KT management function); open innovation theories to investigate the extent to which PROs adopt outbound open innovation approaches, and the organisational capabilities that underpin their open innovation approaches; and finally, it considers issues in the measurement of PROs' performance in KT by reviewing the literature on performance measurement and indicators and highlighting limitations in current approaches.

This thesis is based on a three-paper format, with three general research questions. Each question is addressed in a different paper that constitute chapters 3, 4 and 5. Chapter 1 is the introductory chapter that introduces the main objective of this PhD thesis, definition and structure of KT in PROs in the UK and methodology used to address each research question. Chapter 2 serves as a foundational context setting chapter that explores the role of PROs in the UK's economy and provides essential background to the history and policy framework of PROs in the UK.
Chapter 3, addresses the first general research question in form of a research paper: Ghorbankhani, M. and Rossi, F. (2022). "Intrinsic and strategic complementarity of research and knowledge transfer activities as determinants of knowledge transfer management: evidence from public research organisations". *The Journal of Technology Transfer*, ISSN 0892-9912.

[1]This is according to a recent report by the UK government (International comparison of the UK research base, 2019, available at: https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019) which compared the UK's performance in research against all G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States), as well as Brazil, China, India, Russia, and South Korea. the EU 27 (all current European Union countries apart from the UK), the OECD, and the world.

Chapter 4, addresses the second research question and develops a research paper named “Organisational capabilities and outbound open innovation in public research organisations”. This chapter has been submitted to a journal in the form of an academic article, and it is currently under review.
Chapter 5, “Measuring the performance of public research organisations: the impact of mission heterogeneity” is an academic article that addresses the third research question.

Chapter 6 serves as a comprehensive wrap-up of the thesis including main results, key contributions to literature and policy, limitations and methodological reflections, as well as and raising a number provoking questions for future research.

1.2 Institutional differences and different objectives of PROs and universities

There are many different types of publicly-funded research organisations. While universities have a broader mandate, including teaching and basic research, public funding of PROs and public laboratories primarily aims to produce valuable knowledge for the government and the private sector and develop marketable technology. Hence, PROs are viewed as being positioned between the fundamental science carried out in academia and the industrial/commercial R&D carried out by business (Mazzoleni and Nelson, 2007; Maxwell-Jackson, 2011).[2]

While universities have been extensively studied regarding their KT activities, the government R&D sector and the PROs have attracted less attention and analysis. One main reason for the limited conceptual clarity around PROs is that most of the literature has treated university and non-university government laboratories similarly as they are placed in the same category. However, universities and PROs constitute different institutional arrangements (Broström and McKelvey, 2015). Bozeman

[2] Few previous studies have empirically contrasted the knowledge base of public laboratories and institutes with universities. Crow and Bozeman (1998) discuss how US government laboratories are characterised by more "applied" research while universities are said to focus on "basic" research. Slightly contrasting evidence is presented by Jaffe and Trajtenberg (1996) and Jaffe and Lerner (2001), who note that while the laboratories hit the universities both in terms of patenting volumes and patent quality in the 1970s and early 1980s, the gap was closed in 1990 the number, which makes the public laboratories more like the universities. A similar European trend towards the convergence of the various actors' functions within the broader public research organizations has been reported by Senker (2006).

(2000) argues that the institutional structure of public research affects the nature of interaction with the private sector. Universities and PROs vary due to their institutional differences concerning the assignments, culture, and type of research they undertake.

Several research studies show that research funded by the public sector mainly channeled through universities and PROs, can not only advance frontier scientific knowledge but also provide useful inputs for business innovation (Bozeman, 1994; Slaughter and Rhoades, 1996; Crow and Tucker, 2001; Vorley and Lawton Smith, 2007). It has also been argued that publicly-funded research contributes to two different types of goals: generating new ideas and providing knowledge and technology that help the firm to complete the innovation projects which are already defined by the company (Klevorick et al. 1995; Cohen et al. 2002; Fontana et al. 2006).

Similarly, Broström and McKelvey (2015) distinguish between long-term development of technology and explorative R&D, which is not expected to result in new or significantly improved products or processes within a short time frame and projects related to well-specified product and process development in mature stages of development, which is typically regarded as highly applied R&D. The two types can be considered as “early stage" and "late stage" R&D in a continuous refinement process where the end result is a marketable product (Aghion et al., 2008). Although previous research has shown that university researchers can use contacts with applied research problems in companies to inspire further research and help fund their departments (Lee, 2000), a typical university researcher’s incentive to do so is lower than that of the typical PRO researcher. Furthermore, previous research suggests that academic quality is positively associated with business interest in conducting joint venture research and other forms of interactions related to exploration rather than conducting research for strictly applied purposes (Schartinger et al., 2002).

Some studies (Crow & Bozeman, 1998; Lundvall, 1992) describe PRO as a complement to universities, dedicated to applied R&D and interacting with industry, whereas universities are typically associated with ‘curiosity-driven’ research. Industry benefits from collaborating with PROs primarily because they receive knowledge to support business innovation processes; however, it also benefits from access to human resources, international networks, and public co-funding (Broström, 2012).

A comparison study of commercialisation of 161 universities and 35 PROs in the UK indicates that PROs produce more research output and benefit from greater commercial success than universities (Athreye and Rossi, 2021). The authors provide some explanations for PROs' greater success in commercialisation compared to UK universities: greater focus on more applied and mission-oriented research, PROs engagement with types of research activities with immediate commercial applicability, such as biotechnology and computer science, and the government's tendency to privatise PROs whose research output could be commercialised more easily and their survival is more likely independent of government funding (ibid.). However, the difference between total research expenditure and the average universities and PROs' income in terms of licensing income, as a percentage of research expenditure, is small in OECD countries (the highest in the US by 4.8% licensing income, in Europe by 1.4% and the UK by 1.2% between 2004-2011) (OECD, 2013). Therefore, the licensing income and patent granted have been used as a metric indicating the potential for commercialisation of the invention and, to some extent, better reflect the market needs (Thursby and Thursby, 2010).

Concerning significant research expenditure in public research, metrics beyond the number of patents, spin-offs, or licensing income are required to reflect the KT mechanism and potentiality of commercialisation of research output in this sector.

Hence, research on this topic sheds light on different perspectives of PROs' innovative activities and brings to the fore the importance of understanding how new managerial and governance structures of PROs can also support more effective KT and commercialisation performance.

1.3 Definition of knowledge transfer

The concept of knowledge transfer (KT) has undergone several changes due to the breadth of knowledge channels and broad disciplines it refers to. For example in education, KT has been defined as a *process* of developing knowledge in one specific context and applying and deploying it to a new context to achieve new tasks and to conclude new results by developing new skills (Presseau, 2000). In management, for example, Roy et al. (1995) referred to KT as a *mechanism* for adopting new individual and organisational behavior through appropriating, disseminating, and

applying new knowledge. Within this *process* or *mechanism,* knowledge is considered a product that goes through a minor or radical transformation, is translated to a new language (tool), and utilised in a new context for designated purposes, such as decision-making, problem-solving, improving organisational behavior, etc. (Amara, et al. 2004).

The majority of definitions depict KT as a process or mechanism. This process can take place using many different *channels*, including publications, exploiting intellectual property, contract R&D and consultancy, formal collaboration/partnerships, informal interactions, assessing research skills, and other channels (e.g., Cohen et al., 2002; Martinelli et al., 2008; Agrawal and Henderson, 2002).

In particular, knowledge dissemination has traditionally occurred through scientific publications, conferences, academic staff mobility, research contracts, and licensing. However, due to technological progress in information and communication technology (ICT) and expansion of openness in innovation, technology, and businesses, which are also traceable in public research, other channels have been added to complement the more traditional ones (Cervantes and Meissner, 2014). In recent years, collaborative research such as public-private partnerships, staff mobility, consulting, and contract research, have been complemented by patents, licenses, and spin-offs for the commercialisation of public research. The broadening of KT channels is also driven by the need for access to publicly funded research data and results from science funding agencies.

Moreover, there are multiple approaches for public research to transfer, exploit and commercialise their research output. Consequently, multiple terms have been used in academic and business literature, including “knowledge exchange”, “research utilisation”, “research exploitation”, “research commercialisation”, “knowledge utilisation”, and “public engagement”, etc. (Kitagawa and Lightowler, 2013), to refer to these processes.

An extensive literature review has been conducted for this PhD project to select a term that best fits this project's objectives and encompasses the definition and utilisation of KT channels. As a result, the term “knowledge transfer” has been used to refer to all channels that, in the broadest sense, PROs utilise to diffuse and

disseminate their research output and scientific results. This term includes scientific publications, conferences and workshops, staff mobility, contract research, patents and licensing, spin-offs, consultancy, etc.

Despite the broad range of channels through which knowledge is transferred, not all channels lead to a specific and measurable commercial outcome of public research. Due to political pressures and market competition, government demands to reap the benefits of its considerable investment in public research as a more direct contribution to economic growth (OECD, 2013). Since public research is still central to generating frontier knowledge and responding to emergency needs of the government and society, knowledge created in these centres is not considered anymore independent from commercialisation purposes. Therefore, new approaches have been encouraged to promote more downstream commercialisation activities for public research (Ibid.). However, reliable data and statistical infrastructure to measure the financial outcome of KT channels are limited.

In this thesis, the term "commercialisation" refers to KT channels, including patents, licenses, spin-offs, associates, joint ventures, research contracts, and exchange of researchers, as well as collaboration at any level that generate income and lead to an immediate and measurable market acceptance (Markman et al., 2008) of PROs' research outputs. The recipients of PROs' knowledge in this context are government, industry, policymakers, and overall society. Ultimately, due to the wide range of KT Channels and concerning the direct and measurable financial contribution of some channels to the economy, this PhD thesis refers to "knowledge transfer" as a term implying both commercial and non-commercial channels.

1.4. Why is knowledge transfer important?

A growing literature has emphasised the role of technology advancement- innovation- as one of the key drivers of economic growth (Andergassen et al., 2009; Bae and Yoo 2015; Maradana, et al., 2017; Santacreu, 2015). This has encouraged researchers and policymakers to investigate the link between innovation, entrepreneurship, and economic outcomes (Galindo and Mendez-Picazo 2014; Howells 2005; Malerba and Brusoni 2007; Wang et al. 2005) comprehensively.

Innovation is a process in which knowledge about market trends, customer needs, new technologies, and potential scientific and technological advancements is created. This knowledge can be transformed into novel products, services, and processes whose usefulness relies on the users' perspective. Therefore, knowledge is ''*not a self-contained substance waiting to be discovered and collected. Knowledge* is created *by people in their interactions with each other and the environment*'' (Nonaka et al., 2008, p. 7).

Nielsen and Cappelen (2014) suggest that continuous knowledge sharing is more beneficial than focusing simply on final outputs. A major component of continuous knowledge sharing is a regular meeting between partners involved through allocating time and space to share and create new knowledge in university-industry collaborations. Thus, innovation involves intense cooperation between individuals and teams with different levels of knowledge and skills acquired through experience and expertise in specific domains (Wallin and Von Krough, 2010).

The growing understanding of the link between innovation and KT has led many countries to develop and promote research collaborations and KT mechanisms (Rubin, et al., 20014). Since knowledge is embedded within an organisation's individuals, mechanisms and practices, tools, and networks (Argote and Ingram, 2000), the transfer of organisational knowledge can be quite complicated, specifically because much knowledge in organisations is tacit (Nonaka and Takeuchi, 1995).

The type of knowledge that can be transferred to and from an external party is generally the explicit one since sharing tacit knowledge is complicated: it takes a substantial amount of time, and there is uncertainty about the outcomes and ability to provide solutions that fit the problems (Wallin and Von Krogh, 2010). Roessner (2000) provides a comprehensive explanation of the process of KT: "The movement of know-how, technical knowledge, and technology from one organisational setting to another […] with a wide range of organisational and institutional interactions involving some form of technology-related exchange". Rossner (2000) distinguishes *Sources* of technology (private firms, government agencies, government laboratories (PROs), universities, non-profit research organisations, and the entire nation) and *Users* (small businesses, legislatures, cities, states, and nations). In this context, technology transfer has been used to describe the processes through which ideas, proofs-of-concept, and prototypes move from a research-related to a production-

related phase of product development. Since innovation and KT have "knowledge" at their very core, this thesis considers related literature developed in both domains.

1.5 Differences in public and private organisational governance

PROs span a wide range of scientific disciplines and contribute to public policy, government decision-making, and industry by providing key scientific and technological inputs, emergency response and consultancy services, and developing standard criteria and testing and evaluation measures. Thus, transferring knowledge and technology created in PROs and the organisations that receive public funds to conduct R&D, is considered the major pathway to contribute to GDP, create employment and benefit economic growth (Maxwell-Jackson, 2011). Despite the complications in measuring the impact of public research, it is argued that in the absence of public research, approximately one-tenth of total innovations would have been delayed (Mansfield, 1991). The importance of KT from PROs is more evident in some sectors, such as pharmaceuticals, where innovation relies highly on public research output. However, PROs, in general, tackle some specific operating constraints which impede a higher level of performance within these organisations: slow decision-making, operational, cultural, and policy constraints, high overheads, accounting rules, and limited access to capital as well as access to industry best practices. Maxwell-Jackson (2011) refers to a couple of PROs that have been privatised. By discarding some or all of those constraining factors, the privatised PROs have reported improved performance to a lesser or greater degree. The constraints mentioned above slow the progression of knowledge creation and KT at any level that hamper the PROs' attempts to commercialise their research output. Accordingly, Maxwell-Jackson (2011) identifies three factors that mainly affect the performance of PROs: the extent of technology transfer, over-dependence on government, and public sector operating constraints.

In addition, there are significant differences between private and public organisations. The core differences lie in the type of ownership, financial resources (Perry and Rainey 1998), and social control (Andrews et al., 2011). Public organisations are owned by the government and funded by the income received by the government from taxes as well they are under the control of the political authority. Whereas, in the

private sector, the owners are mainly private agents, and the sales of products and services are the primary sources of income; the market forces are the controlling factor in businesses, while political authority has the most negligible influence as a controlling factor (Perry and Rainey, 1998; Andrews et al., 2011). Other fundamental differences exist in management practices between the public and private sectors (Hvidman, and Andersen, 2016). For instance, within the private sector, managers have access to a broader range of organisational measures, more independence and freedom to use them and take action. This, in turn, can lead to better exploitation of resources within and outside the organisation.

Political pressure is a critical factor for the adaptation of organisational innovation in the public sector on a large scale (Andersen and Jakobsen, 2018). Media, politicians, and reform movements have significant influences on public sector performance being perceived as low (Hvidman, and Andersen, 2016), so managers in the public sector respond to political pressures for improvement. However, public organisations show no particular interest in mimicking institutionalised models, thriving for conformity, or adopting organisational innovations once they learn about other organisations' positive performance. In other words, the critical drive to adopt organisational innovations in public organisations is political pressure, not their knowledge about other organisations' positive experiences in a similar context. Hence, political pressure makes managers adopt organisational innovations merely to send out a signal for change and not to show a willingness to improve performance within the organisation (Hvidman and Anderson, 2014).

Public organisations are primarily inclined to adopt performance management techniques as a tool imported from the private sector, which does not influence their performance outcomes. Adopting performance management, however, in the private sector is more effective and helps improve their outcomes. As a result, the impact of performance management techniques depends on the sector in which they are applied. It also implies that transferring management techniques and tools, such as performance management, is not unanimous across all sectors. Consequently, adopting these techniques results in different outcomes in the public and private sectors.

Both firms and PROs need to maintain and improve their organisational knowledge to sustain their competitive advantages and succeed in an ever-changing market.

Therefore, the organisation and management of public research-industry collaboration require exploration on both the organisational and institutional levels (Perkman and Walsh, 2007). On the organisational level, firms and PROs vary considerably in terms of contractual arrangements and outputs, and there has not been much research on different types of such agreements and their diffusion (Hall, 2004), and furthermore, on types of research conducted within such partnerships (Perkman and Walsh, 2007). On the institutional level, the main issue that needs to be addressed is how existing institutional structures and innovation systems shape organisational arrangements (Ibid.) for PROs-industry collaboration.

1.6. Open innovation practices and knowledge transfer

Several studies indicate that increased knowledge flows from different external partners and an increased number of external linkages led to enhanced innovation performance (Felin and Zengerb, 2014; West and Bogers, 2011) and better financial performance (Leiponen and Helfat, 2010). It has also been argued that using more open governance forms within firms has led to improved innovation outcomes (Keil et al., 2008). The twenty-first century has witnessed the emergence of the open innovation (OI) paradigm in the private sector, based on the premises that firms "can" and "should" use both internal and external ideas and paths to the market in search for their innovative opportunities (Rahman and Ramos, 2013). This paradigm sets no limitation in applying external channels outside the current businesses to take the ideas to relevant markets and generate income (Chesbrough, 2003). Two major processes Chesbrough identifies in OI as utilising external innovations internally and externally commercialising internal innovation have been complemented by Enkel, et al. (2009) - a combination of inbound and outbound flows in coupled mode when enterprises collaborate in both directions. Since Chesbrough (2003) introduced OI as a profit-maximising paradigm, researchers have only recently considered how OI applies to government agencies and independent not-for-profit organisations (Chesbrough and DiMinin, 2014). From this, Chesbrough and Bogers (2014) showed how the business model premise that underlies the definition of OI could be extended to public and not for- profit organisations because of their need to create and capture value to maintain their existence. Despite the growing relevance of KT between public research systems and industry as an essential driver of innovation and

economic growth, most studies focus merely on universities rather than PROs.

Therefore, a comprehensive study is required to fill this gap due to the magnitude of the government's expenditure in PROs as the source of generating frontier science, and the scarce research done on their governance and KT activities. Moreover, although extensive literature exists on knowledge inflows within open innovation, there is a lack of empirical research on the outflow of knowledge within open innovation literature (e.g. Dahlander and Gann, 2010; West and Borges, 2011).

Additionally, policymakers have shown an increasing interest in policies supporting open innovation. Globalisation and growing interest in open innovation and the proliferation of its practices within businesses require the public sector and governmental organisations to provide partners with access to broadly available knowledge and technologies (Van de Vrande, et al. 2009). For example, European R&D policy (European Commission, 2014) has placed KT and collaboration at all levels on top of its agenda for continuous growth in the EU. In this context, Open Innovation (Chesbrough, 2003) has been introduced as leading-edge practice that contributes to the collaboration between government, universities, and industry and particularly boosts the entrepreneurial aspect of the innovative activities.

On the grounds of this, the European Commission put forward an ambitious proposal for juxtaposing KT and OI as two pillars constituting an ecosystem embracing co-creation. In this context, KT is considered the means for OI. The primary premise of OI is managing the purposive inflow and outflow of knowledge and technology through multiple interactions with different actors across the supply-demand chain aiming to accelerate innovation and consolidate internal R&D. This result wouldn't be achievable without the "co-creation of knowledge" through multiple interactions with involved actors based on relationships between suppliers and customers, including industry, academia, and PROs[3].

Implementing open innovation methodologies in the public sector can indeed have myriad positive benefits, including improved awareness of social problems, more

[3] At the time the framework introduced in 2014, UK was a EU country. Therefore, UK's economy and investment in innovation were thoroughly incorporated in data, results, and recommendations stated in this agenda. EU commission's framework for boosting OI and KT will put forward its proposal for a Brexit Adjustment in future.

effective practices based on broad citizen experience, and increased trust between government and citizens (Chesbrough et al., 2011).

For the public research system to better contribute to economic development, it is necessary to shed light on PROs' KT organisational approaches and managerial practices and analyse to what extent they organise their KT activities within the open innovation paradigm. The argument would be, in line with firms' propensity towards more open governance and adopting innovation policies that lead to more efficient innovative outcomes, PROs may need to adopt compatible policies in their innovative and KT governance and strategies. As public institutes, PROs are mainly deeply rooted in closed governance regarding innovation and commercialisation. However, there exist several reasons for PROs to move towards more open governance, including gaining a competitive advantage in the market, effectively commercialising their research output, and maintaining their R&D demand to reach critical mass.

The theoretical argument of this research will contribute to a better understanding of the PROs' KT organisational approaches and managerial practices as well as their outbound OI and fill the gap in the literature concerning knowledge outflow and its governance. The contribution is made by moving beyond the existing KT practices and successful cases of adoption of OI and exploring PROs existing KT channels, including those not willing to adopt OI, due to their particular organisational missions. In this sense, the OI literature primarily emphasises the inevitability of adopting OI in KT practices and provides several examples of successful cases to this effect. However, literature is scarce on outbound OI, and this concept has remained underdeveloped in practice. Furthermore, this research provides significant managerial implications by developing a comprehensive quantitative and qualitative dataset that provides empirical evidence from PROs in the UK. The results reveal the organisational approaches and managerial practices in the PROs' KT activities that create opportunities and/or impediments to commercialising their research output.

1.6 Mixed Methodology-Pragmatism and Data

To fulfil the purpose of the present PhD thesis and to address all research questions identified for each of the three papers included in the thesis, a pragmatic approach to mixed methods for data collection, analysis, and different assumptions (Creswell

2003), seems most appropriate. Pragmatism focuses on actions, context, and consequences (Cherryholmes, 1992; Murphy, 1990; Patton, 1990; and Rorty, 1990).

Pragmatists believe that scientific research takes place in social, political, historical, and all other contexts and that there is a "world" independent of what is going on in our minds. Therefore, they are concerned with the questions such as how we know that our "conception" (House, 1991, P.3 quoted from Bhaskar) of the world is of reality. To answer this question, the pragmatic approach attempts "to interpret each notion by tracing its respective practical consequences" (James, 1981, p.26). However, to address these types of questions, pragmatists have no answer and do not claim they know how far their current "conception" is from reality. Instead, they focus on some explanations and theories that can produce better results and their choice of approach simply due to its capability of producing desired outcome (Cherryholmes, 1992).

Patton (1990) argues that pragmatism considers what works and the solution to problems. The focus is on the research problem, and the researcher can choose pluralistic approaches to collect data to solve the problem (Patton, 1990; Tashakkori and Teddlie, 1998). Since pragmatism is open to various reality and philosophical assumptions, it allows for the quantitative and qualitative assumptions in the mixed method. This, in turn, allows the researchers to choose and apply the techniques and methods to collect and analyse data that best meet the purpose of their research (Cherryholmes, 1992; Creswell, 2003; Murphy, 1990). By mixing quantitative and qualitative data to answer *what* and *how* questions, researchers are provided with a more comprehensive understanding of the problem.

Three general strategies of inquiry are defined within the mixed method: sequential, concurrent, and transformative procedure.

The target population for all three papers in this thesis PROs in the UK. First, to identify the relevant population of PROs in the UK, a comprehensive list of currently active PROs has been constructed by analysing eight recent studies of PROs in the UK[4]. The focus has been identifying the PROs primarily engaged in research activities and those not in the university sector. Due to public research sectors'

[4] These are: Lyall et al. (2004), BIS (2007), BIS (2011), Maxwell-Jackson (2011), Government Office for Science (2013), BIS (2014), Smith (2015), Hughes et al. (2016).

heterogeneity in their governance and structure in different countries and overlapping missions and duties with university laboratories, various taxonomies have been used to refer to these organisations. To deal with this confusion, the primary task was to clearly define the public research organisations in the UK, drawing on a comprehensive literature review, PROs' financial statements, and government reports on their sources of income, operational activities, and performance. In the next stage, all those public organisations that primarily engage in cultural missions (e.g. museums, film, and sports councils) and the 37 Medical Research Council institutes (funded by the Medical Research Council but based at universities) have been excluded from the target list. The remainder was a population of 49 PROs potentially of interest for this study. Once the relevant population (active PROs that carry out research in the UK) was constructed, the target population was selected according to the research questions and the feasibility of data collection for each paper. First, we collected quantitative data about 33 PROs for which administrative data (from financial statements) were available. This data collection process lasted two years between 2017 and 2019, and it led to creating of a 6-year (2011-2017) demographic panel data referring to 33 PROs, combining data from financial statements, PROs' websites, and patent (European Patent Office) and publication (Scopus) databases.

Additionally, 26 in-depth interviews with 23 representatives of 21 PROs and three funding bodies were conducted in the late summer and fall 2020. The potential interviewees were carefully selected among R&D managers, KT managers, and chief scientists actively engaged in KT activities in the 49 listed PROs. The paper presented in Chapter 3 builds on the panel dataset of 33 PROs. The paper presented in Chapter 4 builds on the 26 interviews with 23 representatives of 21 PROs and three funding bodies. Finally, the paper presented in Chapter 5 combines quantitative and qualitative information about 16 PROs whose representatives were interviewed and were also included in the panel dataset. All detailed information about the population sample, data collection, and data analysis have been presented in the related chapter for each paper.

CHAPTER 2. Context: public research organisations in the UK

2.1 Introduction

This chapter sheds light on the historical background, structure, and governance of public research organisations in the UK. It examines the national political motives for innovation and regulatory context to interaction and provides the framework for science and technology policy regulating the function and operation of PROs having active R&D centres in the UK. This section also illustrates different publicly funded organisations and their financial resources and some of the main differences between their structure, governance and resources.

This chapter is specifically important as it provides a historical background of the creation and development of a set of public research and development infrastructures in the UK that receive the major governmental funds and subsidies as well as have contributed to the major science and technology improvements and significant public-private contracts. Research to date has tended to focus on data from universities as sources of basic and complementary knowledge to investigate public research, their linkages to industry as well as the patterns of their interactions, rather than PROs. To bridge this knowledge gap, this chapter concentrates on PROs in the UK that produce similar type of knowledge and even more applied outcomes to provide an overview of a distinctive source of data in public research.

2.2. The role of PROs in the UK's economy

According to the UK research base report (2016), the UK is well-rounded across most research areas and highly prolific regarding the number of articles and citations per researcher and per unit of R&D expenditure. Although the UK's share of global patents in force and patents citing has grown, its share of global patents in force ranked third lowest among the comparator countries[5]. The UK experiences a continuous upward trend of research productivity despite competitive pressure from other research-intensive and emerging countries. The UK's publications witnessed an

[5] The performance of the United Kingdom's (UK) research base is compared with seven other research-intensive countries (Canada, China, France, Germany, Italy, Japan, and the US), four other fast growing nations (Brazil, India, Russia and South Korea), and international benchmarks.

11% rise in 2018 compared to 2014, which was the third highest number of publications among comparator countries, behind China and the US. It also retains the third rank of the world's most highly-cited publication after the US and China (International comparison of the UK research base, 2019). Nevertheless, the UK has indicated a poor record of exploiting its research output in patenting compared to the US and China.

In recent years, there has been a broad consensus among politicians that increasing the total investment in R&D will boost economic growth, societal well-being, and UK 's position on the scientific frontier. Consistent with this, a high reported correlation exists between private and public R&D investment and high productivity, innovation, and growth. However, the allocated budget on science and spending on R&D in the UK has been on a downward trend in many departments, and, in some cases, it has dropped to less than one percent of total spend (Government science capability, 2019; The British Academy, 2022).

There exist extraordinary assets and expertise in the UK's public laboratories that play a crucial role in shaping the government's missions and framing the research that promote innovation and generate new knowledge to deliver new products and services. The wide range of government-owned PROs provides critical resources for the government's directing role of conducting outstanding R&D in an era where science is the "cornerstone" of the economy to enhance government effectiveness for improving societal well-being and securing economic growth. While these PROs possess excellent science, expertise, and research budget, their scientific research activities, expenditure, and outcome vary across governmental organisations and departments. The less efficient deployment of PRO's excellence has ensued from several years of decentralisation and devolution from central government (ibid.).

In a review of the UK's science capabilities in 2019, a number of obstacles to more effective use of the resources in the public research sector were identified. As a result, several guidelines were presented for more strategic use of the UK's R&D capital. The suggested guidelines include: enhanced collaboration of public research sectors in a more integrated way across organisational boundaries and operating across government with a broader range of PROs, academia, industry, and public sectors in the UK and internationally, opening up excellence-based funding competition, and

incentivising strategic use of UK's R&D budgets as well as enhancing UK's spending on R&D.

The establishment of UK Research and Innovation (UKIR) in 2018 was the government's initiative to flourish UK's public R&D and innovation environment and bring together the seven disciplinary research councils, Research England and Innovate UK. While the total net expenditure on R&D and KT activities represented 0,7% of GDP reached £15.5 billion in 2020[6], the share of UKIR's seven Research Councils expenditure on R&D and KT activities was £6.1 billion, about forty percent of the total in the same year. In pursuit of improving the impact of science and in line with the government's ambitions to increase the scale of the UK's R&D expenditure as a proportion of GDP, the government has committed itself to meet a target of 2.4% of GDP invested in the UK R&D by 2027, and a longer-term goal of 3%. The significant outcome expected from this decision is to improve the impact of science by: a) enabling the assessment of the outcomes of scientific activities against the percentage of their R&D spend concerning their needs and objectives, b) interacting with broader networks of academia and industry in the UK and internationally, and c) developing new frameworks to interact with innovative firms to meet the government's demand for science[7].

Furthermore, national policies have undergone considerable changes in the last two decades that have directly impacted the interaction between PROs (national laboratories) and the local private sector, and in turn, on the regional economic development (Lawton Smith and Assimakopoulos, 2020). It was first in the 2000s that the critical role of PROs and universities in supporting major local firms and shaping local economies was recognised, due to their ability to provide business support and embeddedness in the local communities and economies (Smallbone et al., 2015).

In this context, the UK PROs that possess remarkable assets of scientists, experts, and massive infrastructure, play a crucial role in shaping and fulfilling national and

[6] The 0.7% expenditure on R&D and knowledge transfer activities was in-line with the long-term trend of 0.6% to 0.7% since 2009.
[7] Government announces plans for largest ever R7D budget, https://www.gov.uk/government/news/government-announces-plans-for-largest-ever-rd-budget#:~:text=The%20%C2%A339.8%20billion%20R%26D,ambitions%20as%20a%20science%20superpower.

governmental missions, facilitating scientific research (Science Capability Review, 2019), and driving economic growth (Lawton Smith and Assimakopoulos, 2020).

Government-owned and privatised PROs in the UK play a significant role in providing the government, private sector, and society in general, with applied scientific research, technology consultancy, advice of superior quality, emergency solutions, testing, and setting up standards. The contribution of this role to the wider economy became more evident when the ownership structure and management of a few public PROs turned over to the private sector. At this stage, PROs' potential ability to promote KT, commercialise research output from R&D centres, and create employment opportunities become more visible (Maxwell-Jackson, 2011).

Despite a sizable investment in PROs in the UK and their heterogeneity of sector, ownership structure, and funding arrangements, PROs' governance and their contribution to sustainable economic and social welfare have been an under-researched area. Likewise, a substantial part of publicly available sources of information about PROs, including their financial statements and governance, have been unexploited. Drawing on this perspective, this PhD thesis contributes to further exploration of the innovative activities, KT governance, and commercialisation of the research output of a large group of publicly funded R&D organisations in the UK.

2.2 History and policy framework of PROs in the UK

In the last four decades the linkage between academia and industry have been considered in the USA and Europe as necessary means to both advocate national science and technical resources to increase their output and enhance industrial competitiveness (Charles and Howells 1992; David et al. 1994; Ergas 1993; Lawton Smith 2000). During the same period, in the same countries, much effort has been made to facilitate KT between universities as national science resources and industry by developing organisational and infrastructural support.

However, the results indicated a significant failure in KT policies with some exceptional success due to inherent difficulties in setting up organisational frameworks to successfully transfer knowledge and technology from universities to industry and social sectors (Geuna and Muscio, 2009). The results are more or less alike (see Maxwell-Jackson, 2011) in reviewing limited literature on KT performance

of PROs- publicly funded research centres other than universities. Reviewing the history and public policy of innovation in the UK will shed light on some of the mechanisms and operations that have formed the norms of interaction between PROs and industry at different periods and scales.

2.2.1 National laboratories- History and conversion

Establishing state-owned laboratories in the UK and most other countries in Europe, Asia, South Africa, and the US dates back to the mid-19th century when the volume of exchanged products and number of borders to merchandise expanded due to minimised transportation costs. To secure national revenue (including customs duties that comprised a considerable share of governments' income at that time), governments required experts, scientists, and new venues to monitor and impede fraud by levying taxes, reinforcing tariffs, and implementing customs regulations. For example, in Spain, the government contracted external consultants and chemists to boost customs officials and appraisers in national ports, mainly for drug inspection and purity checks of other goods for imposing required tariffs. To improve the efficiency of this system, governments noticed the urgency of establishing state-owned laboratories.

The emergence of national research institutions in the UK dates back to the foundation of the Excise Laboratory (1842) to detect adulteration of tobacco on behalf of HM Customs & Excise. The laboratory multiplied, and by the mid-20th century, it became established as a free-standing central department called the Government Chemist, with the responsibility to investigate a large number of samples and conduct research on behalf of other government authorities. In the late 19th century, industrial countries such as Germany, the United States, and Britain sat up their public research laboratories in furtherance of military science, focusing on physics. This led to the establishment of the National Physical Laboratory (NPL) in 1900 to standardise and verify instruments for testing materials and supporting the military industry. From there, other public research centres in the UK were established and developed for military-oriented and civil purposes. During the second world war, UK private laboratories joined the public sector to develop an integrated supply chain. This collaboration under one central governance was imperative for the country to tackle an unfavorable circumstance it found itself (Charles and Howells, 1992).

The post-war era was a significant one for the development of national laboratories in Europe and North America. In pursuit of stimulating and speeding up large-scale R&D projects, the governments invested in strategic areas such as defence, e0nergy, and space. This era is identified as "the beginning of big science and big technology", as each OECD member allocated considerable resources to its R&D centres (OECD, 1989). Nuclear energy and space were two major scientific and technology areas that absorbed a huge amount of government funding. This led to governments' extensive investment in a broader range of public research and the establishment of new laboratories to fulfill specific needs. The evolution of these laboratories in the UK led to the establishment of the United Kingdom Atomic Energy Authority (UKAEA) in 1954, later known as AEA, and specialised in nuclear energy (Lawton Smith, 1997).

Between 1960 and 1980, most of the OECD countries devoted major national resources to nuclear, defence, energy and telecommunication, and aircraft programmes (Lawton Smith, 2000), among which the UK government spent two-thirds of its R&D expenditure (Ergas, 1993). Following a re-evaluation of the role of national laboratories in the mid-1960s, most of the OECD countries employed a narrow-down approach based on priorities for their research efforts and activities in national laboratories. Successively they strived to undertake strategies for better exploitation and enhanced application of the national scientific resources in the industry (Lawton Smith, 2000). In the UK, concerns about the governance and function of the national laboratories and related policies led to the passing of the Science and Technology Act in 1965. This Act aimed to facilitate funding for scientific research and development activities within national laboratories. As a part of this Act, national laboratories could undertake limited research outside their specialised field by collaborating with commercial organisations and initiating research contracts. UKAEA was among the first laboratories which commenced commercialisation of its research output without being engaged with manufacturing and holding ownership as a major shareholder in any counterparties' businesses. This trend continued until the end of the 20th century with the major role of national laboratories in science (Lawton Smith, 1997).

In the same vein, the public research ecosystem in Europe underwent dramatic changes in governance of the public research sector (Crow and Bozeman, 1998). The

financial crises, heavy load of bureaucracy procedures, and diminished level of public trust (Pollitt, et al., 2007) in the late 1970s caused governments to carry out reforms.

The reforms aimed to enhance public research's efficiency and effectiveness, improve performance, and re-orient their objectives and services to fulfill the citizen's expectations (Ibid.). This led to the introduction of New Public Management (NMP) in 1980, (Ferlie, et al., 1996), which resulted in the transformation of governance of the public research sector (including both higher education institutions (HEIs) and PROs) from wholly-owned and rigidly controlled by the government (Capano, 2011) to more autonomous entities (de Boer, et al., 2007). This transformation permits the public research sector to pursue more market-oriented strategies mainly driven by economic incentives (Hicks, 2012). Furthermore, the enhanced autonomy of the public research sector ensued from such reforms, enabling them to develop organisational strategies in line with their research priorities, create a clear organisational hierarchy (Fumasoli and Lepori, 2011), and design their research teams (Heinze et al., 2009).

The slow movement of the UK national laboratories towards commercialisation of their research output allowed for an initiative in 1988 aiming to enhance the "quality and efficiency of government services". To enforce this initiative, several Executive Agencies were created under the supervision of the corresponding Minister and in collaboration with Treasury. The assigned Chief Executive of each Agency functioned to fulfill the predetermined policy within accessible resources. As a result, most of the national laboratories in the UK were converted to agencies and the number of Executive Agencies reached 76 by 1992, with around 290,000 employees (Lawton Smith, 1997). In addition, the conversion of several non-defence national laboratories (including NPL, National Engineering Laboratories (NEL), National Weight and Measures Laboratories, and the Laboratory of the Government Chemist) to agencies was preparation for privatisation (Lawton Smith, 2000).

In the 1990s- the post-Cold War era, the maturity of nuclear technology, high expenses of upkeeping old power stations and reactor utilities, and challenges of waste disposal on the one hand and promoting environmental technologies and enhancing microelectronics skills, on the other hand, became essential for governments.

The extremely adverse economic environment in the early 1990s, recalled as the worst economic recession since the Second World War, led to high rates of unemployment and increased interest rates in Europe, allowed for the launching of a new initiative in 1993 of White Paper on growth, competitiveness, and employment (Endo, 1999). The primary objectives of this act were to improve the science and technology base and to secure the efficiency and effectiveness of government R&D (Lawton Smith, 2000). The priorities of this Act were set within an action plan: 1 . Promote the technologies use of information 2. Provide basic trans-European services 3. Create an appropriate regulatory framework 4. Develop training on new technologies 5. Improve industrial and technological performance.

In the UK, the government retreated from national laboratories' "mission-oriented" programmes (Ergas, 1993). For instance, NPL was established in 1900 under the supervision of the Royal Society. Then it was controlled by Department of Scientific and Industrial Research in 1918, which transferred to Department of Trade and Industry (DTI) in 1965 and became an Executive Agency under the state's "Next steps" reforms. While these reforms aimed at reducing research expenditure and enabling to priority setting of research, they resulted in limited cost reductions and efficiency savings. Thus, a more ambitious initiative was required to remove public research sectors' constraints and create greater commercial freedom for realising NPL's full potential (Mann, 2019). In 1992, when the government emphasised public expenditure cuts, all DTIs laboratories confronted several layouts with considering an option: to merger, privatise, remain as an Executive Agency, join the central government, or close. Since NPL, as the UK's National Measurement Institute, had a strategic value for the government, it adopted a GOCO (Government Owned Contracted Operated) business model "*that enabled the government to continue to own the laboratory but entrust its operation to the private sector so as to engender benefits of best commercial practices*", (Mann, 2019,.13), until 2014 that returned to government and its GOCO contract terminated.

Other laboratories, such as National Engineering Laboratory and the Laboratory of the Government Chemist were privatised (Lawton Smith 1997; Lawton Smith, 2000), Warren Spring Laboratory was closed, and the National Weights and Measures Laboratory remained and Executive Agency (Mann, 2019).

2.2.2 The current organisational structure of PROs

The Public Research Organisations (PROs), in line with OECD's (2011) definition, entail a varying degree of publicness in terms of the extent to which government has influence not only on their ownership structure but also on the type of research and funding. PROs in the UK are affiliated either to a UK Research Council or a Government department as a "specific parent body". PROs associated with the government departments or Research Council should fulfill the government's missions and objectives and provide research services their parent body requires. PROs are classified into two categories: a) those that are part of or directly sponsored by Government departments, including cultural institutes that may also receive funding from other sources, NHS regions, and departmental research bodies representing all other government department PROs that are not covered by the first two categories. b) those part of or directly sponsored by one of the UK Research Councils. The Research Council Headquarters do not undertake research but oversee research funding and administration. However, related institutes/units are responsible for undertaking research on behalf of their parent council. The ownership of these research institutes may entirely belong to the Research Council, which also provides the majority of financial sources. Otherwise, they act as "centres of excellence" which may receive a minor grant from their parent research council from their overall research funding.

According to the Baker Pre-budget Report (1999) on stability and steady growth for Britain, the areas of interest of PROs for conducting research and providing services are:

• Improving the quality of life;

• Promoting economic development through advances in basic science;

• Informing Government policy-making; and,

• Undertaking statutory scientific testing and regulatory functions.

The type of research conducted in PROs is generally applied rather than fundamental, enabling them to provide a wide range of services and support the governmental policies for pre-defined purposes. The performance of these organisations is highly associated with their missions and roles in supporting specific governmental objectives and their benefits for overall societal well-being. In assessing the PROs'

performance, the quality of their research is evaluated in terms of the scientific and technical services they provide. PROs provide services that entail testing and standardising products and procedures, specialist consultancy and emergent consultancy, timely, up-to-date, comprehensive, and long-term scientific and technical advice for policymakers and decision-making. In addition, the assessment of PROs' performance takes into account the extent to which they fulfill the government's requirements for delivering high-quality research to benefit wider society and economy as well as the PROs' financial performance connected to the level of input they received from the government (Maxwell-Jackson, 2011).

The new political environment, reductions in government spending, and growing interest in knowledge and technology transfer as well as a need for accountability and performance caused governments to embark upon cultivating entrepreneurial behavior (Coccia and Rolfo, 2010) and even consider a partnership with private companies as a catalyst for accelerating innovation and improving public service (Mann, 2019). However, despite several reforms concerning the public research sector, in the U.S., Europe, and the UK, public research remains one of the most current and controversial debates that occasionally brings about a less than satisfactory outcome (Dresner, 2000).

While Chapter 2 lays the ground by illustrating broader context of PROs' history and policy framework, it is essential to note that a comprehensive literature review on PROs is presented in chapter 5 of this thesis. Chapter 5 delves deeper in the specificities of PROs where it focuses specifically on PROs' mission, KT engagement, and performance measurement. By defining and categorising PROs' missions and through an in-depth analysis of their KT activities and performance indicators, this chapter enriches the understanding of how PROs contribute to economic growth, highlights the limitations in existing performance indicators and emphasises the need for more calibrated and contextualised measures that accounts for the full scope of the PROs' KT activities beyond traditional quantitative metrics.

Chapter 5 provides comprehensive results through bibliometrics approach and in-depth interview analysis to address the specific research questions defined for this academic article. Chapter 2 and 5 together provide a holistic understanding of the significant role of PROs in the UK's innovation and economic growth.

CHAPTER 3. Intrinsic and strategic complementarity of research and knowledge transfer activities as determinants of knowledge transfer governance in public research organisations

Abstract

While public research organisations (PROs) are increasingly expected to actively transfer knowledge to business, government and wider society, limited research exists about how they manage this important function. Particularly, it is not known under what conditions it is more effective for PRO to vertically integrate KT management, or to outsource it to specialist providers. Extending the theory of firm boundaries to PROs, this study argues that this choice is influenced by two types of complementarity between research and KT: *intrinsic complementarity* (occurring when the KT process requires unique tacit knowledge) and *strategic complementarity* (occurring when the nature of the knowledge recipients matters to the PRO). By exploiting a unique six-year panel dataset of 33 PROs in the United Kingdom, this study confirms that higher degrees of both types of complementarity are associated with greater likelihood to vertically integrate KT management, and that these effects are independent of economies of scale and sector specificities.

3.1. Introduction

KT management is increasingly considered an important function of the public research system, including universities and government-funded research institutions, the latter also known as public research organisations (PROs). Government-funded research performed in these organisations can not only advance the scientific frontier but also provide useful knowledge inputs for business innovation (Bozeman, 1994; Vorley and Lawton Smith, 2007; Mazzucato, 2015), this way supporting businesses' long-term economic competitiveness. Universities and PROs are under increasing pressure to engage with external stakeholders within industry, the public sector, and society more generally (Maxwell-Jackson, 2011; Ankrah, et al., 2013), in order to demonstrate their public value to the policymakers and to the taxpayers they are accountable to, as well as to supplement dwindling public investment in research with

private income arising from KT activities.

Despite the growing relevance of KT management as a crucial activity within the public research system, there are very few studies that have analysed how this new activity should be organised, particularly whether it would be more efficient and effective for it to be vertically integrated within research organisations or outsourced to specialised providers. Where this issue has been investigated, it has usually been done in relation to universities rather than PROs (Sengupta and Ray, 2017).

Moreover, there is a lack of convincing theoretical explanations for the organisational choice whether to vertically integrate or outsource KT management. This study aims to fill this gap in research by making a theoretical and empirical contribution to the understanding of what drives PROs to vertically integrate or outsource KT management.

This study articulates a conceptual framework to describe how the 'make or buy' decision, which so far has been investigated mainly in relation to firm boundaries, applies to a less studied context – the public research sector – and to a specific type of knowledge process – KT from research performers to external stakeholders. The organisational literature on firm boundaries suggests that firms should integrate certain activities (or capabilities) when they are complementary to other activities in ways that generate unique bundles capable to deliver competitive advantage (Mahoney and Pandian, 1992; Milgrom and Roberts, 1995; Argyres and Zenger, 2012).

This study applies and extends the theory of firm boundaries to the case of PROs, where the objective function is not directly related to profit but to the attainment of their institutional mission, and where it looks specifically at the complementarity between research and KT. It argues that two types of complementarity between research and KT - generating unique bundles of activities that fulfill the PRO's institutional mission better than if they were unbundled - matter in order to decide whether the KT management activity should be integrated. One is is termed in this paper as *intrinsic complementarity*, which occurs when effective KT requires tacit knowledge, which is uniquely possessed by the research performers. The other is termed *strategic complementarity*, which occurs when effective KT involves some control on which external stakeholders knowledge is transferred to. It is hypothesised

that both types of complementarity lead PROs to integrate KT management functions, and that these are independent of other efficiency considerations, like economies of scale and sector specificities. These hypotheses are tested empirically by exploiting a unique, purposefully constructed panel dataset of 33 PROs in the United Kingdom (UK), built from public administrative records (annual reports and financial statements) for the six financial years between 2011/2012 and 2016/2017, combined with information derived from other publicly available sources like publications and patent databases, and the PROs' websites.

This study is innovative in several respects. First, although there has been much research on the outsourcing of knowledge processes, it has mainly focused on private firms, driven by profit-making considerations. These studies have explained the 'make or buy' decision using capabilities (Demsetz, 1988; Kogut and Zander, 1992; Langlois, 1992; Barney, 1999) or transaction costs (Williamson, 1975) as determinants of firm boundaries, or more recently, in a dynamic perspective, a combination of both (Odagiri, 2003; Jacobides and Winter, 2005, 2012; Foss and Foss, 2008; Argyres and Zenger, 2012). Less has been done in relation to public sector organisations, where studies have discussed the cost efficiency and political expediency of outsourcing public services (e.g. Grimshaw et al., 2002; Jensen and Stonecash, 2004; Elinder and Jordahl, 2013), rather than how complementarities between activities influence the decision to outsource. Second, the studies of public services outsourcing usually focus on generic services, some of which may be knowledge-intensive (Avery, 2000; Young, 2005), but they do not focus specifically on the outsourcing of KT management functions on the part of research performers. Third, studies of KT management in research organisations, have mainly focused on universities rather than PROs.

Since this study contributes to better understanding of the phenomenon of KT management, it can provide useful guidance to PROs that wish to boost the effective exploitation of their research, and to policymakers that intend to support them in doing so. In fact, studies show that boosting innovation in the public sector requires an overarching strategy on the part of government to introduce organisational innovations and practices that support KT (Lee et al., 2012; Cervantes and Meissner, 2014).

The UK is an interesting setting for this study for several reasons. First, the country

possesses a sizeable (although it has shrunk in recent years) and very heterogeneous PRO sector, characterised by a variety of ownership and funding arrangements, making this an appropriate scenario in order to investigate organisational differences across PROs. Second, the UK experience can be of interest to other countries, given that the adoption of managerial practices in the public sector is widespread (Boden et al., 2004; James, 2009), anticipating trends that have been replicated in many countries in Europe and elsewhere (Nedeva and Boden, 2004; Senker, 2000; Cruz-Castro et al., 2020). Despite its importance, the PRO sector in the UK is under-studied compared to the university sector. One of the problems might be the lack of publicly available data. While the UK government has invested substantially in understanding and promoting universities' KT engagement (Huggins and Kitagawa, 2012; Rossi and Rosli, 2015), it has paid less attention to PROs: the Department of Business, Innovation and Skills carried out a few surveys of PROs' KT activities in the early 2000s, but this exercise stopped after 2012/13 (see BIS, 2007, 2011, 2014). More recently, a survey of individual researchers working for a set of PROs (Research Council Institutes) has uncovered widespread engagement with industry and other stakeholders (NCUB, 2016).

The paper is structured as follows. Section 3.2 presents a review the literature on PROs' KT activities, and draws on organisation theories to identify the determinants of the choice to vertically integrate or outsource KT management functions. Section 3.3 describes the data and methodology. Section 3.4 presents and discusses the findings. Section 3.5 concludes.

3.2. Literature review

3.2.1. Knowledge transfer management in PROs

PROs are an important component of the public research systems of most countries including, or even particularly, in emerging economies (WIPO, 2011). They are positioned between the fundamental science carried out in academia and the industrial R&D carried out by business (Mazzoleni and Nelson, 2007; Maxwell-Jackson, 2011). PROs are very heterogeneous in relation to aspects like their mission (which ranges from 'pure' knowledge development, to the provision of evaluation, testing, emergency response and consultancy services to government, industry and the general

public), scientific disciplines, legal status, and ownership (Cruz-Castro et al., 2020). This heterogeneity reinforces the importance of analyzing them separately from universities, also in relation to their KT management.

PROs, in fact, are increasingly expected to contribute to national economic growth by transferring knowledge to external stakeholders, and they do so through a variety of engagement channels, which they combine in different ways (de la Torre et al., 2021). Recent studies show that PROs engage in contract research with industry, patenting and licensing, mobility of staff and conferences, promotion of start-ups (Rubenstein, 2003; D'Este and Patel, 2007; Perkmann and Walsh, 2007; NCUB, 2016) and in more market-oriented activities like the provision of prototyping, analysis and testing, calibration and certification services (Coccia and Rolfo, 2002). PRO staff also participate in more informal KT activities, such as providing informal advice and participating in networks, and contributing to public and community engagement through activities like taking part in educational projects, delivering lectures, organising exhibitions (NCUB, 2016). The management of these multifaceted activities has become a more pressing concern for PROs (Cervantes and Meissner, 2014).

This study analyses the determinants of PROs' approaches to KT management by specifically focusing on the choice whether to vertically integrate or outsource KT management functions to specialised companies. Outsourcing key business functions is increasingly seen as a crucial component of contemporary organisational business models (Merino and Rodríguez, 2007), and it is increasingly discussed in relation to knowledge processes (Mudambi and Tallman, 2010). Organisations in the public sector might benefit from the advantages of outsourcing, which include efficiency gains (Quinn, 1999), the possibility to access specialist knowledge and capabilities (Hayer, 2016; Wright et al., 2008), the development of greater business focus (Quinn and Hilmer, 1994) and flexibility (Kremic et al., 2006) and of greater absorptive capacity (Un, 2017). This organisational model might become particularly attractive to PROs as their volume of KT activities increases in response to policy pressures.[8] Hence, the choice whether to vertically integrate or outsource some knowledge KT

[8] Indeed, studies of universities have shown that, as their KT engagement intensifies, they increasingly rely on intermediaries and specialists to manage some of their KT functions (Yusuf, 2008; Hayer, 2016).

functions is likely to become increasingly relevant to PROs. Better understanding of the drivers of this choice allows to identify which PROs are more likely to need support with outsourcing, or to benefit from interventions that improve their in-house KT management abilities.

While a substantial amount of literature has investigated the engagement of the public research sector in KT to industry, the specificities of the KT activities of PROs remain under-researched. Most studies in this stream of literature focus on universities only. When non-university PROs are studied, they are often part of larger samples that include universities as well (e.g. Mazzoleni and Nelson, 2007; Dutrénit and Arza, 2010; Arza and Lopez, 2011; Arnold et al., 2010; Fudickar and Hottenrott, 2019). Some studies deploy even more heterogeneous samples that combine both government research institutes and private non-profit organisations engaged in R&D activities such as research foundations (Mina et al., 2009; Teirlinck and Spithoven, 2012; Landry et al., 2013).

A growing literature on KT management in the public research sector, mainly focused on universities, has identified a variety of organisational arrangements used to support this activity. Their choice increasingly results from strategic decisions, aimed at fitting the institution's resources with the constraints and opportunities present in its rapidly changing external environment (Hewitt-Dundas, 2012; Martin, 2012; Kitagawa et al., 2016; Rossi, 2018). In turn, organisational arrangements have been found to impact the nature of the institution's engagement in KT (Ambos et.al., 2008; Perkmann et.al., 2013; Lockett et al., 2015; Sengupta and Ray, 2017). Studies of universities' KT management have documented a progressive diversification of KT activities and organisational approaches. Earlier efforts focused mainly on the process of research commercialisation through the sale and licensing of intellectual property (IP), using either internal units, or various kind of external units (profit or non-profit making, owned or not by the university) providing advice, funding, and expertise in exchange for payment of a fee and/or of a share in the university's IP (Rogers et al., 2009; Tang et al., 2009). Over time, universities have diversified their KT activities beyond IP commercialisation, and KT management has become more varied and more decentralised, often involving several layers within the university, and combining internal structures and outsourcing in different ways (Sengupta and Ray, 2017; Sánchez-Barrioluengo et al., 2019).

With respect to the objective to understand what drives PROs to vertically integrate or outsource knowledge KT activities, this literature suffers from two main limitations. First, findings from studies of universities cannot be immediately transposed to PROs, which are different in many respects, including: (i) their activities (PROs' teaching activities, when they exist at all, are limited to doctoral supervision and professional training, and PROs' research activities are often closely directed to the achievement of government objectives (Cruz-Castro et al., 2015); (ii) their subject focus (PROs tend to specialise in one field or a few closely related fields, while universities can have very diversified subject portfolios); (iii) their governance (PROs can have varied ownership and management structures, and can be affiliated with different parts of government (Sanz-Menéndez et al., 2011), whereas universities usually maintain an arms' length relationship with government whose role is limited to funding provision). Secondly, studies in this stream of research tend to be descriptive, paying limited attention to the conceptualisation of the choice of organisational approach in more theoretical terms.

The next section builds on the organisational literature about firm boundaries more generally, and about the outsourcing of knowledge processes in particular, in order to develop a conceptual framework linking the KT management 'make or buy' decision to the nature of the complementarity between research and KT in light of the PRO's objectives.

3.2.2. Research and knowledge transfer complementarity and the organisation of knowledge transfer management

The theory of outsourcing has made a lot of progress over the last decade. Initially, the decision to outsource activities was explained on the basis of transaction costs, building on Williamson's pioneering work (1975). The key argument here was that activities are integrated if the cost of outsourcing is higher than the cost of integrating, where the outsourcing cost includes the transaction costs deriving from imperfections in factor markets. The latter comprise the costs of searching for and screening potential suppliers, as well as the cost of the potential holdup problem arising when the supplier is able to acquire crucial capabilities that render the outsourcing firm vulnerable to increasing prices (Brandenburger and Stuart, 1996, Lippman and Rumelt, 2003). The other viewpoint came from the resource-based theory of the firm

and its extensions, such as the knowledge-based theory of the firm (Grant, 1996) and the dynamic capability theory (Teece et al., 1997). This stream of literature argues that firms should produce internally what they can do better than other firms, and outsource what they can do less well than other firms. Any activities for which the firm does not possess superior capabilities should be outsourced to suppliers that, by virtue of specialising in a specific activity and of performing it on a larger scale, are both more capable (Argyres, 1996; Kaufman et al., 1996; Mudambi and Tallman, 2010) and more efficient (Kakabadse and Kakabadse, 2000).

More recently, some approaches have combined the two perspectives, suggesting that capabilities and transaction costs are interlinked (Argyres and Zenger, 2012). On the one hand, current superior capabilities can be explained as the outcome of past governance decisions driven by transaction costs, so transaction costs considerations underpin the emergence of capabilities. On the other hand, transaction costs continue to matter even once superior capabilities have been established, since capabilities are changeable and a company can build superior capabilities (or vice versa other companies can steal a company's superior capabilities) through the purchase of strategic factors, including key human resources (Capron and Mitchell, 1998; Nagarajan and Mitchell, 1998).

According to this combined view, a firm should vertically integrate activities[9] when they are complementary to its other activities, in ways that generate unique bundles capable to deliver competitive advantage (Dierickx and Cool, 1989; Ghemawat, 2005; Argyres and Zenger, 2012). The value of an activity is therefore strongly firm-specific, as it depends on the relationship between this activity and the other activities in the firm's bundle: when the activity is complementary in ways that confer unique competitive advantage, it is said to enjoy a relationship of unique complementarity. Table 3.1 summarizes the predictions of this view: firms are likely to integrate activities that are uniquely complementary to their other activities, whereas they are unlikely to integrate unique activities that are not complementary to their other

[9] The literature on firm boundaries talks of assets, resources, and activities, which are seen as the underlying components of configurations out of which capabilities emerge (Amit and Shoemaker 1993). For ease of exposition, in this paper we use the term 'activities' to refer to the combinations of physical assets and human and intellectual resources that are used in the production of a good or service, which the organisation can decide to vertically integrate or outsource. Some studies in the organisational studies literature prefer the term 'assets' (sometimes intended as also encompassing 'resources' and 'activities'; Argyres and Zenger, 2012).

activities, or generically complementary activities (Argyres and Zenger, 2012).

Table 3.1. Integration outcomes of different types of complementarity

State of activity	Generic	Unique
Complementary with other activities in the bundle	Outsource	Acquire or develop internally
Non complementary with other activities in the bundle	Outsource	Outsource

Source: adapted from Argyres and Zenger (2012)

Managers who are able to detect and combine uniquely complementary activities can enjoy substantial rents (Barney, 1986) provided that: first, they do not reveal to others the value of the bundle of activities while they are assembling them (if they did, the owners of the complementary activities might attempt to extract higher rents from the sale of these activities), and, second, they do not allow others to appropriate the value of the bundle through unfavourable governance arrangements (for example, by outsourcing some of the uniquely complementary activities to others, who might then be able to keep the focal firm hostage).

In order to apply this framework to the case of PROs to predict when research and KT activities should be bundled or not, it is necessary to make some adaptations. Most studies in the firm boundaries literature take it for granted that the feedback as to whether a bundle comprising a particular activity delivers competitive advantage, comes from the profit signal: the ability to generate returns from the bundle greater than the returns that would be generated from a bundle that includes an alternative activity. However, the rate of return for the investment made is not a relevant success metric for all kinds of organisations. Jacobides and Winter (2012) indeed noted that what organisations find 'rewarding' depends on what the system around them rewards – which could be administrative goals in a state bureaucracy, or key performance indicators in a business department of a large corporate structure. Hence, they argued that the reward system that the organisation operates under influences the operation of the feedback processes through which the value of bundles of activities is established, and consequently also the decisions whether to integrate or outsource such activities. Since government-funded research institutions are evaluated by the government on the basis of their success in fulfilling their institutional mission, this criterion should provide the feedback process regarding whether the KT management activity should

be integrated within the PRO or not.

The PRO's institutional mission is not directly to generate external revenue (although this is encouraged), but rather to produce and diffuse knowledge for the benefit of the PRO's relevant stakeholders. The latter can be internal - government, other stakeholders represented in governing bodies – and external – businesses and other communities, depending on the PRO's focus (for example, for a PRO in the public health sector the whole population potentially affected by a disease can be a relevant stakeholder)[10]. Accordingly, PROs should integrate KT management activities when these are uniquely complementary to the PRO's core research activity, so that their bundling allows the PRO to achieve its institutional mission better than the unbundling of these activities and the outsourcing of KT.

It can be argued that the extent to which the bundling of KT with research in a PRO allows it to benefit its relevant stakeholders better than outsourcing, depends on two sources of unique complementarity, which can be termed intrinsic complementarity and strategic complementarity.

Intrinsic complementarity between research and KT management occurs when knowledge has a strong tacit component[11] so that its effective transfer requires the involvement of people who possess this tacit knowledge element - typically the people who have themselves performed the underpinning research. In the presence of tacit knowledge, the bundling of research and KT management within the PRO leads to more effective diffusion of knowledge to relevant stakeholders, and hence better fulfillment of the PRO's institutional mission, for several reasons.

First, bundling facilitates the circulation of tacit knowledge between the people involved in research and those involved in KT. The organisational setting is able to generate common language, a shared identity, and a more trusting social environment (Kogut and Zander, 1992; Nahapiet and Ghoshal, 1998; Monteverde, 1995; Gertler,

[10] These missions are often explicitly noted by PROs, for example: "*We have a duty to maximise the benefit to the UK of the new technologies and knowledge that are developed during the course of our defence work*" (DSTL, Annual Report 2016/17); "[*The PRO] promotes technology growth in the UK, with new enterprises acting as a catalyst for UK industry and enabling broader utilisation of skills now and in the longer term*" (UKAEA, Annual Report 2016/17); "*We support businesses, agencies and governments in making short and long-term decisions, making the world a safer and more resilient place tomorrow, and for the years – and decades – to come*" (Met Office, Annual Report 2016/17).

[11] Tacit knowledge is defined as the non-codifiable accumulation of skills that arise from the learning gained from practice (Reed and DeFillippi, 1990). It is non-verbalised, intuitive, scarce, difficult to imitate, and therefore it is an important source of competitive advantage (Becerra et al. 2008).

2003) which promotes the circulation of knowledge, including tacit knowledge, between the various people involved in the process of KT, something that would be difficult to achieve if some of the latter were based in a different organisation. The organisational setting is also able to mandate the involvement of specific people in the KT process, including the researchers themselves, which is particularly important when tacit knowledge is involved. Instead, reliance on an external organisation would require a costly process of communication and education (Demsetz, 1988; Conner and Prahalad, 1996) on the part of the PRO to make sure that the correct people are involved in the process.

Second, in the presence of tacit knowledge there are difficulties in the use of strategic factor markets. If effective KT requires the people involved in the transfer process to deeply understand the research performed by the PRO, a specialised provider of KT management services might need to invest a lot of resources in developing knowledge specific to the research of the client PRO – for example by seconding staff to the PRO so they can understand their activities better, by developing client-specific software and by recruiting highly specialised human resources. Suppliers are unlikely to make such co-specialised investment in absence of carefully crafted safeguards (Klein et al., 1978; Williamson, 1985; Ceccagnoli et al., 2010). Because of the high costs of creating and enforcing these safeguards contractually (Teece, 1986), this makes it more likely that the PRO will integrate KT. There might also be a risk of opportunism on the part of the supplier if they were to indeed acquire co-specialised knowledge (Narula, 2001; Holcomb and Hitt, 2007; Spithoven and Teirlinck, 2015) particularly in commercially or security sensitive areas of research, which would make the PRO hostage to the supplier's pricing.

Finally, since markets function better when they are able to effectively link reward with productivity (Alchian and Demsetz, 1972), outsourcing is more likely if organisations are able to compensate suppliers based on an accurate measurement of their performance (Poppo and Zenger, 1998). In the presence of tacit knowledge, the value of the transferred knowledge is difficult to measure since it depends highly on who is doing the transfer. It is therefore difficult to price, and to compensate the supplier accordingly[12].

[12] Arora (1996) makes the argument that contractual problems in contracting for know-how in the presence of tacit knowledge can be overcome by bundling technical services (which have a component

Hence, the first hypothesis is that:

H1: The greater the intrinsic complementarity between research and KT, the greater the PRO's likelihood to vertically integrate KT management.

Strategic complementarity between research and KT management occurs when the fulfillment of the institution's mission is strongly related to the ability to direct knowledge to particular stakeholders. If the PRO's mission is linked to transferring knowledge to specific external stakeholders, it becomes very important for the PRO to maintain some degree of control on the KT process to ensure that it is primarily directed to the intended recipients. When this occurs, KT management is strategically complementary to the PRO's core research activity, because the way in which KT is managed (and particularly, the type of stakeholders it is designed to benefit) is integral to the fulfillment of the PRO's mission. By vertically integrating KT management, the PRO can keep under control the KT opportunities that are pursued to make sure they are aligned with institutional objectives.

This argument has been under-developed in the literature on firm boundaries as an explanation for the 'make or buy' decision, as the need to control the nature of the clients to which a product or service is sold does not appear to be very prominent for the majority of firms (with the exception of firms in sensitive sectors like defense, for example). Nonetheless, some firm studies have noted that vertical integration is preferred when the supplier might exploit its knowledge of the firm's research, or its proposed solution to a problem, outside the original contract with the focal firm (Martínez-Noya et al., 2013) and to the benefits of others. While this could be framed purely as a problem of opportunism which might be dealt with through appropriate contractual safeguards, it also highlights a concurrent problem that the supplier might decide to transfer knowledge to stakeholders that were not intended to receive it. Other studies have noted that firms tend to outsource to specialist suppliers when their client base is larger and more heterogeneous (Choi and Hong, 2002; Jones and Hill, 1988; Kistruck et al., 2015), since it is difficult for firms to efficiently connect with

of tacit knowledge) with complementary inputs such as patents or equipment. Arora's argument however applies to the relationship between an organisation transferring knowledge and a client organisation wishing to receive that knowledge. This study instead focuses on the organisational arrangement used by PROs in order to manage the process ofKT, rather than on the management of relationship with the KT recipients. Indeed, complex arrangements that bundle technical services and complementary inputs are probably more likely to occur if KT management is vertically integrated within the PRO, as the process of bundling these activities itself requires tacit knowledge.

many different clients across multiple product and geographic markets (Jones and Hill, 1988); conversely, organisations whose activities are intentionally directed to a smaller client base (e.g., in our case, PROs that direct their KT activities to a smaller pool of stakeholders) should be less likely to outsource these activities.

Hence, the second hypothesis is that:

H2: The greater the strategic complementarity between research and KT, the greater the PRO's likelihood to vertically integrate KT management.

3.3. Data and methodology

3.3.1. Data collection

This study exploits a unique, purposefully constructed panel dataset of 33 PROs in the United Kingdom for six financial years from 2011/2012 to 2016/2017, built from public administrative records (annual reports and financial statements). The development of the sample of PROs to include in the study has been quite laborious, since no comprehensive official list of PROs in the country exists, and since the sector has seen numerous changes, with several mergers between institutions, dismissals of institutions or transfer of institutions to the private or charity sector.

A comprehensive list of currently active PROs was created by analysing eight recent studies of PROs in the UK[13]. These studies adopted various definitions of PROs, but most of them included the following three categories: (a) Departmental Research Bodies and Cultural Institutions: institutes affiliated to one or more government departments, whose mission is to perform research and/or cultural activities (76 institutions); (b) Research Council Institutes: institutes affiliated to one or more of the UK's seven research councils[14] (27 institutions); (c) Medical Research Council (MRC) units: units that received funding by the MRC but are based within universities (34 units).

[13] These are: Lyall et al. (2004), BIS (2007), BIS (2011), Maxwell-Jackson (2011), Government Office for Science (2013), BIS (2014), Smith (2015), Hughes et al. (2016).

[14] These are: Arts and Humanities (AHRC), Biotechnology and Biological Sciences (BBSRC), Engineering and Physical Sciences (EPSRC), Economic and Social Research (ESRC), Medical Research (MRC), Natural Environment (NERC), and Science and Technology Facilities (STFC). Following the passage of the Higher Education and Research Bill (2017), the seven councils have been merged into a single agency called UK Research and Innovation (UKRI) which also includes the innovation funding agency Innovate UK.

An in-depth search of each of these institutions' websites was carried out to ascertain whether they were still active, and whether they were actually involved in research activities. This led to the exclusion of organisations that primarily engaged in cultural missions, such as museums and film and sports councils, as well as institutions that no longer engaged in research, for example an institute that has now become purely a payment agency. The 34 MRC units which, although funded by the Medical Research Council, are not stand-alone organisations but are based within universities, and rely on university staff and structures, were also excluded. This way the sample was reduced to 49 organisations, of which 28 are Departmental Research Bodies and 21 are Research Council Institutes. For each of the 49 PROs in the sample, information was collected from their websites about their main demographic characteristics: founding date, legal status, mission, department of affiliation, location, ownership structure.

Geographically, PROs are concentrated in London, the South East and the East of England (many around Cambridge and Oxford) and in Scotland. PROs are characterised by a varied range of ownership and management arrangements. In particular three main types of arrangements can be distinguished. Executive Agencies are clearly designated units of a central government department, administratively distinct, but remaining legally part of it; they have a clear focus on delivering specific outputs within a framework of accountability to ministers (Cabinet Office, 2016). Non-departmental public bodies (NDPB) "have a role in the processes of national government, but [they are] not a government department or part of one, and accordingly [they operate] to a greater or lesser extent at arm's length from ministers" (Cabinet Office, 2016, p.13). Public Corporations are partly or fully owned by the government using a variety of legal arrangements (e.g. Company limited by guarantee; Government owned, Contractor operated); these tend to be much more independent of government control (Royal Society, 2020).

Information from the PROs' annual financial statements was then collected for six financial years (2011/12, 2012/13, 2013/14, 2014/15, 2015/16 and 2016/17). The information from annual financial statements could only be collected from 33 organisations that report independently, six (18%) of which are affiliated to a research council (BBSRC), and the remaining 27 (82%) are affiliated to government departments. Table 3.2 shows the distribution of PROs in the population and in the

sample.

Table 3.2. The population of active PROs in the UK and in the sample

	Population		Sample	
	Number of PROs	**% PROs**	**Number of PROs**	**% PROs**
Departmental Research Bodies	28	57.1%	27	82%
Research Council Institutes	21	42.9%	6	18%
Total	49	100.0%	33	100.0%

Hence, this study relies on a 6-year balanced panel of 33 organisations, for a total of 198 observations. The information from financial statements includes:

a) number of employees (full time equivalent, FTE);
b) governing board information: size, gender composition, presence of members disclosing external interests;
c) funding sources, distinguishing between public funding (core grant from government and competitive grants from government and other public bodies, including research foundations) and private funding (income from industry contracts, royalties and other sources; excludes investment income and income from equity ownership);
d) number of subsidiary companies (wholly owned by the PRO) and associate companies (partly owned by the PRO);
e) number of incubators and/or science parks the PRO is directly or indirectly affiliated with.

By searching the websites of the PROs and of the subsidiaries and associate companies mentioned in the financial statements (as well as by reading the PROs' annual reports) it was possible to distinguish between: subsidiaries and associate companies to which the PRO outsources KT management functions (research commercialisation, including IP licensing and research contracting; service provision including testing, consultancy, other business services) and subsidiaries and associate companies dedicated to exploiting research outputs (spinoff companies).

Additional information was also collected from external sources. In particular, information about the PROs' patenting activities in each year (number of patent applications, IPC categories, number of co-applicants from industry, university, other PROs, other organisations, number of citing documents) was collected from the

European Patent Office's database. The number of scientific publications of each PRO in each year, divided by field of science, was collected from the Scopus database. Additional information was collected about the main sectors that are users of the PROs' knowledge, divided into 21 categories (Smith, 2015, p.19).

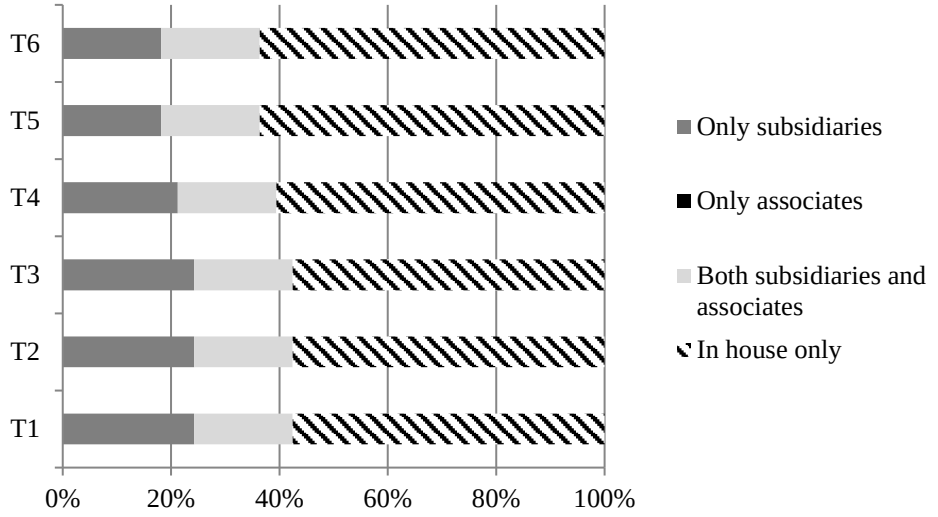
3.3.2. Variables construction

Dependent variables

The dependent variable is a binary variable called *In_house* which is equal to one when the PRO does not outsource its KT management activities to external (subsidiary or associate) companies. On average, 40% of PROs have outsourced some or all of their KT management activities over the period considered. Of these, 22% relied only on subsidiaries, while 18% relied on both subsidiary and associate companies (these companies are sometimes partly owned by more than one PRO). None of the PROs relied on associate companies only. The remaining 60% did not outsource their KT management activities to subsidiaries and associate companies. Figure 3.1 shows the shares of PROs that rely on in-house and outsourced KT management (in the latter case, distinguishing between outsourcing to subsidiaries and to associate companies) by year.

While the dependent variable measures whether PROs do not outsource KT management activities to subsidiaries and associate companies only, rather than to external companies more generally, there are several reasons to believe that this variable is a good proxy for vertical integration of KT management. First, the literature on KT management shows that, in the public research sector, external technology transfer offices very often take the form of subsidiary companies (Hughes et al., 2016; Sengupta and Ray, 2017; Prokop, 2021), therefore this does not appear to be an unusual arrangement. Second, to further validate the variable,the annual reports of the PROs that did *not* outsource KT management activities were read carefully, to check whether there was any mention of outsourcing to external companies other than the subsidiary and associate companies mentioned in the financial statements; no mentions of other external companies were found.

Figure 3.1. Shares of PROs that rely on in-house and outsourced KT management



Independent variables

In order to test H1 (*The greater the intrinsic complementarity between research and KT, the greater the PRO's likelihood to vertically integrate KT management*) it was necessary to measure the extent to which the KT process relies on tacit knowledge developed in the course of the underlying research. It was argued earlier, in fact, that PROs should vertically integrate intrinsically complementary activities involving tacit knowledge and the consequent development of organisation-specific capabilities (Kogut and Zander, 1996; Martínez-Noya and García-Canal, 2016). Instead, if the knowledge involved in the performance of the activity allows some degree of codification (Mithas and Whitaker, 2007), the process would require a lower degree of organisation-specific knowledge, and production by a specialised supplier in an outsourcing relationship could be a more attractive option.

In the case of research activities, it has been argued that the objectives underpinning the research have a bearing on the extent of codification of the resulting research outcomes. It has been argued that research that is more basic in nature, that is, research that seeks to understand fundamental phenomena without an immediate concern for specific applications (Stokes, 1997), tends to result in knowledge that is more abstract and universal, based on a commonly accepted language that has relatively constant meaning across context (Autio 1997; Johnson et al. 2002). This knowledge is therefore easier to fully convey in codified form (Cowan et al., 2000).

Instead, more applied research, that is, research that seeks to produce knowledge for a specific end-use (Stokes, 1997), tends to produce knowledge that is more context-dependent and therefore more difficult to codify entirely (Johnson et al. 2002). Hence, it is expected that a greater share of applied knowledge in the PRO's knowledge base will increase its likelihood to vertically integrate KT management activities. Indeed, there is some evidence that academics working in fields where applied research is prevalent, such as engineering, are more actively engaged in KT activities than academics working in fields with a greater presence of basic research, such as the natural sciences (Landry et al. 2007). This evidence is aligned with the argument that the greater role of tacit knowledge in fields with a greater component of applied knowledge, requires a more direct involvement of researchers in the KT process.

To operationalise the prevalence of applied research in PROs' knowledge production activities, the study exploits information about the journals in which the PROs publish, based on the argument that (i) the influence of an article is determined much more by the characteristics of the journal it is published in than of the article itself (Van Dalen and Henkens, 2001), (ii) basic research is comparatively easier to publish than the applied research (Hicks, 1995), (iii) journals that are more highly cited by published articles tend to focus on more basic research, whereas journals that are less cited tend to focus on more applied research (Lim, 2004), and (iv) journals in applied fields tend to cite journals from closely related basic research fields than they cite other journals within their own applied fields. Conversely, there is a limited flow of citations from basic research journals to applied fields. As a result, basic research journals typically receive more citations, therefor higher impact factor compared to their applied counterparts (Cross, 2007). For instance, journals in basic medicine fields record higher impact factors compared to those within clinical medicine fields (Seglen, 1997).

This is because basic scientific breakthroughs provide the foundation upon which more applied research is developed, and therefore basic research articles are more heavily cited than applied ones. We therefore construct the variable *Share_journals_applied* as the share of journals in which the PRO publishes that are *not* in the top quartile of the ranking of most-cited journals (based on the Science

Citation Index produced by Scimago[15]). A similar variable was used by Lim (2004) who, in order to capture the number of applied research articles of companies in the pharmaceutical sector, computed the number of articles they published in journals belonging to the bottom three quartiles of the impact factor distribution.

In order to test H2 (*The greater the strategic complementarity between research and KT, the greater the PRO's likelihood to vertically integrate KT management*) it is necessary to capture the extent to which the transfer of knowledge to specific stakeholders is important to the PRO. In fact, it was argued earlier that if the PRO fulfills its institutional mission by transferring knowledge to specific stakeholders, the PRO would wish to maintain some degree of control on the KT process to ensure that it is primarily directed to the intended recipients. Based on this argument, it would be expected that PROs whose KT stakeholders have greater influence on its governance (and hence are better able to determine how the PRO should fulfill its mission) will be more likely to vertically integrate KT management: through vertical integration, in fact, the PRO can keep under greater control the KT opportunities that are pursued, to make sure they are aligned with the objectives of its stakeholders.

To operationalise the influence of the stakeholders that are the main recipients of PRO's KT, government and industry, on the PROs' governance, this study exploits information about the PRO's governing board and relationship with government. In the case of industry, it is possible to capture the presence of industry representatives in the governing board; in fact, it can be expected that industry representatives on the board will be keen to ensure that the PRO's KT activities primarily benefit their sector, and will prefer such activities to remain under the control of the PRO through vertical integration. Since few PROs provide information about the professional background of their board members, this study considers the presence of disclosure of external interests on the part of board members as a proxy for the members' involvement in commercial ventures. A binary variable that takes value 1 if any of the board members have disclosed external interests in the annual reports of the PRO (*External_interests*) and zero otherwise, is constructed. In the case of government, the study measures the influence of government on the PRO's governance based on the accountability of the PRO to ministers. It is expected that PROs that are more directly

[15] Available at: https://www.scimagojr.com/journalrank.php (accessed June 2022).

accountable to government ministers will want to ensure that their KT activities are aligned with the government's objectives, and will prefer to vertically integrate the management of these activities. As a measure of the PROs' direct accountability to government, an ordinal variable, *Government_control*, is created, that takes value 3 if the PRO is an executive agency accountable to a central government department, 2 if the PRO is an executive agency accountable to a devolved administration or another government agency, 1 if the PRO is a NDPB, and zero if the PRO is a public corporation.

Based on these arguments, it is expected that *External_interests* and *Government_control* will positively influence the likelihood to vertically integrate KT management functions.

Control variables

Controls include the current age of the PRO (*Age*) and its size measured in terms of number of full time equivalent employees (in thousands) (*Employees*). It is expected that larger PROs will have more internal competences, and more resources to invest in KT management. Additionally, larger PROs might have a larger scale of KT operations (since the size of the organisation is positively related to the level of KT; Belenzon and Schankerman, 2009).[16] If PROs perform KT activities on a large scale, this activity might be more routinised (Ponomariov, 2008), and it might be more efficient for them to develop the competences to manage the KT process internally. So, a larger scale of KT operations may be associated with greater probability to vertically integrate KT management activities. [17] Additional controls include the PRO's main user sectors, to account for the specificities of those sectors that might influence the likelihood of performing KT management in-house (for example, clients' concerns about safety and security might make vertical integration more

[16] In the case of universities, size has been found to be positively related to the amount of private research funds (Von Tunzelmann and Kraemer Mbula, 2003), interactions with companies (Bruno and Orsenigo, 2003; Landry et al., 2007) and spinoff creation (O'Shea et al., 2005).

[17] While it might have been appropriate to use the income from private sources as a measure of the scale of the PRO's KT operations, it is not possible to do so because in the present dataset the reported private income is endogenous to the choice of governance model for KT management. In fact, those PROs that outsource will report some of their KT income in the accounts of the subsidiary or associate, and hence their accounts are likely to understate the amount of income they derive from private sources. Hence, the PRO's amount or share of private income is not included in the models.

likely). Several binary variables are created that aggregate the sectors proposed by Smith (2015): *Health* (includes Human Health and Wellbeing, Disease Control), *Agrifood* (includes Agriculture, Animal Health, Food, Biological Sciences, Plants, Marine Environment and Aquatic Life), *Environment_protection* (includes Climate Change, Environmental Science, Sustainability), *Defense_space* (includes Security and Space and Earth Observation). Each PRO can have more than one main user sector.

The following table (3.3) presents some basic descriptive statistics for the dependent, independent and control variables mentioned, for each period and aggregated over the six periods. None of the time-varying variables have significantly different means across the six periods. The variables' correlation matrix is reported in Appendix 3.1.

Table 3.3. Descriptive statistics for dependent, independent and control variables

	Time varying	Mean T1 N=33	Mean T2 N=33	Mean T3 N=33	Mean T4 N=33	Mean T5 N=33	Mean T6 N=33	Mean T1-T6 N=198	Std.dev. T1-T6 N=198	Min T1-T6 N=198	Max T1-T6 N=198
In_house	YES	0.58	0.58	0.58	0.61	0.64	0.64	0.60	0.49	0.00	1.00
Government_control	YES	1.33	1.33	1.33	1.33	1.24	1.24	1.30	1.22	0.00	3.00
External_interests	YES	0.39	0.36	0.39	0.42	0.45	0.52	0.42	0.50	0.00	1.00
Share_journals_applied	YES	0.61	0.63	0.60	0.60	0.60	0.57	0.60	0.20	0.08	1.00
Employees	YES	1.27	1.31	1.36	1.30	1.28	1.28	1.30	2.03	1.35	11.18
Age	NO	87.55	87.55	87.55	87.55	87.55	87.55	87.55	89.71	5.00	348.0
Health	NO	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.45	0.00	1.00
Agrifood	NO	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.43	0.00	1.00
Environment_protection	NO	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.41	0.00	1.00
Defense_space	NO	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.39	0.00	1.00

3.4 Findings

Table 3.4 presents the outcomes of a panel logistic regression model on the variable

In_house, explaining the PRO's likelihood to vertically integrate KT management activities on the basis of proxies for the intrinsic and strategic complementarity between research and KT management, as well as a range of control variables. The baseline model (a) includes only the control variables. Models (b), (c), and (d) add the three main independent variables proxying for the extent of intrinsic complementarity (*Share_journals_applied*) and strategic complementarity (*Government_control*, *External_interests*).

The random effect model is preferred because of the nature of the variables, which include some time invariant independent variables (*Government_control*) as well as time-varying independent variables that exhibit limited variability over time (*External_interests*). If predictor variables vary greatly across individuals but have little variation over time for each individual, then fixed effects estimates will be imprecise and have large standard errors (Allison, 2009). With relatively small T there is also a risk of inconsistent fixed effects estimates. To further check the appropriateness of our random effect model, the hybrid model proposed by Allison (2009) is also included (model (e)). In this approach, each time-varying variable is replaced with the deviation from the individual-specific mean, while also including the individual-specific means of time-varying variables and all the time-invariant variables. According to Allison, this approach produces the same coefficients and standard errors as the fixed effects model for time-varying variables, while allowing for the inclusion of time invariant variables. The model also provides a way to further test the appropriability of the random effect models by checking whether the coefficients of the mean-difference and mean variables are significantly different from each other. If they are not significantly different, then the assumptions of the random effect model (that the individual error is uncorrelated with the time-varying variables) are met. If they are significantly different, then the assumptions of the random effect model do not hold and the fixed effect model would be more appropriate.

Because the variable *Share_journals_applied* is computed using information about publications in the Scopus database, the observations where the number of Scopus publications in a certain year was zero are dropped, which reduces the size of the sample to 186 observations (31 PROs).

The models are all significant with $p<0.001$; rho is also significant in all model,

confirming that the panel estimator is preferable to a pooled approach. The coefficients and their significance are stable across all models. Finally, the tests on the equality between the mean differences and the means of the time-varying variables cannot reject the null hypothesis of equality of the coefficients, suggesting that the random effects model is appropriate (Allison, 2009).

The models suggest that stronger government influence on the PRO's governance significantly increases the likelihood of vertically integrating KT management activities. Also the presence of board members declaring external interests has a positive and significant effect. Both results are consistent with the hypothesis that the greater strategic complementarity between research and KT management increases the likelihood of vertical integration of the latter.

Table 3.4. Regressions on the determinants of PROs' integration of KT management activities

	(a)	(b)	(c)	(d)	(e)
VARIABLES	In_house	In_house	In_house	In_house	In_house
Government_control				5.592***	5.564***
				(1.428)	(1.750)
External_interests		12.598***	13.436***	6.669*	6.855*
		(3.541)	(3.656)	(3.412)	(3.693)
Share_journals_applied			16.853*	21.094*	
			(8.997)	(12.476)	
Mean_diff_share_journals_applied					11.452
					(15.798)
Mean_share_journals_applied					36.096
					(29.085)
Employees	1.502**	2.168**	0.992	1.162	
	(0.759)	(1.055)	(0.863)	(0.824)	
Mean_diff_employees					-0.811
					(6.801)
Mean_employees					0.964
					(0.871)
Age	-0.039**	-0.090***	-0.118***	-0.099***	-0.121***
	(0.017)	(0.025)	(0.020)	(0.022)	(0.030)
Health	-0.473	0.722	0.111	0.515	-0.577
	(3.255)	(5.056)	(4.760)	(4.657)	(6.437)

Agrifood	-1.421	1.581	-0.914	3.151	2.023
	(2.659)	(4.244)	(3.560)	(4.297)	(4.200)
Environment_protection	4.997+	7.186*	5.570	9.568**	9.423*
	(3.098)	(4.351)	(4.091)	(4.432)	(5.238)
Defense_space	23.002***	14.677***	13.994***	14.428***	12.304**
	(3.606)	(4.289)	(4.430)	(4.190)	(5.336)
T2	-0.045	0.049	-2.042	-2.507	-1.722
	(2.555)	(2.677)	(3.116)	(3.687)	(3.631)
T3	-0.063	0.099	-0.340	-0.358	-0.381
	(2.545)	(2.615)	(3.161)	(3.909)	(3.550)
T4	3.068	3.142	1.604	1.873	1.959
	(2.604)	(2.713)	(3.032)	(3.568)	(3.462)
T5	5.617**	5.931**	5.000+	6.303+	6.126+
	(2.577)	(2.981)	(3.395)	(4.082)	(4.009)
T6	5.634**	5.418*	5.390*	6.916*	6.072+
	(2.571)	(2.835)	(3.201)	(3.899)	(3.719)
Constant	-3.020	-2.529	-6.470	-18.366*	-23.565+
	(3.928)	(6.630)	(7.719)	(10.321)	(16.209)
lnsig2u	5.806***	5.706***	5.708***	5.679***	5.792***
	(0.473)	(0.501)	(0.529)	(0.507)	(0.566)
Observations	186	186	186	186	186
Number of ID	31	31	31	31	31

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1, +p<0.15.

Greater share of applied knowledge in the PRO's knowledge base has a positive and significant effect on the likelihood of vertically integrating KT management activities, which is consistent with expectations. Hence the evidence supports the hypothesis that greater intrinsic complementarity between research and KT management increases the likelihood of vertical integration.

In terms of control variables, *Age* has a negative and significant effect on the likelihood of performing KT management in-house. Older PROs might be expected to have more internal competences and to be more likely to vertically integrate KT management activities, however the opposite is found; that is, older PROs are less likely to vertically integrate. Sectoral effects are present, with PROs working with the environment protection and defense and space sectors significantly more likely to vertically integrate KT management activities; particularly in the latter case this is probably due to sensitivities around the use of the PRO's knowledge.

Finally, the size of the PRO has a positive effect on the probability to vertically integrate, in line with expectations, but with a very small coefficient. The role of size

is explored further in the next section.

3.4.1. Robustness checks

To further investigate the effect of the PRO's size, the quadratic term for the variable *Employees* measuring the size of the PRO, *sqempl*, is introduced (this regression is shown as model (a1) in Appendix 3.2). The coefficient of *Employees* becomes negative and significant (p=0.10), and increases in size, while the coefficient of the quadratic term is positive (but very small) and significant. This suggests that size has a positive effect on the likelihood to vertically integrate KT management activities but only for larger PROs (approximately above 3,282 employees). Since the variable Employees is quite skewed with a couple of large outliers with more than 5,000 employees, it is possible that the quadratic effect is driven by the outliers. If these outliers are removed from the sample the variable *Employees* and its square are no longer significant (table (b1) in Appendix 3.2). Hence, there is evidence of a critical mass effect, whereby it makes economic sense to have certain functions internally for PROs that are bigger than a certain size (as larger PROs are better resourced and can acquire the internal competences to deal with KT management), but this only holds when two very large PROs are taken into consideration.

In model (c1) in Appendix 3.2 different proxies for the independent variables are considered. Since the binary variable *External_interests* suffers from low variability, which reduces its explicatory power, an alternative measure for the presence of external stakeholders in the PRO's governing body is proposed: the number of members of the governing board (*Board_members*). The rationale for using this variable is that in the literature it has been found that larger boards are more diverse from a demographic and cognitive perspective (including occupational diversity) (Carter et al., 2003; Barroso Castro et al., 2009). The results show that *Board_members* has a positive but not significant effect on the likelihood to vertically integrate.

The same model also includes an alternative proxy for the presence of tacit knowledge and therefore intrinsic complementarity. In the case of KT, some activities are characterised by a greater degree of knowledge codification than others. The sale or licensing of a piece of intellectual property (IP), like patents or software copyright, will have a greater component of codified knowledge than consulting activities aimed

at solving a client's specific problem. Thanks to the codified nature of the IP, it is possible for specialist suppliers to develop capabilities in the sale and licensing of IP that are to a large extent independent of the specific organisation that produced the IP (PraxisUnico, 2016). Conversely, activities like problem solving for clients involve a high degree of tacitness (Asheim and Gertler, 2005). It would be difficult for a specialised supplier to develop all the capabilities needed to KT processes involving many different PROs and their many different potential clients. Building on these arguments, vertical integration can be expected to be more likely when the PRO engages only in activities with a high tacit knowledge component, like research contracting and consulting, and outsourcing to be more likely when the PRO also engages in activities involving the transfer of codified IP, like patenting. The variable *Nopatents* is a binary variable equal to one when the PRO does not engage in patenting, and zero otherwise (e.g. the PRO engages in patenting). The results show that lack of patents has a positive and significant effect on the probability to vertically integrate, as expected. This is consistent with findings from studies of university researchers, which show that researchers transfer knowledge much more actively when no patenting is involved (Landry et al., 2007) suggesting that in this situation there is greater intrinsic complementarity between research and KT.

Finally, model (d1) introduces an alternative size measure, the absolute level of public (core and competitive) funding received by the institution (*Income_public_funding*) and its square. This variable behaves similarly to *Employees*, having a positive and significant effect on the likelihood to vertically integrate KT management only above a certain amount.

3.5. Conclusions

The evidence suggests that the degrees of intrinsic and strategic complementarity of KT capabilities with core research capabilities play a role in the decision whether to outsource or vertically integrate KT management. The more intrinsically and strategically complementary KT is to research, the more likely KT management is to be performed in-house. The extent of intrinsic and strategic complementarity is determined on the basis of the extent to which the bundling of KT together with the core activity (that is, research) allows the institution to perform its institutional mission (benefiting its stakeholders) better than unbundling KT through contracting

with specialised suppliers – either because bundling increases the effectiveness of KT (intrinsic complementarity) or allows to direct KT to strategic beneficiaries (strategic complementarity).

These findings have theoretical and practical implications. In theoretical terms, this study extends the theory of firm boundaries relating to knowledge processes to the case of public research organisations, which are not primarily driven by the profit motive and whose core activity is research. This conceptual framework could be applied to public research organisations in other national settings. It might also provide useful insights for the understanding of outsourcing choices in relation to KT management for other types of public and private organisations that have research as their core activity, including universities, private research companies, and other companies that have research as their primary activity.

In terms of policy, the findings suggest that governments intending to encourage PROs to improve their KT management capabilities should not assume that all PROs should follow the same governance models. Some PROs, namely those that carry out research that has a high tacit knowledge component and those that intend to transfer knowledge to specific stakeholders, should be incentivised to improve their internal capabilities for KT management. Other PROs, namely those that perform research whose outputs can be easily codified and those that aim to transfer knowledge to a broad variety of stakeholders, should be encouraged to rely on specialised suppliers, and when those suppliers are not available perhaps some efforts should be invested in their creation, as such suppliers might ensure efficiency gains thanks to their scale and specialisation.

The present paper aims to open up a research agenda into KT management within PROs, and, given its limitations, can be considered as a first step leading to further investigations. First, this is a small-scale study, and it would be interesting to replicate this study on a larger scale, possibly by means of surveys of PROs of different types and in different countries. Second, the constructs of intrinsic and strategic complementarity are not observable, and in this study they have been proxied using the few variables available, based on publicly available sources, which could indicate the presence of tacit knowledge and of a strong role for external stakeholders in the governance of the PRO. Data collected directly from PROs by means of surveys, for example, might allow to develop variables that more closely measure the constructs of

intrinsic and strategic complementarity. As a direction for future research, it would also be interesting to explore in greater detail the patterns that have been identified, by complementing this quantitative investigation with qualitative analyses of PROs' approaches to KT management. These might include the collection of more detailed information about the different possible ways to organise in-house KT management, and the analysis of how PROs' approaches to KT management have changed over time, how approaches differ across countries, and what comprehensive strategic choices have led to the adoption of certain models.

CHAPTER 4. Organisational capabilities and outbound open innovation in public research organisations

Abstract

The public research system (including universities and public research organisation, PROs) plays a crucial role in creating frontier science and in stimulating socio-economic development. Despite substantial government spending on PROs and growing concerns about the effectiveness of their KT engagement, there is very little research on the governance of their knowledge outflows. This study analyses the extent to which PROs engage in outbound open innovation (OI), and the organisational capabilities that support such engagement, including desorptive capacity, supportive organisational culture, and multiplicative capability. Building on 26 in-depth interviews with representatives of PROs and funding bodies in the United Kingdom, the study finds that PROs tend to follow one of two possible approaches to outbound OI – which can be called 'commercial OI' and 'open science' – and that each approach is underpinned by different organisational capabilities.

4.1. Introduction

Open innovation (OI) is based on the premise that firms "can" and "should" use both internal and external ideas in their search for innovative opportunities and pathways to the market (Chesbrough, 2003, 2006). Since Chesbrough's early seminal works, there has been extensive research on OI, most of it focusing on firms as beneficiaries of inbound flows of knowledge (Enkel et al. 2009). Among other themes, this stream of literature has focused on: how firms implement inbound OI (Slowinski et al., 2009; Lazzarotti et al., 2011; Aslesen and Freel, 2012); the firms' organisational capabilities that are associated with the adoption of inbound OI (Bröring and Herzog, 2008; Grimaldi, et al., 2013; Wikhamn, 2013; Hafkesbrink and Schroll, 2014; Brunswicker and Vanhaverbeke, 2015; Lazzarotti et al., 2015; Mahdad et al., 2020); and the practices that make inbound OI more effective (Laursen and Salter, 2006; Bessant, 2008; West and Lakhani, 2008; Bigliardi et al., 2012; Du et al., 2014; Martinez et al., 2014; Naqshbandi and Kaur, 2014; Brunswicker and Vanhaverbeke, 2015; de Faria et al., 2020).

Less attention has been paid to the process of transferring ideas to the external environment and exploiting them in different markets, called outbound OI (Lichtenthaler, 2008, 2011, 2015). It has been argued that outbound OI may influence an organisation's performance both negatively (Kline, 2003; Lichtenthaler, 2010) and positively (Davis and Harrison, 2001; Chesbrough, 2006) depending on the risks and benefits of transferring technology.

Similarly, limited attention has been paid to how OI applies to government agencies and independent not-for-profit organisations (Chesbrough and DiMinin, 2014). Although Chesbrough (2003) introduced OI as a profit-maximising paradigm, researchers have more recently argued that the business model premise that underlies the definition of OI can be extended to public and not for- profit organisations, because of their need to create and capture value to maintain their existence (Chesbrough and Bogers, 2014). There is a growing literature calling for greater use of OI and collaborative innovation in the public sector (Fuglsang, 2008; Bommert, 2010), and analysing public sector' strategies, drivers and barriers, and challenges of multi-actor involvement, as well as decision making processes in collaboration with external actors (Hennala et al., 2011; Ojasalo and Tähtinen, 2016; Kankanhalli et al., 2017; Mergel, 2018; Gershman et al., 2019). However, the business models, and related organisational capabilities, that support the implementation of OI on the part of public sector organisations have not yet been investigated in detail.

The present study intends to address this two-fold gap in research, by investigating the extent to which public research organisations, or PROs (that is, organisations funded by the government or other public agencies, whose objective is to undertake scientific research, carry out scientific testing and regulatory functions, provide key scientific and technical input and advocate government for policy making; Baker Report, 1999) – engage in outbound OI activities, and the business models (and corresponding organisational capabilities) that support such engagement.

Governments increasingly encourage organisations in the public sector to engage in OI, by means of open innovation policies (Lee et al., 2012). These can include the set-up of publicly funded collaborative research and development (R&D) centres involving industry, universities and PROs (Young et al., 2008) and the provision of recommendations for the adoption of OI practices (European commission, 2014). It can be expected, therefore, that many PROs will attempt to engage in OI, and that

some organisational capabilities will be particularly conducive to these attempts. This study aims, first of all, to shed light on PROs' engagement in various OI activities (such as IP licensing, setting up spinoff companies, contract research, consultancy, staff exchanges with industry, and so on), analysing to what extent they organise their KT activities within the OI paradigm, as articulated in the OI literature. Second, the paper aims to understand which organisational capabilities, which are an important element of an organisation's business model, underpin the successful use of outbound OI in PROs. It relies on original qualitative data, collected through 26 in-depth interviews with 23 representatives of 21 PROs and 3 funding bodies (a government department and two research councils) in the UK.

The UK is an interesting case, for several reasons. It has a large and well-funded PRO sector including many prestigious institutions performing world-class research (Maxwell-Jackson, 2011). The PRO sector is also very heterogeneous in terms of ownership-governance structures, the extent of public support received, the extent to which the government can direct research objectives, and research focus. It has been observed that differences between industries or sectors (Aslesen and Freel, 2012) or organisations' ownership structures (Li et al., 2008) can affect attitudes, behaviours and thus engagement in OI. The heterogeneity of UK PROs should therefore allow the opportunity to observe different ways in which PROs engage in OI, and different organisational factors supporting their engagement.

By conceptualising the factors that are linked to different approaches to successful outbound OI in PROs, the paper will fill a gap in the OI and managerial literature in relation to the governance of PROs' knowledge outflows. Additionally, the paper will provide significant managerial and policy implications by identifying the business models, in particular in terms of the underlying organisational capabilities, that facilitate successful engagement in outbound OI for PROs. Such understanding is very helpful for PRO managers as well as policymakers, since, while the UK's public research system performs high quality research and generates innovative solutions, it under-performs when it comes to the ability to commercialise research outputs (Maxwell-Jackson, 2011). Hence, improving PRO's performance in OI can help to improve the UK's national innovation system.

The paper is structured as follows. Section 4.2 reviews the literature on the business models and organisational capabilities that support the adoption of OI practices,

developing a conceptual framework to drive the analysis. Section 4.3 presents the data and methodology used in the study. Section 4.4 presents the findings, which are discussed in section 4.5. Finally, section 4.6 concludes with implications for theory, management and policy.

4.2. Literature review and conceptual framework

OI has emerged as a feasible alternative approach to innovation in opposition to the traditional closed innovation model, where innovation is developed within in-house R&D laboratories and distributed to the market (Chesbrough, 2006). A large part of innovation involves identifying, absorbing, and integrating knowledge (Wallin, and Von Krogh, 2010), which in turn requires intense collaboration between people and teams, exchange of experiences, expertise and practices at different levels. OI helps firms to advance technology and accelerate innovation (Chesbrough, 2006) by using both internal and external paths to market (Chesbrough, 2003). In this context, there has been research on how to implement OI in practice (Laursen and Salter, 2006; Dahlander and Gann, 2010: Pisano and Verganti, 2008; Wikhamn 2013; Van de Vrande et al., 2009; Zynga et al., 2018: West and Gallagher, 2006). Mortara and Minshall (2011) point out that firms' adoption of OI depends variably on three factors: innovation requirements, timing of innovation and organisational culture. Since Enkel et al (2009) and Gassmann and Enkel (2004) distinguished OI activities into inbound (i.e. knowledge flowing in to the organisation), outbound (i.e. knowledge flowing out from the organisation), and coupled (i.e. ongoing co-creation of knowledge with other parties), the studies of inbound OI have been over-represented while there has been far less research on outbound OI, involving the exploitation and commercialisation of knowledge outputs.

Although the relationship between the adoption of outbound OI and performance is not straightforward (Sisodiya et al., 2013), moving the exploitation of knowledge outside of the organisation's boundaries can have several advantages, such as faster time to the market and commercialisation of their ideas in different industries (Enkel and Gassmann, 2010). This process raises opportunities for enhanced revenues through various streams of income, for example from licensing fees, joint ventures and spinoffs (Gassmann and Enkel, 2004). In the case of PROs, transferring knowledge to external organisations, including start-up companies, large businesses,

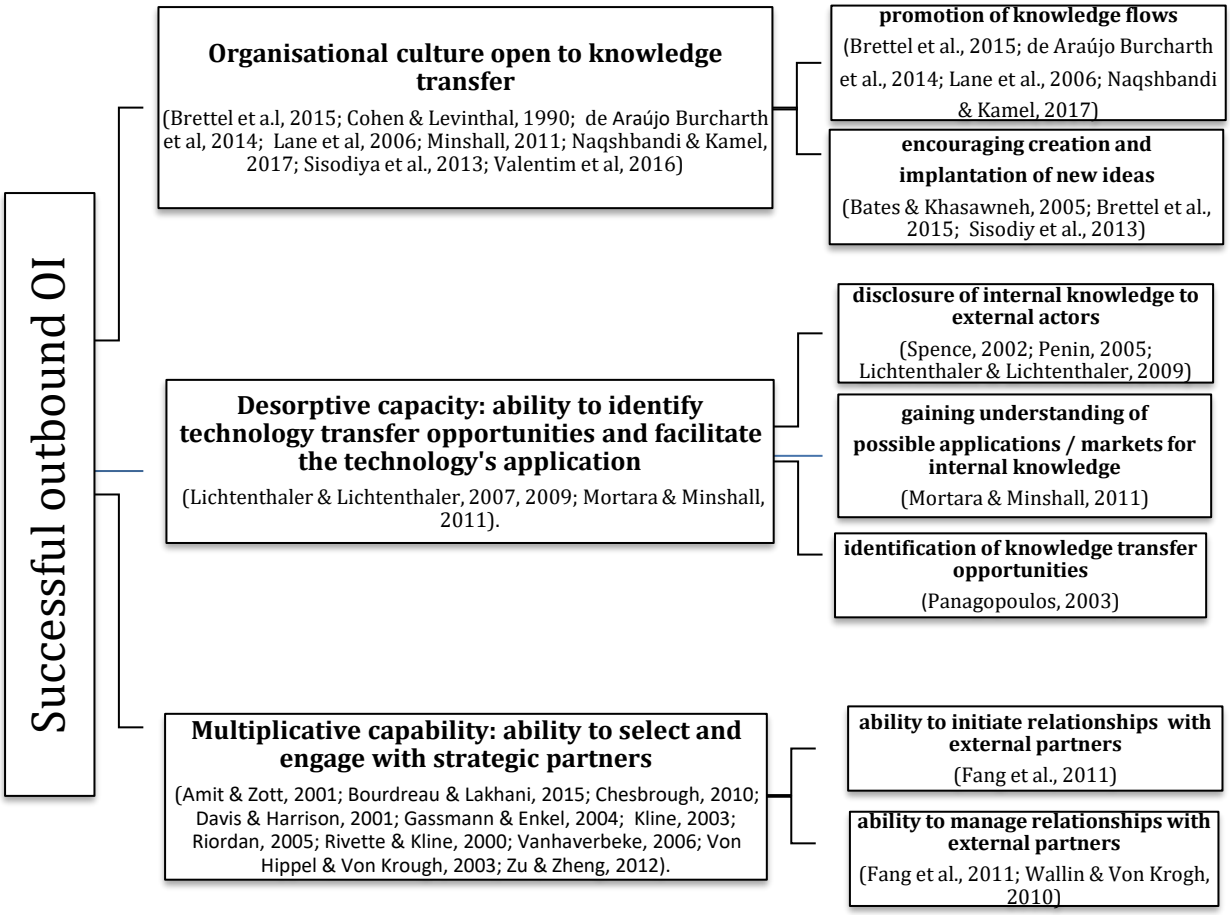
government departments and other public sector organisations, who can then use it to develop innovations, is usually part of their institutional mission (Arnold et al., 2012; Cervantes and Meissner, 2014).

Evidence emerging from the analysis of organisations engaged in inbound OI processes suggests that those organisations that are most successful at capitalising on the integration of external sources of knowledge into their innovation processes, are able to restructure their business models to accommodate OI strategies (Chesbrough and Schwartz, 2007; Hienerth et al., 2011; van der Meer, 2007). The importance for organisations to design their business models so as to accommodate OI has been established since the inception of the concept of OI (Chesbrough, 2006). In fact, since a business model denotes the firm's core logic for creating and capturing value, its elements are all impacted by the extent to which the firm engages in OI processes, and the ways in which it does so. It can be argued that the need to have an appropriate business model outbound OI, which also affects the way in which an organisation creates, delivers and capture value.

From an organisational perspective, business models can be interpreted in a normative sense as devices for structuring and designing organizations (cf. Foss and Saebi, 2017), and in a descriptive sense as manifestations of how organisational variables are configured (Winter and Szulanski, 2001; Zott et al., 2011). While the components of business models are articulated differently by different authors, the majority of studies generally converge on the idea that business models are composed of several elements, which can be summarised into four main conceptual categories: value proposition, value creation, value delivery and value capture (Chesbrough and Rosenbloom, 2002; Osterwalder et al., 2005; Chesbrough, 2007; Johnson et al., 2008; Zott et al., 2011; Foss and Saebi, 2017). The value proposition articulates the job to be done, the product and/or service offering, and the target customers. The value creation consists of the key organisational resources that the firm can rely on to produce value, which include its organisational capabilities and resources. The value delivery consists of the organisational processes (including metrics, rules and norms) used to deliver the value proposition. The value capture describes the formula that the firm uses to generate profit – incuding revenue model, cost structure, margin model, resource velocity (Johnson et al., 2008).

In particular, recent research has identified several organisational capabilities required for implementing OI successfully in various organisations, however, most of these studies refer to inbound OI, whereas the analysis of outbound OI and their underpinning factors has been much more limited. By focusing on the organisational capabilities that, according to the literature, facilitate successful engagement in outbound OI, a conceptual framework is developed for the analysis of value creation processes through outbound OI in PROs. The framework identifies, in particular, three key organisational capabilities supporting successful performance in outbound OI – desorptive capacity, supportive organisational culture, and multiplicative capability. These are summarised in Figure 4.1, and discussed in the next sections.

Figure 4.1. Organisational capabilities that support outbound OI according to the literature



4.2.1. Desorptive capacity

The concept of absorptive capacity was applied primarily to explain firms' ability to effectively use external knowledge. Absorptive capacity is defined as ''*the ability of an enterprise to recognise the value of new, external information, assimilate it, and apply it to commercial ends*'' (Cohen and Levinthal, 1990, p. 218).

Investment in R&D has been found to enable the organisation to search for, identify and incorporate external knowledge (potential absorptive capacity) (Laursen and Salter, 2004; Fontana et al., 2006; Lichtenthaler and Lichtenthaler, 2009; Spithoven et al., 2011; Robertson et al., 2012). At the next level, organisations need to possess integrative capability (Chiaroni et al., 2009; Lichtenthaler and Lichtenthaler, 2009; Robertson et al., 2012; West and Bogers, 2014), that is, the ability to integrate their externally sourced knowledge with their internal knowledge (realised absorptive capacity) to improve their competitive advantage (Zahra and George, 2002). In an earlier definition, Cohen and Levinthal (1990) referred to the cumulative nature of absorptive capacity and the value of pre-existing knowledge for the assimilation of external knowledge. In these studies, absorptive capacity is mostly related to inbound OI (Gassmann and Enkel, 2004), hence it has been argued that *"absorptive capacity cannot explain all dimensions of [OI] in terms of capabilities"* (Vanhaverbeke and Cloodt, 2014, p. 270), since it does not explain outbound or coupled OI.

In a context where capabilities related to outbound or coupled OI have been given little attention (Brunswicker and van de Vrande, 2014), the contribution by Lichtenthaler (2007) is particularly valuable, because he proposes a capability framework ('desorptive capacity') that complements the concept of absorptive capacity and focuses on "*a firm's capability of external knowledge exploitation*", or according to Fosfuri (2006) "*outward knowledge transfer*".

Lichtenthaler and Lichtenthaler (2009) focus on the knowledge capabilities required for internal and external knowledge exploration, external knowledge retention (the organisation's ability to enter into exchange relations with others and to extend its internal knowledge base, supported by what they call 'connective capacity'), and external knowledge exploitation (the organisations' ability to transfer knowledge externally), as well as on interactions among these capabilities. According to these authors, external knowledge exploitation is supported by desorptive capacity, defined as "*a firm's ability to externally exploit knowledge. Desorptive capacity comprises the*

process stages of identifying external knowledge exploitation opportunities and subsequently transferring the knowledge to the recipient (Lichtenthaler and Lichtenthaler, 2009, p. 1322).

Organisations with strong desorptive capacity seek to better understand the applications of their knowledge in different technologies and markets, so that they can better exploit internal knowledge in a variety of ways both in current and new markets (Mortara and Minshall, 2011). To do so, they are likely to voluntarily disclose knowledge to less informed economic agents (Spence, 2002; Penin, 2005; Lichtenthaler and Lichtenthaler, 2009), in order to gain feedback from suppliers and users, to expand networks, reputation and business opportunities and to increase higher-order knowledge (Penin, 2005). By signalling their technical and scientific potential and comparative advantages, these organisations can attract potential partners and establish new opportunities for collaboration, particularly if some minimal level of knowledge protection is guaranteed (Panagopoulos, 2003).

An organisational feature that supports desorptive capacity is the ability to manage knowledge effectively. As knowledge moves in and out simultaneously, it is very important to manage the knowledge flow, checking what external knowledge has been acquired, what internal knowledge has been produced, whether and how it has been signalled externally, and how it matches the needs of the market. This systematic management of knowledge not only enables firms to deal with ambidirectional knowledge flows efficiently (Ahn et al., 2013), but it can also help them to implement other capacities related to inbound and outbound OI.

4.2.2. Organisational Culture

Organisational culture plays a critical role in promoting and implementing innovation within the organisation (Bates and Khasawneh, 2005). Several scholars link organisational culture and OI (Sisodiya et al, 2013; Golightly et al., 2012; Huston and Sakkab, 2006, Naqshbandi and Kamel, 2017, Naqshbandi et al., 2014), arguing that some of the cultural factors in organisations impede OI, while others promote it.

Organisational culture plays a significant role in order to support an organisation's absorptive capacity (Sisodiya et al., 2013). While previous studies have focused on the links between organisational culture, absorptive capacity and inbound OI, it is

possible to argue that organisational culture also plays a role in supporting outbound OI. In this respect, the literature is scarce, and empirical results are contradictory. On the one hand, Naqshbandi and Tabche (2018) could not confirm the hypothesis that an organisation's absorptive capacity and its learning culture are intertwined to achieve knowledge commercialisation. On the other hand, several studies suggest that an appropriate organisational culture plays a role in supporting outbound OI. It has been argued that since organisational culture affects how knowledge is assimilated, diffused, exploited and commercialised (Brettel et al., 2015), it affects outbound OI. A stern and inflexible organisational culture leaves no room for uncertainty (Brettel et al., 2015), and discourages the pursuit of new ideas, which in turn constrains the sharing and exploiting of knowledge (Sisodiya et al., 2013) and the commercialisation of new knowledge and technologies (Cohen and Levinthal, 1990).

Vice versa, an organisational culture that promotes knowledge flows within the organisation and encourages creating and implanting new ideas, is also associated with effective commercialisation of created knowledge (Naqshbandi and Kamel, 2017; de Araújo Burcharth et al., 2014). By supporting KT to employees, and knowledge absorption by employees (Lane et al., 2006), an organisation creates new knowledge, which in turn is exploitable through collaborations with external partners (Valentim et al., 2016).

4.2.3. Multiplicative capability

Finally, the firm's success in outbound OI is related to its ability to expand its scope wider than its boundaries, and benefit from the "capabilities of multiple firms and multiple industries" in value creation - called multiplicative capability (Amit and Zott, 2001; Gassmann and Enkel, 2004). Multiplicative capability enables a firm to transfer and multiply its knowledge to the outside world, which in turn leads to success in commercialisation of ideas (Xu and Zheng, 2012). The studies that investigated external exploitation of knowledge (Enkel at al., 2009) have mainly been in form of case studies (Kutvonen, 2011) with no direct investigation of multiplicative capability. However, the importance of multiplicative capability has been highlighted by studies of companies with generic technologies in their profile, where high degree of outbound openness is associated with few restrictions imposed on the modification, customisation, and redistribution of outputs (Von Hippel and Von Krough, 2003); the

software development community (Chesbrough, 2010), new product development projects (NPD) (Tang et al., 2021; Bourdreau and Lakhani, 2015; Gassmann and Enkel, 2004), and telecommunications equipment technology (Davis and Harrison, 2001; Riordan, 2005; Rivette and Kline, 2000; Kline, 2003).

Evidence suggests that the benefits of outbound OI are amplified when various components including inter-organisational networks, transactions, and capacities throughout a supply chain are connected, fit together and integrated in a coherent OI strategy, which defines firm's relationships with other firms, complementary sources and competitors (Gassmann and Enkel, 2004). This is particularly important for the commercialisation of radical innovations. While incremental innovations benefit from the organisation's existing networks of suppliers, customers and channels, in order to commercialise radical innovations, the innovative organisation needs to deal with external networks and engage all essential players to launch a new technology or product. Interfacing different partners and managing external networks in the value system provide strong evidence that OI can contribute to commercialisation of radical innovation (Vanhaverbeke, 2006).

Organisations' networks, in forms of strategic alliances and long-term business partners, are increasingly considered as the locus of value creation through increased transaction efficiency, improved coordination between organisations, moderated asymmetries in information, as well as shortened time to the market (Dyer and Singh, 1998; Dyer and Nobeoka, 2000; Gulati et al., 2000; Perks, 2000; Wong, et al., 2005; He et al., 2020). Firms' competitive advantage can no longer be based on exclusive knowledge possession, but increasingly depends on faster and more open flows of knowledge and on adopting more dynamic alliance models (He et al., 2020)

All this suggests that an organisation's multiplicative capability is underpinned by its ability to build and maintain relationships with external partners. This results in greater KT to a firm's external partners (Fang et al., 2011), creating more opportunities to gain returns from external inputs and enhance performance (Wallin and Von Krogh, 2010) and producing relevant effects on the firm's growth and innovativeness (Lorenzoni and Lipparini, 1999).

To maintain relationships with external partners, organisations need to be able to deal with a variety of issues (Wallin and Von Krogh, 2010): identifying the staff and team

to participate in OI; identifying the owners of the assets and IP resulting from OI; sharing profits and losses among parties; taking decisions over important issues within the organisation with staff and with outsiders; resolving conflicts with external parties; controlling contributions made by outsiders; deciding over the number of outsiders involved in projects and their level of skills, as well as the type of technology and its maturity.

Among the factors that support relational capabilities are the firm's communication capabilities, which are essential for both knowledge acquisition and co-creation (de Silva and Rossi, 2018). While these issues have been investigated extensively in relation to firms, the multiplicative capability of PROs when deploying outbound OI is an under-researched area that requires further exploration.

It must be noted that the organisational capabilities supporting outbound OI are, in theory, not unrelated to each other. An organisational culture open to KT will create incentives for organisations to develop desorptive capacity, by identifying opportunities to transfer technology and to apply it. It will also encourage the organisations to develop relationships with external organisations, enhancing its multiplicative capability. Organisations that are able to manage relationships with external partners might develop a more open organisational culture and will be encouraged to improve their desorptive capacity. In turn, desorptive capacity is improved when it is enhanced by the ability to maintain external relationships and by a favourable organisational culture. The empirical analysis presented in this paper allows to analyse the nature of PROs' engagement in outbound OI and the extent to which the organisational capabilities identified in the literature support the PROs' different approaches to outbound OI.

3. Data and methodology

The focus of the empirical analysis is the PRO sector in the UK. Public research has varied classifications and is called differently in different countries. The OECD (2013) defined public research as research primarily funded by public resources; Arnold et al. (2012) explained public research as research funded by taxpayers to be invested in the production of knowledge for the benefit of society. Public research is carried out in universities and in non-university PROs (OECD, 2013), the latter

sometimes also called national laboratories, or government research institutes or Public Research Institutes (PRIs) (OECD, 2011). PROs' research outcomes are often meant to help the government carry out its functions (such as protecting national security or public health), but they can also be disseminated more generally to the public or used by industry and other stakeholders. Indeed, there is increasing pressure on PROs to generate income to supplement public investment in research, and to demonstrate the value they create. This requires these organisations to engage more effectively with external stakeholders, including public and private sector and society in general. Their KT management processes have become more varied and more decentralised, often involving several layers, and combining internal management and outsourcing in different ways (Sengupta and Ray, 2017; Coccia and Rolfo, 2010; Cervantes, and Meissner, 2014; OECD, 2013; Arnold et al., 2012; Broström and McKelvey, 2015; OECD, 2014).

In the UK, the science infrastructure is partly undertaken by universities and partly by a diverse selection of PROs.[18] . Each PRO belongs to a specific 'parent body', which has the control over the investment made to support them and their functioning. The parent body is either a UK Research Council or a Government department. Therefore, PROs are divided in two categories; a) those that are part of Government departments and/or directly funded by those departments[19]; and b) those that are under the umbrella of one of the UK's seven Research Councils[20]. Within this framework,

[18] UK government sources use the term 'Public Sector Research Establishments (PSREs)' to refer to these organisations. However, this study prefers to use the term PRO for consistency with the literature. According to the definition provided by the OECD (2011), these organisations are heterogeneous group of research institutes with varying degrees of "publicness". In line with the case of PROs in the UK, the public nature of these organisations is linked to a varied range of influence imposed by government mainly on their funding and type of research activities, and not necessarily to direct government ownership.

[19] Departmental Research Bodies sponsored by Government Departments include: Cultural institutions, NHS regions, and Departmental research bodies, the latter being included in our definition of PROs (Siora, et al., 2014).

[20] The seven UK Research Councils are: Biotechnology and Biological Sciences Research Council (BBSRC); Economic and Social Research Council (ESRC); Arts and Humanities Research Council (AHRC); Arts and Humanities Research Council (AHRC); Medical Research Council (MRC); Natural Environment Research Council (NERC); Science and Technology Facilities Council (STFC). Since 2018, these seven Research councils are part of a new body, UK Research and Innovation (UKRI), a non-departmental public body sponsored by the Department for Business, Energy and Industrial Strategy (BEIS).UKRI brings together the seven research councils, Research England, which is responsible for supporting research and knowledge exchange at higher education institutions in England, and the UK's innovation agency, Innovate UK. The parent Research Council may either own the research institutes or provide the majority of their funding, or in some instances may support them with minor funding as a block grant.

PROs vary in legal status, governance structure and size in terms of number of employees. The fundamental function of PROs has been defined as to undertake scientific research and service provision to fulfill national and governmental missions in improving welfare, enhancing economic growth through basic science advancement, and conducting scientific testing and regulatory functions, as well as providing policy makers and government with advice and information.

To shed light on PROs' engagement in outbound OI and deepen knowledge about the different outbound OI processes they engage in and the organisational capabilities underpinning this engagement, individuals working in PROs, who are actively engaged in KT activities with the private sector or with other governmental organisations on a regular basis, were interviewed. These individuals had roles such as R&D managers, knowledge exchange / KT managers, chief scientists engaged in KT, Deputy directors, Science and commercial directors, Business development managers, Innovation managers. Additional interviews were carried out with some individuals working for funding bodies (two Research Councils and a Government department), to provide some general context to the analysis.

To identify the relevant population of PROs in the UK to be targeted in this project, a comprehensive list of currently active PROs was created by analysing eight recent studies of PROs in the UK (see Ghorbankhani and Rossi, 2022). Since the study intends to focus on PROs that are primarily engaged in research activities and that are not part of the university sector, the sample excludes all those public organisations that primarily engage in cultural missions (e.g. museums, film and sports councils), as well as the 37 Medical Research Council institutes, which are funded by the Medical Research Council but are based at universities. This leaves a population of 49 PROs affiliated either to a UK Research Council or a Government department.

The 49 PROs in this list were approached requesting an interview. It was possible to secure interviews with 23 respondents working for 21 different PROs, as well as three funding bodies (two Research Councils and one Government Department). The following table (4.1) lists the details of the organisations that were interviewed: anonymised ID of the organisation, year of foundation, type of organisation, position of the person interviewed.

Table 4.1. Interviewees' details

Interviewee ID	Year of foundation of organisation	Type of organisation	Interviewee's position
I_1	2006	PRO affiliated to government department	Principal Agricultural Economist
I_2	1987	PRO affiliated to government department	Deputy Chief Scientist
I_3	1993	Research Council Institute	Knowledge exchange manager
I_4	1962	Research Council Institute	Director of innovation and impact
I_5	1994	Research Council Institute	Innovation manager
I_6	2009	Research Council Institute	Head of Business Development & Impact
I_7	1975	PRO affiliated to government department	Director, Science and Commercial
I_8	2011	PRO affiliated to government department	Knowledge exchange coordinator
I_9	1910	Research Council Institute	Head of business development
I_10	1920	PRO affiliated to government department	Head of marketing and business development
I_11	1994	Research Council Institute	Technology transfer officer
I_12	1994	Research Council Institute	Innovation MD
I_13	1900	PRO affiliated to government department	Postgraduate Institute director
I_14	1791	PRO affiliated to government department	Chief Scientist
I_15	1914	Research Council Institute	Knowledge Exchange and Commercialisation Manager
I_16	2005	PRO affiliated to government department	VP commercialisation (of private company commercialising the PRO's research)
I_17	2013	PRO affiliated to government department	Head of business development
I_18	2017	Research Council Institute	Head of business development
I_19	1884	PRO affiliated to government department	Associate director for science, enterprise and innovation
I_20	1992	PRO affiliated to government department	Principal advisor on science and biodiversity
I_21	1795	PRO affiliated to government department	Head of research, design and innovation
I_22	1795	PRO affiliated to government department	Chief customer officer
I_23	2008	PRO affiliated to government department	Technology commercialisation manager
I_24	2007	Funding body	IP manager
I_25	2016	Funding body	Senior economist
I_26	1965	Funding body	International research and innovation analyst

Note to Table 1: I_11 and I_12 work for the same PRO. I_21 and I_22 work for the same PRO.

The 26 semi-structured interviews were carried out in 2020-2021; each interview lasted between 48 minutes and 1h 20 minutes. A copy of the questions outline used for the interviews is reported in Appendix 4.1.

The interviews were recorded and transcribed. Each interview transcript was subsequently coded using Nvivo. Each transcript was free coded separately by two different coders (Bryman and Bell, 2003) who then agreed on a common coding system in the course of several meetings. The codes thus agreed were then grouped by one of the coders into six main themes, aligned with the objectives to analyse the

engagement of PROs in OI, and to the factors supporting this engagement. The themes were the following: (i) the main outbound OI activities that PROs engage in; (ii) the motivations for engaging in OI, the targets of OI, the main sources of revenue; (iii) the PROs' organisational culture in relation to OI; (iv) the organisational structures that PROs adopt to support OI; (v) the incentives and rewards scheme used to promote OI; (vi) the practices used to support outbound OI.

Table 4.2 shows the codes relating to the first theme, the main outbound OI activities that the PRO engages in.

Table 4.2. Codes relating to outbound OI activities of PROs

Licensing of data and other intellectual property
Spinout companies
Delivering training to industry - others
Selling products and services (software, testing, analysis, products, services)
Consultancy for external organisations
Reports, divulgative materials, booklets
Research contracts with businesses and other organisations
Collaborative research
Collaborations with students (supervision, internships)
Providing facilities, equipment, collaboration space to business
Staff exchanges
Building relationships with external organisations
Networking and outreach activities
Scientific publications
Open sharing of data / technology
Website or web platform to support KT
Data repository or platform

Table 4.3 lists the codes related to the second theme, including: the PROs' motivation for engaging in OI, the main targets of the knowledge transferred through outbound OI, the PROs' main sources of revenue.

Table 4.3. Codes relating to PROs' OI motivation, targets and sources of revenue

Motivation for OI
'Public good'; promoting better innovation
Pressure from funders
Reputation
Income (more income, income diversification, income concentration)
Targets for OI
Business, industry
Policymakers
Schools, communities
Sources of revenue
Commercial income
Core government funding

Competitive research funding

Finally, Table 4.4 lists the codes relating to the remaining four themes: the culture around OI, the organisational structures used to manage OI, the incentives used to promote OI (such as internal incentives, initiatives and funding available for OI), and practices supporting outbound OI, such as training and market scoping.

Table 4.4. Codes relating to PROs' culture, organisational structures, incentives and support practices

Culture around OI
Culture open to collaboration and OI
Staff awareness of OI
Structures to manage OI
Internal legal team to deal with IP, licenses and contracts
Internal KT office (KTO, business development team, contract manager, comms dept)
OI and KT support staff
External company (owned by PRO or external consultants to commercialise technology
Committee or specific individuals overseeing OI strategy
Industry board
Internal incentives / initiatives / funding for OI
Implicit reward for OI engagement (career progression, reputation, etc)
Explicit reward for OI engagement
Reward for IP commercialisation
Initiatives to promote OI in organisation (facilitating networking, innovation champions, internal website, internal funding …)
Specific funding to support OI
Use of metrics / indicators to measure OI performance
Presence of OI strategy
Practices supporting OI
Market research activities
Engaging with industry to better understand market demand
Internal processes to identify OI opportunities (collaborators, customers, activities, technologies)

The codes were used not only as a guide to interpret the data, but also as a basis from which to score qualitative variables. For each of 21 different PROs, variables were creayed corresponding to each of the codes listed in Tables 4.2, 4.3 and 4.4 above. In particular the variables were attributed value 2 if the corresponding activity was mentioned as being present, 1 if it was not mentioned, and 0 if it was explicitly said that the activity was not present.

For example, the following statement was marked as 0 for the variable *Culture open to collaboration and knowledge transfer:*

> *"we have teams that meet regularly to make sure we're using the best technologies, techniques of best science and all refreshing the partnerships we*

have, especially with universities and research institutes. But beyond that I wouldn't say we're driven by advances and in knowledge exchange at all, because main goal is to sort of work with government policy advisers and ministers". [Interviewee I_20]

Instead, the following statement was marked as 2 for the same variable:

"it is ingrained in our in our culture. So we already have, for instance, you know, people, companies may contact me and say we want to work. What kind of things are you guys working on at the moment on? And that becomes an internal conversation with anyone who's got anything to share" [Interviewee I_15]

In the following analysis, both descriptive statistical analysis of the qualitative variables coded from the interview transcripts, and illustrative quotations from the interviews, were used to address two main questions: (i) what kind of outbound OI practices do PROs adopt? (ii) which organisational capabilities are associated with the adoption of outbound OI practices?

4.4. Findings

4.4.1. PROs' adoption of outbound OI practices

First, the analysis tried to identify which type of OI practices the PROs adopted. To do so, the 17 variables representing the OI activities of PROs (listed in Table 4.2) were converted into binary variables (1 if the activity was present, 0 if it was not mentioned or was explicitly mentioned as absent). To facilitate interpretation, these 17 variables were then aggregated into 6 variables, according to established categories present in the literature (see, e.g., Salter and Martin, 2001; Cohen et al., 2002; Schartinger et al., 2002; Perkmann and Walsh, 2007):

- *IP_Commercialisation*, including: licensing of data and other intellectual property; spinout companies;
- *Services_provision*, including: delivering training to industry – others; selling products and services (software, testing, analysis, products, services); consultancy for external organisations; reports, divulgative materials, booklets; research contracts with businesses and other organisations;

- *Research_collaborations*, including: collaborative research; collaborations with students (supervision, internships); providing facilities, equipment, collaboration space to business; staff exchanges;
- *Relationships_building*, including: building relationships with external organisations; networking and outreach activities;
- *Dissemination*, including: scientific publications; open sharing of data / technology; website or web platform to support KT; data repository or platform.

In order to identify patterns of engagement in OI, a principal component analysis was run on these six variables, which capture the engagement of PROs in outbound OI activities. Table 4.5 shows the principal components' loading factors after imposing a Varimax rotation. The analysis returns two highly significant components with Eigenvalues greater than 1, and satisfactory reliability measures. The Kaiser-Meyer-Olkin measure of sampling adequacy is acceptable at 0.62. The first component is strongly associated with *Services_provision, Research_collaborations, Relationships_building*, while the second component is strongly associated with *Dissemination.*

These groups of practices seem to highlight two different approaches to OI: one based on a more commercial approach to outbound OI, the other based on open dissemination of scientific knowledge and data.

Factor scores for the two components were derived, allowing to create two variables that were named, respectively *Commercial_OI* and *Open_science*.

Table 4.5. PROs' engagement in outbound OI: principal component analysis

Outbound OI model	**Variable**	**Factor loading**	**Reliability**
Commercial_OI: 'commercial' outbound OI model	Services_provision	.613	Eigen Value 2.102; Variance explained 42.03% CR- 0.7535
	Research_collaborations	.607	
	Relationships_building	.406	
Open_science: 'open science' outbound OI model	Dissemination	.813	Eigen Value 1.204; Variance explained 24.08%

These two approaches appear to be alternative rather than complementary, displaying a negative correlation. Most PROs tend to have a high value of one factor and a low value of the other.

The two models are associated with different motivations for doing OI. Table 4.6 shows the mean values of *Commercial_OI* and *Open_science* for PROs that have expressed various motivations for engaging in OI, according to the four motivations variables listed as 'Motivation for OI' in Table 4.3. These are binary variables where 1 denotes the presence of the motivation, and zero its lack of mention or explicit absence.

Table 4.6. Approach to outbound OI and motivation for engagement

Motivation for OI variables:	*Commercial_OI*	*Open_science*
'Public good'; promoting better innovation	0.375*	-0.088
Pressure from funders	0.124	0.439
Reputation	1.191	-0.876
Income (more income, income diversification, income concentration)	0.026	-0.262*

***p<0.01, **p<0.05, *p<0.1

The table shows that typically PROs that are motivated by public good objectives and better reputation and income have higher values of *Commercial_OI* while those who are motivated by pressure from funders have higher values of *Open_science*. That income motivation is less associated with *Open_science* is not surprising, given that open science channels generally do not produce income. PROs that take an open science approach are motivated to engage in outbound OI by their funders' pressure. These PROs perhaps intrinsically would prefer to just focus on their core mission of doing research and advising government, however pressure from funders induces them to engage more actively in the dissemination of their research outcomes through scientific publications, open sharing of data / technology, websites or web platforms to support KT and data repositories or platforms. As noted by one of the interviewees:

> "*Delivering on societal benefits of science for public good - that's the contractual requirement, which then comes down to money, and if we do not, then those funders stop funding*". [Interviewee I_8]

Instead, PROs that engage in commercial OI often state that this engagement is due to the need to grow income and to diversify their sources of income:

> *"We are seeing changing buying patterns as people move away from analogue navigation, using paper charts to digital charts and the digital charts have*

less margin. And therefore, that's affecting our revenue on bottom line. Hence the strategy, to diversify and move into new markets through an open innovation type of model to expose data to new clients and allow them to exploit that data that obviously generates revenue through licencing of the data". [Interviewee I_21]

" We are also trying kind of see how we diversify over income, what are the modes of diversification of income, and that is something that is being certainly led by..., and [the organisation] is certainly, you know, as a commercial entity, is also kind of looking at that economical aspect, which is important in terms of imprint of diversification". [Interviewee I_11]

Other PROs highlight that their engagement in commercial OI is also driven by the altruistic motive to benefit external stakeholders by providing them access to their research expertise:

"There is another strong driver for us to identify additional income streams; working with industry or as partners, and also drivers very philanthropic and altruistic that we would like to see impact arising, promote research activities. We would like to benefit our local community, and you know our country". [Interviewee I_6]

"The driver is to solve the challenges that present for customers. […] We should be delivering innovative technologies to serve customer challenges and support them in their operations". [Interviewee I_23]

Indeed PROs that aim to promote better innovation have higher orientation towards the *commercial OI* model.

The evidence also shows that the targets of OI are different, with those targeting policymakers having higher value of *Open_science*, while those targeting schools and communities have higher value of *Commercial_OI*. No significant difference is found with respect to business (Table 4.7).

Table 4.7. Approach to outbound OI and targets of engagement

Targets for OI variables	*Commercial_OI*	*Open_science*

Business, industry	1.265	1.460
Policymakers	-0.104	0.0197
Schools, communities	1.620*	0.669

***p<0.01, **p<0.05, *p<0.1

The use of different OI approaches in relation to different target sectors is clearly illustrated in the case of data. On the one hand, the value of openly disseminated data for policymaking purposes is highlighted by several PROs:

> ”*We're also very heavily involved in producing official statistics for government, performance indicators on a lot of research survey work we do feeds into that*”. [Interviewee I_20]

On the other hand, other PROs discuss how they engage in commercial transactions around data with specific industries:

> “*Now we have a whole ocean modelling group that predicts natural disasters and weather forecasting. So that modelling capability is very, very interesting to hedge funds, the reinsurance market, commodities risk, trading market, all of that market*”. [Interviewee I_12]

> “*We're looking for new sectors to grow into, really in this in this country, as well as, maybe then supporting new types of data on new use of data. We're interested in how we move further into 3D representation, for example, so it is more of evolution of products, sideways moves into new sectors or growth in a sector of it. So, like in the energy sector that we serve, it might be trying to get more utilities using our data*”. [Interviewee I_14]

Considering the link between model of OI and sources of revenue, the evidence shows that PROs that have commercial income and competitive research funding have higher values of *Commercial_OI*, whereas there are no differences in terms of core funding (Table 4.8).

Table 4.8. Approach to outbound OI and sources of revenue

	Commercial_OI	*Open_science*

Commercial income	**0.389**	-0.083
Core government funding	**0.263**	**0.213**
Competitive research funding	**0.474***	-0.009

For those PROs that engage in commercial transactions, these are an important source of income.

> "*We sell services and products into the marketplace. So that's where the money comes from. Money for commercialisation and things like patents etc., is in the budgets of the heads of departments. So they will they will essentially funds patent applications or trademark applications, out of their budget*" [Interviewee I_13]

That both commercial income and competitive research funding are correlated with having a commercial approach to OI can explained by the fact that they are both driven by the need to compensate for lower public funding:

> "*Over the last 10 years the mode of funding from Scottish government has decreased and we have increased the funding we get from other sources, such as the BBSRC part of UKRI, also from commercially funded research and also from other research funder such as EU*" [Interviewee I_10]

Therefore, it is found that most PROs engage in outbound OI, but that they do so in different ways. In particular, two main different approaches to OI emerge: an 'open science' approach to outbound OI, based on the open dissemination of research findings, and a 'commercial' approach to outbound OI, based on the commercial exploitation of the knowledge produced by the PRO. PROs that engage in OI under pressure from funders, that aim to work with policymakers, and that rely on core government income, tend to be more oriented towards the 'open science' model. PROs that engage in OI because they want to contribute to better innovation, increase their reputation and gain external income tend to be more oriented towards the 'commercial OI' model. PROs that aim to work with the community, and that rely on competitive research income and private income, tend to be more oriented towards the commercial OI model.

4.4.2. Outbound OI and organisational capabilities

The analysis then focuses on the extent to which the PROs that engage in outbound OI according to the two approaches that have been identified, display the organisational capabilities that, according to the literature, are supportive of successful value creation through outbound OI: desorptive capacity, organisational culture open to OI, and multiplicative capabilities.

To do so, several variables are considered that proxy for these organisational capabilities, following the framework presented in Figure 4.1. In particular, each organisational capability – desorptive capacity, organisational culture open to OI, and multiplicative capabilities – is measured using some of the variables listed in Table 4.4.

Organisations with strong desorptive capacity are likely to: signal their technical and scientific potential to actors outside the organisation, in order to gain feedback from suppliers and users, to expand networks, reputation and business opportunities and to increase higher order knowledge (Penin, 2005); seek to gain understanding of the applications of their knowledge in different technologies and markets; manage their internal knowledge, for example by investigating what internal knowledge has been produced and whether and how it has been signalled externally, and how internal knowledge matches the needs of the market. For these reasons, the following variables, available from the interviews, are used in order to capture the presence of desorptive capacity:

- whether the PRO implements internal processes to identify OI opportunities (collaborators, customers, activities, technologies);
- whether the PRO engages with industry to better understand market demand;
- whether the PRO performs market research activities.

An organisational culture that promotes knowledge flows within the organisation and encourages creating and implanting new ideas, supporting KT to employees, and knowledge absorption by employees (Lane et al., 2006), supports the effective commercialisation of created knowledge (Naqshbandi and Kamel, 2017; de Araújo Burcharth et al., 2014).

The following variables, available from the interviews, are used in order to capture the presence of an organisational culture that is open to OI:

- whether the PRO has a culture open to collaboration and OI;
- whether PRO staff is aware of the importance of engaging in OI;
- whether the PRO implements initiatives to promote OI in the organisation (facilitating networking, innovation champions, internal website, internal funding …);
- whether the PRO offers specific funding to support OI;
- whether the PRO has an explicit OI strategy.

Finally, multiplicative capability is defined as an organisation's ability to expand its scope wider than its boundaries, and benefit from the capabilities of multiple firms and multiple industries in value creation. An organisation's multiplicative capability is underpinned by its ability to build and maintain relationships with external partners, starting from the ability to select the right strategic partners to multiply the new technology, to the ability to manage the relationships with those partners over time. Typically, it can be expected that PROs that have set up specific structures to build and manage external relationships, will be better able to do so.

For these reasons, the following variables, available from the interviews, are used in order to capture the presence of multiplicative capability:

- whether the PRO has an internal legal team to deal with IP, licenses and contracts;
- whether the PRO has an internal KT office (KTO, business development team, contract manager, communications dept);
- whether the PRO has internal KT and OI support staff.

Table 4.9 shows the correlations between the two different approaches to OI and variables capturing desorptive capacity, organisational culture, multiplicative capability. It is evident that there are positive correlations between the commercial OI model and the variables proxying desorptive capacity, organisational culture open to OI, and multiplicative capability. Instead the correlations between the open science model and these variables are negative (except for the presence of an OI strategy).

Table 4.9. Correlations between the two different approaches to OI and variables capturing desorptive capacity, organisational culture, multiplicative capability

Construct	Variables measuring each construct	*Commercial_OI*	*Open_science*
Desorptive capacity	Internal processes to identify OI opportunities (collaborators, customers, activities, technologies)	0.3839	-0.2885
	Market research activities	0.1788	-0.0632
	Engaging with industry to better understand market demand	0.1761	-0.1054
Organisational culture	Culture open to collaboration and OI	-0.2115	-0.2363
	Staff awareness of OI	0.0054	-0.3537
	Initiatives to promote OI in organisation (facilitating networking, innovation champions, internal website, internal funding …)	-0.4618	-0.3415
	Specific funding to support OI	0.2968	-0.1432
	Presence of OI strategy	0.26	0.2266
Multiplicative capability	Internal legal team to deal with IP, licenses and contracts	0.1629	-0.4033
	Internal KT office (KTO, business development team, contract manager, communications dept)	0.0718	-0.1623
	KT and OI support staff	0.0613	-0.1517

These correlations suggests that the arguments made by the OI literature on the organisational capabilities that support OI (desorptive capacity, organisational culture, multiplicative capabilities) hold for those PROs that adopt a 'commercial' approach to OI, while those that adopt an 'open science' approach do not have these capabilities to the same extent.

These findings are confirmed by quotations from the interviews. PROs that adopt the commercial OI model have developed ways to identify OI opportunities, and to facilitate the exploitation of their knowledge by potential users.

> *" So we look at the strategic themes where we need to improve our offerings to the market. We have a Horizon Scanning Radar that we apply to developing those themes and identifying those themes, and then we refine from that we taken assessment on what is a viable, visible and desirable. And from that, we then refine those themes and those subs projects that we are going to invest in".* [Interviewee I_21]

> *" We follow the trends in general. We talk to industry, and then we talk to specific network that we are members of and we get feedback from them. And then we work together towards what it is that, the need for an industry, really."* [Interviewee I_18]

"We have something called a new product introduction process, which is all about understanding market need, understanding who the customers are engaging with customers to understand their needs." [Interviewee I_13]

These PROs have set up structures that facilitate the identification of strategic partners and that can manage the relationships with those partners over time:

" *We have someone in my team embedded in each bits of the organisation. So we have, I think, 13 departments there. So there's some of my team in each of those departments, kind of, day-to-day working with scientists trying to instill that culture change and that, um, and thinking about what, what does the customer need from the start of a project?*" [Interviewee I_13]

"*We have our global sales and business development team, and then we also have a channel on distributing team. The channel and distribution team is responsible for putting in place the NDAs, the legal agreement, that type of thing that's required to support the partnership, and then the business development team is responsible for working together with the SME to achieve the outcomes*". [Interviewee I_21]

Finally, they have an organisational culture that is open to collaboration with external partners including industry:

"*And we already have very regular science seminars in which they invite external speakers to talk to our people and our people go to other places to talk about there their research*". [Interviewee I_15]

PROs that adopt the open science model instead tend to have an organisational culture that is more anchored to the traditional approach of free dissemination of scientific knowledge. They emphasise a culture of research excellence and engagement with research stakeholders, rather than a culture of innovation and engagement with business:

"[Scientists] feel that they are reluctant to be involved with business or entrepreneurship. And they are totally apart from the concept of commercialisation so that they don't want to get involved in this part" [Interviewee I_19]

> ” *Most of the terms that you've mentioned would be toxic in our colleagues, you know the shutters would go down. They don't like commercialisation, they don't like markets, they don't like product development, and so that that's not a language they'll understand. So it, um, in terms of engaging with end users of research, that's a different matter in each section of the organisation has good stakeholder networks that are relevant to their expertise*” [Interviewee I_4]

The findings confirm the arguments from the open innovation literature. The studies of outbound OI that have looked at firms, which tend to have a commercial approach to OI, have suggested that desorptive capacity, organisational culture and multiplicative capabilities are important organisational capabilities for successful outbound OI. This study finds that those PROs that take a commercial approach to OI, appear to build on the organisational capabilities identified as important for outbound OI by the firm literature. Instead, PROs that have an open science approach have not developed these capabilities to a large extent. They build their OI approach mainly on their internal research strengths and their traditional connections with research stakeholders.

Developing desorptive capacity, organisational culture supporting KT and multiplicative capabilities could be important steps towards moving to a more commercial OI model.

4.5. Discussion

OI has been introduced as one of the leading practices that contribute to the collaboration between government, universities, and industry, particularly boosting innovative activities' entrepreneurial aspects. OI emerged from companies’ need to seek internal and external paths to the market for innovative opportunities (Rahman and Ramos, 2013), to achieve more efficient innovative outcomes, and to enhance financial performance (Keil et al., 2008). Only in recent years researchers have focused on how OI can be applied to public and non-profit organisation (Holmes and Smart, 2009; Albors-Garrigos et al. 2010; Chesbrough and Di Minin, 2014), and how business models that underpin OI can be extended to those organisations (Chesbrough and Bogers, 2014). It has been noted that budgetary restrictions and growing awareness of social challenges, have triggered the emergence of entrepreneurial

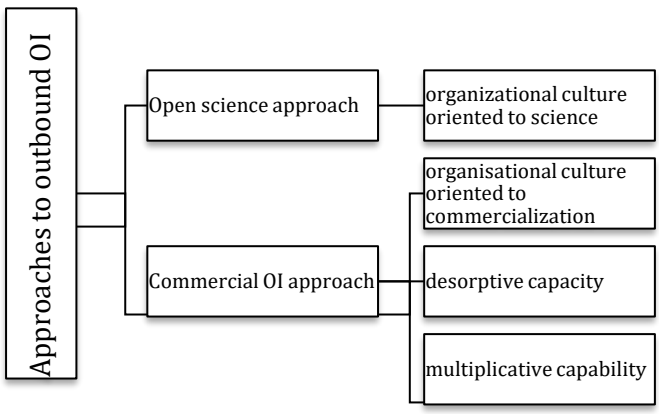
orientations of non-profit organisations in form of taking a proactive, risk-taking and innovative approach in their collaboration with firms (Al-Tabbaa et al., 2022).

Thanks to the thematic content analysis of 23 in-depth interviews with 21 PROs in the UK, this study has been able to broaden the understanding of how PROs engage in outbound OI, in particular by identifying two distinct approaches – one based on a more commercial approach involving the provision of services, research collaborations and building relationships with industry and other stakeholders, the other based on open dissemination of scientific knowledge and data.

When analysing whether the organisational capabilities that the OI literature has identified as important in order to support outbound OI in firms, are also important in the case of PROs, the study has highlighted some significant differences between the two approaches. In particular, it can be argued that the theoretical framework proposed based on the literature review only fits well those PROs that take a more commercial approach to OI: those PROs in fact do exhibit desorptive capacity, supportive organisational culture, multiplicative capabilities. However, there are also numerous PROs that do not seek commercial exploitation and instead focus on 'open access' and traditional publications. These PROs have an organisational culture oriented to scientific production and dissemination, and do not invest in developing desorptive capacity and multiplicative capability.

The figure below (Figure 4.2) revisits the framework proposed in Figure 4.1 to account for the different approaches to OI adopted by PROs.

Figure 4.2. Organisational capabilities that support outbound OI in PROs



The literature on OI has emphasised that a firm's business model is central in determining whether and the extent to which it will adopt OI practices (Chesbrough, 2006; Chesbrough and Appleyard, 2007). An open business model for the firm that creates an awareness of how to compete, how to differentiate itself and how to position in the presence of external factors (Chesbrough, 2006, 2007), also identifies and designs the organisational culture (Herzog and Leker, 2010), and can support the adoption of OI.

The present analysis of outbound OI in PROs suggests that the two different approaches to OI that have been identified are linked to different business models. Adopting the configurational view of business models, where several components can be distinguished – value proposition, value creation, value delivery and value capture, and the articulation between them (Foss and Saebi, 2017; Zott et al., 2011) – it is possible to link each approach to OI to a different underlying business model, as illustrated in Table 4.10.

Table 4.10. Business models associated to different approaches to outbound OI

	Commercial OI approach	**Open science approach**
Value proposition	Income, reputation, public good; target segments: business, community	Public good, funders' pressure; target segments: policymakers
Value delivery	Services provision, research collaborations, relationship building	Dissemination
Value creation	Desorptive capacity Organisational culture Multiplicative capability	Research capabilities
Value capture	All sources: core funding, competitive research funding, commercial income	Core funding

4.6. Conclusions

Most public organisations are in the early stages of adoption of OI (Lee et al. 2012). They need to develop an understanding of OI and undertake measures to adopt OI, particularly outbound practices, in the presence of their existing organisational routines and learning cultures, which may be unsuited to models of open and collaborative innovation. In this context, scarce literature focuses on the PRO-industry links (Crows and Bozeman, 1998; Lundvall, 1992) despite government's significant spending on PROs.

This study contributes to OI debate in three ways. First, by focusing mainly on PROs receiving substantial government funding, and contributing to leading-edge applied science and government decision making, this study extends boundaries of OI in management theories, to be applied in the PRO context. It provides insights on how PROs organise their outbound OI activities and how and to what extent they apply OI with respect to their heterogenous organisational mission, governance and managerial strategies.

Second, this study contributes to existing OI literature in stretching the underdeveloped definition of desoptive capacity initially introduced by Lichtentather and Lichtentather (2009), into a more operationalised version used for the purpose of this research project.

Third, this study focuses on outbound OI (Lichtenthaler and Ernst, 2009; Schroll and Mild, 2011) in PROs, in order to shed light on PROs' internal and organisational capacity and shortcomings in transferring their own research and knowledge output through outbound OI. It theorises, based on empirical evidence, two different OI business models for PROs, one focused on the commercialisation of knowledge through multiple channels, the other focused on the open dissemination of knowledge; each business model has a different approach to value proposition, value delivery, value capture, and its value delivery is underpinned by different organisational capabilities. This extends the literature on OI business models in the public sector.

The study has several implications for policy and management. In terms of policy, our findings highlight that PROs operate with different business models when it comes to OI, and suggests that these different models should be taken into account when setting targets for PROs and evaluating their performance; it would not make sense to require PROs that operate with different value propositions and targets to achieve the same objectives. Policymakers' evaluation of PROs' performance should be sufficiently flexible to allow them to demonstrate successful performance under different business models.

In terms of management implications, our findings suggest that there are different organisational capabilities that underpin different OI business models and that PROs that wish to follow one or the other approach need to develop the related organisational capabilities. While public managers are increasingly expected to

maintain a mode of simultaneous competition and cooperation (Rosenberg Hansen and Jacobsen, 2016), we discuss the practical implications for PRO managers who should learn from the experience of successful PROs, bearing in mind that they need to focus on the capabilities that are particularly appropriate for their business model. Our study also highlights the components of each organisational capability that relate to one or the other business model. This also provides useful knowledge for PRO managers who can focus on developing the components of each organisational capability.

For example, PROs that wish to develop desorptive capacity can focus on internal processes to identify OI opportunities, market research activities and engaging with industry to better understand market demand. PROs that wish to develop multiplicative capability can set up an internal legal team to deal with IP, licenses and contracts, an internal KT office, and invest in KT and OI support staff. PROs that wish to develop an organisational culture supporting commercial OI should increase staff awareness of OI and invest in internal support for OI.

Further research could delve deeper into the experiences of PROs that are particularly successful at each OI business model to better articulate the components of each organisational capability. It could also investigate whether one or the other model is associated with successful performance of PRO. Since this study has focused on PROs in the UK, where there is a relatively small number of very heterogeneous PROs, further research could focus on other public research systems, including systems that include a larger number of PROs, systems that display greater coordination and less heterogeneity (for example, with PROs belonging to one or two main organisational structures), systems where PROs operate under weaker institutional frameworks. Finally, the focus of our study – outbound OI in PROs – is different from and complementary to the approach adopted by most of the OI literature – which has tended to focus on firms' inbound OI processes. Therefore, further research could focus on how to better connect PROs with outbound OI capabilities with firms' inbound OI capabilities, improving knowledge flows within the innovation system.

CHAPTER 5. Measuring the performance of public research organisations: the impact of mission heterogeneity

Abstract

This paper intends to address a gap in research at the intersection of the literature on the performance of public research, and on the specificities of PROs' missions and KT engagement. Through a systematic literature review on PROs' performance assessment, the study shows that, to date, PROs' performance in contributing to innovation has been measured through a limited number of performance indicators, which do not reflect the full scope of PROs' activities. It is argued that this is problematic, as such approaches to performance measurement do not fully capture PROs' contribution to innovation, and do not account for the heterogeneity of PROs, in particular in relation to their mission. A conceptual framework is developed that associates different PROs' missions to different approaches to KT, which lead to different performance indicators being appropriate for PROs with different missions. Drawing on quantitative and qualitative information about 16 PROs (derived from public databases and semi-structured interviews), the study shows that the KT activities of PROs extend beyond those captured by the traditional quantitative indicators (patents, spinouts, private income) and that PROs with different missions use different structures to support their KT engagement and specialise in different KT activities.

5.1. Introduction

Public research organisations (henceforth PROs) – that is, research performing centres and institutes with varying degrees of 'publicness' (OECD, 2011) – are a crucial component of the public research systems of most countries. Their responsibilities encompass undertaking scientific research and service provision in pertinent areas, with objectives that include: improving quality of life; promoting economic development through advances in basic science; informing government policy making; undertaking statutory scientific testing and regulatory functions (OECD, 2014; Maxwell-Jackson, 2011). PROs play a key role in addressing compelling and concrete challenges in society at large (Wanzenbo et al. 2020).

While PROs are analysed by a growing literature, much remains to be understood about PROs' performance in contributing to innovation.

On the one hand, most studies of PROs focus on their research productivity, rather than on their contribution to innovation (Bozeman, 2000; Maxwell-Jackson, 2011). Research productivity still constitutes an essential aspect of PROs' activity and is a key element based on which they are evaluated (Bozeman, 2000). Still, on its own, it is not enough to gauge PROs' ability to contribute to innovation. The pressure on researchers to demonstrate utility, user relevance and industry connections and thus a demand for evaluating societal quality of scientific research have noticeably increased across all public research sectors (Van der Meulen and Rip, 2000). Despite the PROs' wide range of inventions and discoveries with potentiality for commercialisation, chances are limited that those inventions be converted to innovations and therefore be commercialised. PROs often need to actively transfer knowledge to external stakeholders to ensure that their research outputs are applied and used (Athreye and Wunsch-Vincent, 2021).

On the other hand, some studies measure the performance of PROs in transferring knowledge to external stakeholders – whether businesses, governments, third-sector organisations, communities, and so on – and thus contribute to innovation. However, these are few, and they often consider mixed samples, including universities as well as PROs, and sometimes even a broader range of research organisations (e.g., Cohen, et al. 2002; David, et al. 1999; Coccia, 2019; Belderbos, et al. 2015; Fudickar and Hottenrott, 2019; Hindle and Yencken, 2004). PROs are a different type of organisation from universities, in several aspects including their focus (PROs do not have, or have in minimal degree, a teaching mission), subject specialisation (PROs tend to be more specialised than universities), and research orientation (PROs' research tends towards the applied end of the spectrum, while universities' research tends towards the basic research end). Therefore, studies on universities' performance in KT cannot easily be generalised to PROs. Additionally, studies of PROs' performance tend to focus on a limited number of outputs, which do not portray the full extent of PROs' activities. This might hamper their ability to effectively evaluate and compare the performance of PROs, particularly as these organisations tend to be heterogeneous from the point of view of the missions that they are expected to fulfill when it comes to innovation support (the types of stakeholders they are supposed to

transfer knowledge to, the type of knowledge they are expected to provide). Particularly, if the different missions of PROs drive them to set up their KT processes differently, focusing on different activities, then performance analyses that use the same, small range of outputs for all PROs, may not adequately capture their performance, and the problem may affect some PROs more than others.

This paper intends to address a gap in research at the intersection of the literature on the performance of public research, and on the specificities of PROs' missions and KT engagement. Based on a systematic review of the literature on the performance of PROs, the range of indicators and approaches used to measure performance are identified. Then, thanks to a combination of qualitative and quantitative evidence about 16 PROs in the UK (collected from in-depth interviews with 18 respondents in 16 PROs, as well as from secondary data sources) the study shows how measuring PROs' performance using the set of outputs typically considered in performance analyses, is a reductive approach that does not capture the full breadth of KT activities that PROs engage in: performance rankings change substantially depending on what indicators are used, and PROs produce a much larger range of research and KT outputs than those usually considered in papers that focus on performance measurements. The study also shows that those outputs differ depending on the mission of the organisation. The aim of the paper is to highlight these issues and to propose suggestions for improvement in performance measurement and avenues for further research.

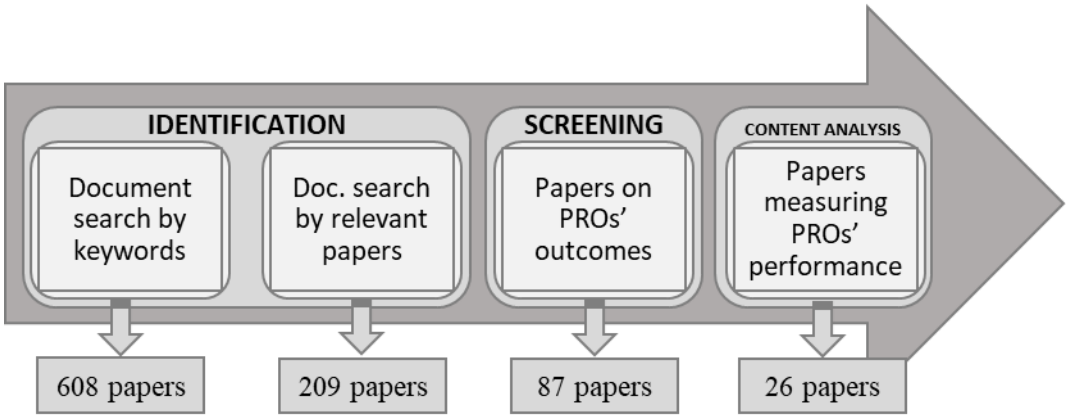
The paper is structured as follows. Section 5.2 presents a systematic review of the literature on the measurement of performance of PROs, highlighting the typical approaches and indicators used in this field. In section 5.3, the heterogeneity of PROs is discussed particularly in relation to their mission. A review of the literature on the various types of innovation support missions of public organisations is presented, and a conceptual framework linking the different missions to different approaches to KT is developed. Section 5.4 presents the data and methodology; the study relies an original dataset containing information about 16 PROs in the UK in 2016/17, complemented with 18 in-depth interviews with representatives from 16 of these PROs. Section 5.5 presents the empirical findings. In section 5.6, the findings are discussed in light of the current literature and of the study's conceptual framework.

Section 5.7 concludes with implications for management and policy, limitations, and avenues for further research.

5.2. A systematic review of the literature on the performance of PROs

In order to provide a systematic overview of the literature on the performance of PROs, in October 2022 a search was performed on all articles in the Web of Science database whose abstracts, titles or topics included keywords referring to public research organisations; to capture a broader range of articles, the search also included some keywords referring specifically to PROs in five European countries (Germany, France, Italy, Spain, UK) whose PRO systems are particularly investigated, and where PROs play a relevant role in the public research system. Figure 5.1 provides an overview of the processes involved in the initial phase of the literature review. Some papers were then added from other sources, in particular the papers citing some prominent articles on PRO efficiency (Bonaccorsi and Daraio, 2003; Meng et al., 2008; Liu and Lu, 2010; Lee and Lee 2015).

Figure 5.1. The systematic literature review process



In this identification phase, those documents not written in English, Italian or Spanish, the non-peer reviewed academic articles as well as duplicates, were discarded. Overall, 817 papers were listed at this stage. The list of keywords and the number of papers the search returned for each keyword are presented in Table 5.1.

Table 5.1. Systematic literature review: search outcomes

Keywords	Number of papers found
General keywords	
"Public Research Organization"	49
"Public Research Organisation"	20
government research institute	57
government research institute & performance	15
National Government Laboratory	14
Country-specific keywords	
Max Plank Institute & Germany	50
Leibniz Association & Germany	20
Consiglio Nazionale Ricerche	50
"public research organ" & Italy	18
"public research organ"&Germany	14
Spanish National Research Council	173
Consejo Superior de Investigación	76
Public Sector Research Establishments, PSREs UK	3
Public Research Organisations & UK	4
Public Research Organisations & France	22
Centre Nationale de la Recherche	4
CNRS France	19

The abstracts were skimmed to identify papers relevant to the performance of PROs: this reduced the list to 87 papers. Upon further investigation of the articles' contents, it was found that, out of these 87 papers, only 26 concerned the measurement of the performance of PROs. The remaining 61 papers mainly discussed specific aspects of the PRO's activity: patenting behaviour, publishing behaviour and research dissemination practices, governance and research orientation, project management skills, the development of specific products or services, the dynamics of collaborations between PROs and industry or between PROs and PROs and governing institutions (mainly the performance of firms interacting with PROs or involved in triple helix). Some papers focused on the impact of research performed by PROs (one was a pilot application of novel research impact assessment methods, another was an analysis of impact patterns, combining specific research outputs with specific actors that generated various types of impact). Some papers presented case studies, in the sense that they analysed the activities of one PRO or, at the most, two PROs. Finally, there were some papers on disparate topics such as policy changes and reforms in PROs, a literature review on knowledge management practices, the performance of firms interacting with PROs, or the classification of PROs according to their outputs.

The following subsection focuses in more detail on the remaining 26 papers, which specifically analysed the performance of PROs.

5.2.1. Measuring the efficiency of PROs

Seven papers dealt with the efficiency of PROs in R&D performance (Table 5.2). Their objective was to rank PROs according to performance: two of them used Data Envelopment Analysis (DEA) variants deal with time effects, while five dealt with the low discrimination power of DEA when using small samples and several inputs/outputs and dealing with size effects. Of these five papers, four did so through DEA extensions and one (Mohan, 2005) by just running parallel DEA analyses focusing on specific dimensions of the R&D process (thus selecting a few inputs/outputs in each analysis). Except in the case of (Mohan, 2005), the other six papers hardly developed the results regarding PROs, since their main objective was to prove the usefulness of DEA methodological developments.

It is also interesting to note, that four of these papers considered two phases in the R&D production process: a first one related to the production of knowledge and technologies, and a second one related to their transfer (marketisation or dissemination). Among these studies, Xiong et al. (2018) identified strong scale effects as well as lower performance in the KT transfer phase, for the case of Chinese Public Research Institutes. Liu and Lu (2010) differentiated Taiwanese research institutes into four categories: achievers (performed well at both the technology development and the technology diffusion stage), innovator (efficient at the technology development stage), marketers (inefficient at the development stage but being efficient at the diffusion stage) and underdogs (inefficient at both stages).

Table 5.2. Summary of indicators used to measure the efficiency of PROs

Reference		**Methodology**	**Dimension**	**Inputs**	**Outputs**
Single R&D process	Bonaccorsi and Daraio (2003)	DEA (VRS, order-m): 240 French & Italian Government-funded Research Institutes (GRIs)	**Human resources**	No. researchers, research staff	No. excellent R&D research leaders & graduate education
	Meng et al. (2008)	Two level DEA (AHP & DEA): 15 Chinese basic RIs	**Income**	Parent body's grant, total funds	- External research funding - Income from technology transfer
	Lee and Lee (2015)	DEA + weights restrictions (AR-I & ARG): 1.481 R&D projects (from 10 Korean GRIs)	**R&D expenditure**	Research expenditure	Investments by technology recipients to produce products
			Facilities	Value of research equipment	-
			Time	No. months worked on projects	-
		(2 inputs: T. amount of fund and N. of	**Publications**	-	- No. international publications - No. articles: in SCI, in non-SCI

		participating researcher; 7 outputs:)	**IIP**	-	- No. patents: national, foreign - No. patent applications: national, foreign
			Miscellaneous	-	Weighted sum of publications, awards, invited talks, invention patents
			External factors	Geographical Agglomeration Index (environmental variable)	-
Two-stage R&D process	Mohan (2005) Liu and Lu (2010) Xiong et al. (2018) Yue et al. (2020)	4 parallel DEA (CRS): 8 Indian PRIs Network analysis on DEA efficiency scores: 32 Taiwanese RIs Two-stage dynamic DEA (CRS): 17 Chinese RIs Super-efficiency DEA + vector autoregression model: 30 Chinese RIs	**Human resources**	- No. staff: scientific, professional and technological, S&T - No. staff with PhD and master - No. staff with bachelor + technicians	-
			Publications	- No. Publications - No. papers: related to S&T, in SCI, in international journals - No. internal research technical reports	-
			Technology production	No. patents: total, domestic	No. technologies developed
			Income	Funds	- External cash flow earned - Income from: technology & patent licensing, technology services, licensing (reduced by management cost), marketisation (S&T services and technology (transformation, development, transfer), technological consultation, services, training and contracts, and other income)
			R&D expenditure	S&T expenditure (staff costs, equipment purchasing, and other daily expenditure), S&T funding	-
			Carry-over indicators	- Management cost - Newly approved (national and provincial) projects	-

The other papers mainly focused on measuring the outputs of PROs, rather than their efficiency. These papers either ranked PROs according to their performance, or linked performance to organisational factors.

5.2.2. Measuring the outputs of PROs

In particular, most studies applied r r analysis (Table 5.3), either to measure the performance of PROs in KT (sometimes also including publications as output measures), or to analyse the scientific productivity of PROs. The descriptive analysis was applied on the indicators that they considered relevant, which varied depending on the scope of the study. For example, Pagliaro and Coccia (2021) measured the scientific productivity of PROs in relation to income, comparing the growth in the number of publications and the growth in the income of PROs. Instead, Coccia (2008b) measured the effect of bureaucratisation on the scientific performance of PROs and Coccia (2008a) measured the trade-off between basic research and KT in PROs. Azagra-Caro and de Pablos (2009) focused on patents only as a measure of performance, and extended patent analysis from universities to PROs. Instead, a few other studies relied on a wide range of indicators (and even qualitative information) often collected through surveys (e.g. Siora et al., 2014; Paik et al., 2009; Lee, 2011)).

A couple of papers adopted qualitative approaches to performance evaluation. Maxwell-Jackson (2011) relied on desk research of financial information as well as interviews; while Coccia (2001) measured the performance of PROs using a method similar to Delphi (Syn)[21].

Table 5.3. Summary of indicators used to measure PROs' outputs: qualitative and quantitative studies

Methodological approach		**No. Papers**	**Dimension**	**Indicator**
Quantitative	**Descrip-tive analysis**	8	**Human resources (HR)**	No. employees per commercialisation unit, FTE staff employed in commercialisation/industrial liaison offices
				Average annual no. researchers
				Mobility of researchers to other institutions (University, Government research institute, Private, Spin-off), Business representatives on governing bodies

[21] Coccia (2001) proposes some topics to a group of researchers in order that they may offer quantitative estimates on the performance of each research activity carried out in their institutes. The main feature of the general performance is captured with some average values and a learning process in rounds. The score of method is used to classify the structures in ranks.

			Publications	No. publications: total, growth, (total & average per year) domestic, (total & average per year) international, SCI publications, SCI publications per 100 million wons
				No. papers: total, national, international, average per year and researchers, per R&D expenditure per year
			R&D contracts	No. R&D contracts: total, (number & ratio) by the PRO's ex-researchers
				No. coopertive R&D contracts: total, (number & ration) with the POR's start ups
			Industrial & intelectual property (IIP)	No. patent applications: total, domestic, by field of knowledge, in co-ownership,
				No. patents: total, domestic, foreign, per researcher, average per per researcher and year, average per R&D expenditure per year
				No. technologies developed: total, (number & share) transferred, licensed
				No. Licenses: total, IP lincenses, technology licenses (total, to SMEs, to large firms)
			Spin-offs	No. Spin-offs
			Income	Income: growth, from business consultancy
				Royalty income: total, per researcher, ratio out of R&D expenditure, average ratio of royalty to R&D expenditure per year
				Revenues from KT (i.e. analysis and technical tests (chemical and physical), technological services (homologation, calibration, nuclear magnetic resonance, etc.), quality services (accreditation, certification, quality control, etc.), environmental services (water monitoring, pollutant emission control, etc.), information technology services (data elaboration, supply of databases and data, etc.), health services, research contracts with firms and institutions)
			Expenditure	R&D expenditure: total, average.
			Bureaucracy	Time spent on the i-th administrative activity
				No. Documents: filled in, required
				Time dedicated to: recruit term contract personnel, organisation of events, participate in meetings and to draw up projects, drawing up final balances and budgets, purchase of scientific materials
				Time waiting for approvals (project application, joint agreement/collaboration, budgets and changes to the expenditure capacity of the Expenditure Centre.
Qualitative	**Syn (similar to Delphi)**	1	-	Qualitative estimates of PRO activities
	Desk research & interviews	1	Analyses the performance of PROs in terms of (i) the extent to which the government is getting what it wants at the required quality level, and are there wider benefits to the economy, and (ii) how has the organisation performed financially	

Source: authors' elaboration based on Coccia (2001), Coccia (2008b), Coccia and Secondo (2008), Azagra-Caro and de Pablos (2009), Paik et al. (2009), Lee (2011), Maxwell-Jackson (2011), Siora et al. (2014), Pagliaro and Coccia (2021).

Other papers included a broader range of outputs to explore the determinants of PROs performance. As an example, Son et al. (2019) explored the effects of PROs' technology entrepreneurship and external relationships on their KT performance. They did so through a survey to universities and other public research institutes, presenting results separately. KT performance was measured using the number of technology license agreements, the amount of technology licensing income, and the number of spin-off formations. Table 5.4 and table 5.5 summaries the indicators used to measure PROs' outputs in studies that successively apply regressions and bibliometrics approaches.

Table 5.4. Summary of indicators used to measure PROs' outputs: studies applying regressions

Variables	Dimension	Indicator
Dependent variables	**IIP**	- No. domestic patents - No. technology licenses
	Spin-offs	No. spin-off formations
	Income	Technology licensing income
Independent variables	**Human Resources**	Staff: total, share of civil servants, share of working staff, share of university personnel
	Institutional collaboration	Technological cooperation with: other units within the PRO, other (domestic & foreign) PROs, (domestic universities & foreign) universities, (domestic & foreign) business firms, other institutions
	IIP	Technology entrepreneurship: at the organisational level, at the individual level - (both variables built through PCA)
	Income	- Private sector R&D funding - Income from: national projects, other projects, contracts
	Dissemination	Use of websites to promote their technologies: own website, government's website
	Institutional characteristics	- Scientific area - Existence of a service centre or the joint management of research units - Dummy for outlier institutes
	External factors	- Region where the patent was issued - Party in the government
Control variables	**HR**	No. TTO's full-time employees
	IIP	No. Patents granted
	KT support policies	Shares of royalties for inventors
		Financial incentive for TTO employees
	External factors	No. private companies in the same region as the PRO
Multivariate analysis 2 out of 3 papers combine the regression with multivariate analysis	**KT strategies**	Strategies for technology license or spin-off formation
	KT support policies	Support policies for technology license or spin-off formation
		Incentive policies for technology license or spin-off formation
	Searching	Participation in technology marketing
	Planning	Participation in education on technology license or spin-off formation
	Marshalling	Utilisation of support policies or systems from government or external organisations for technology license or spin-off formation
	Implementing	Participation in establishment of technology-based start-ups

Source: authors' elaboration based on Azagra-Caro et al. (2007), Naso (2016), Son et al. (2019).

Also, six papers focused on the bibliometic behaviour of PROs, some of them revising their scientific output (Gonzalez-Albo, et al., 2012), and others focusing on:

- their citation impact (Abramo et al., 2011, compared it to world average and discipline average);
- the scientific output by fields of knowledge (Abramo et al., 2008, ranked research units according to the weighted sum of publications in a given macro area; while Dorta-Gonzalez and Ramirez-Sanchez, 2014, focused on the Arts & Humanities Citation Index and compared universities and PROs);
- the links between bibliometric behaviour and organisational factors (Heinecke, 2018).

Table 5.5. Summary of indicators used to measure PROs' outputs: bibliometrics

Dimension	Indicator
Activity	Activity index
	No. documents: total; shares by type, field of knowledge, journal & language
	No. publications (weighted by the normalised impact factor of the journal in a given macro area)
Impact	Impact Factor: average, relative
	% articles Q1
	No. Citations: with and without self-citations, average by document, share non-cited documents, relative Citation Rate, non-citation relative rate, standardised by field (expected citation rate (XCR) & annual world citations), standardised by journal (Journal expected citation rate (JXCR) & citations received by all publications in the same year & journal)
	h index, inmediacy index
Nature	Research level of journals (basic vs. applied nature), type of research areas coverd by publications
Scientific collaboration	Average (authors or centres) by document
	Collaboration rates
	International collaboration: share of papers with at least one co-author from a foreign institution (by country), frequency of international collaboration and international collaboration index

Source: authors' elaboration based on Abramo et al. (2008), Abramo et al., (2011), Gonzalez-Albo, et al. (2012), Dorta-Gonzalez and Ramirez-Sanchez (2014), Maldonado Carrillo and Montesi (2018), Heinecke (2018).

5.2.3. Exploratory analyses of PROs' activities

Beyond the 26 papers previously, some described publications were also found that presented exploratory analyses of the range of activities that PROs engaged in, identifying many possible outputs, but without making any overall attempts to measure performance: NCUB (2016) analysed the KT activities of staff employed in UK PROs (Research Council Institutes) by means of a survey; STOA (2012) identified a range of different KT mechanism that were used to transfer knowledge from PROs to industry. In general terms, these reports relied on the same indicators as the previous 26 papers. However, OECD (2013) proposed 11 measures for near-term implementation with metrics such as student employment on funded projects, alumni in the workforce, and services to external clients.

Last but not least, the publications revised in this section dealt with the performance of PROs considering their formal R&D activities. However, Olmos-Penuela et al. (2014) illustrated the importance of informal collaborations between researchers and non-academic partners in the social sciences and humanities (SSH). In so doing, they performed semi-structured face-to-face interviews with CSIC's heads of SSH institutes and consulted CSIC and university databases 2002-2007. They concluded that "informal collaborations not officially recorded by the organisation are much

more common than formal agreements and that many collaborations remain informal over time", and provide a full list of the informal collaborations identified.

Summing up, most studies of PROs performance focus on similar outputs. Most indicators refer to scientific outputs (publications, citations) and research commercialisation activities (patents, licenses, spinoffs), as well as overall income. Only a few papers (Coccia, 2008a; Meng et al., 2008; Maldonado-Carrillo and Montesi, 2018) take a broader view of PRO's KT activities, by: measuring revenues from a wide range of activities; distinguishing between research, impact and collaboration activities; including research leaders and graduate education as part of research output measurement. The papers that carry out exploratory analyses show that forms of KT that are normally not measured when analysing PRO performance are actually the most used and important, while those modes of KT that are more frequently measured (such as patenting, licensing and spinning out companies) play a marginal role. Therefore, with very few exceptions, most analyses of PROs' performance do not include the measurement of important KT activities. Additionally, the vast majority of the studies assume that all PROs have similar approaches to KT, and focus on the same outputs for all PROs, not considering that different types of PROs might have different production functions.

The present study takes advantage of a unique dataset which combines qualitative and quantitative information about the research and KT activities of 16 PROs in the UK. Thanks to the breadth of information collected about these organisations, it was possible to describe and measure their engagement in a variety of KT activities beyond those commonly considered in studies of PROs' performance, and to discuss the limitations of measuring performance using only a narrow set of outputs.

5.3. Mission heterogeneity of PROs and performance

While all PROs are expected to engage in research and KT, and to do so more and more efficiently, they are not a homogeneous group. In particular, PROs' activities vary extensively in terms of mission and types (Intarakumnerd and Akira, 2016). Their missions vary in terms of: (i) *objectives* that they are expected to fulfill, in relation to innovation support and the types of stakeholders they are supposed to transfer knowledge to (de la Torre et al., 2021), (ii) the *type of knowledge* they are

expected to provide, in terms of type of output they are supposed to produce (Crow and Bozeman, 1999; Coccia, 2006).

Typically, some PROs are oriented to the development of knowledge and technology (technology development mission), others are primarily oriented to the application of knowledge in order to provide services and policy advice (policy/service mission). In fact, Azagra-Caro et al. (2007) state this differentiation for the case of several European countries (France, Germany, Italy, Spain, The Netherlands, etc.), although these authors use a different terminology (project-based research institutions vs. contract research institutions).

This is also true for the UK where, typically, some PROs are oriented to the development of technology and knowledge (technology and knowledge development mission), others are primarily oriented to the application of knowledge in order to provide services and policy advice (policy support and services provision mission). In fact, UK government[22] has recently proposed to classify UK PRO's missions in the following three categories:

1. Development and exploitation of new technologies and knowledge assets (Technology and knowledge development mission): the PSRE plays a role in research and development, enhancing existing or developing new technologies, products, services, and other knowledge assets (models, methods, procedures).

2. Policy-making and regulatory support to government (Policy support mission): the PSRE provides crucial research, information, monitoring/surveillance capabilities, data, and scientific advice to inform government policy.

3. Operational science services to government, business, and society (Service provision mission): the PSRE provides operational science services (for example, forecasting, measurement, collection custodians, horizon scanning) to government, society, and businesses.

It can be argued that the heterogeneous missions of PROs shape the approach to KT chosen by the PROs, and this in turn will lead to different models of the PRO's KT process. Therefore, not all outputs will be relevant to all PROs: it can be expected that

[22] See: https://www.gov.uk/government/publications/public-sector-research-establishment-value-framework/guidance-on-assessing-performance-and-value-of-public-sector-research-establishments (accessed July 2022).

the performance ranking of the same PROs will be different according to the outputs considered; certain types of outputs will lead to better performance of PROs with technology and knowledge development mission, and other types of outputs will lead to better performance of PROs with policy support and service provision mission.

Using the terminology of Mazzucato (2018) it can be argued that:

- technology and knowledge development mission PROs tend to perform the role of market creators. Because they focus on research and development, enhancing existing or developing new technologies, products, services, and other knowledge assets (models, methods, procedures), they have longer-term objectives, building relationships with key actors with the view to shape markets in the future. So they can be expected to set up infrastructures like incubators to help them grow spinoff companies, commercialisation offices to develop relationships with companies acquiring their intellectual property, and to perform better in research contracts and research collaborations with companies.
- Policy support mission and service provision mission PROs provide crucial research, information, monitoring/surveillance capabilities, data, and scientific advice to inform government policy and they provide operational science services (for example, forecasting, measurement, collection custodians, horizon scanning) to government, society, and businesses. Therefore they tend to perform the role of market fixers, helping companies and other partners with their current challenges. So they can be expected to perform better in consultancies and provision of services, with a more transactional approach.
-

5.4. Data and methodology

5.4.1. Data

Sample and data sources

This study exploits a unique, purposefully constructed dataset of PROs in the UK, combining data from public administrative records (annual reports and financial returns), public databases (Web of Science, Espacenet) and from in-depth interviews. To identify the population of PROs in the UK, a comprehensive list of currently

active PROs was created by analysing eight recent studies of PROs in the UK (Lyall et al. (2004), BIS (2007), BIS (2011), Maxwell-Jackson (2011), Government Office for Science (2013), BIS (2014), Smith (2015), Hughes et al. (2016)). The final list included 49 organisations, divided into 28 Departmental Research Bodies funded by one or more government departments and 21 Research Council Institutes funded by one of the seven Research Councils[23].

Information was collected from these PROs' websites about their main demographic characteristics: founding date, legal status, mission, department of affiliation, location, ownership structure and field of activity. Additional information was collected i from the PROs' annual financial statements for six years (2011/12, 2012/13, 2013/14, 2014/15, 2015/16 and 2016/17)[24]. Since information from annual financial statements could only be collected from organisations that report independently, the final sample for which complete information was available included 33 organisations. Further variables were derived from other sources: information about PROs' publications was derived from Scopus and Web of Science, information about their patents was derived from the European Patent Office's database, information about the user sectors of PROs' knowledge was derived from Smith (2015).

In addition, in-depth interviews were performed in 2020-2021 with 23 representatives of 21 PROs. Of these 21 PROs, 16 are included in the quantitative panel dataset mentioned above. Since the present analysis relies on the combination of qualitative information derived from the in-depth interviews and quantitative information derived from the panel dataset, the rest of the analysis focuses on the 16 PROs for which both in-depth interviews and quantitative information are available. A dataset of 16 PROs was created by combining the quantitative information about PROs referred to the most recent year available (2016/17) with qualitative variables coded from the in-depth interviews.

[23] These are: Arts and Humanities Research Council (AHRC), Biotechnology and Biological Sciences Research Council (BBSRC), Engineering and Physical Sciences Research Council (EPSRC), Economic and Social Research Council (ESRC), Medical Research Council (MRC), Natural Environment Research Council (NERC), and Science and Technology Facilities Council (STFC). In 2017, the seven councils have been merged into a single agency called UK Research and Innovation (UKRI) which also includes the innovation funding agency Innovate UK.

[24] In the UK, the tax year goes between April 1st until March 31st of the following calendar year.

information from interviews. Coding

Since for some of the 16 PROs it was possible to interview more than one person, the overall number of available interviews is 20. Each interview lasted between 48 minutes and 1h 20 minutes[25]. The interviews were recorded and transcribed. The following table (5.6) lists the details of the organisations that were interviewed: anonymised ID of the organisation, year of foundation, type of organisation, position of the person interviewed.

Table 5.6. Interviewees' details

Interviewee ID	**Year of foundation of organisation**	**Type of organisation**	**Interviewee's position**
I 1	2006	PRO affiliated to government department	Principal Agricultural Economist
I 2	1987	PRO affiliated to government department	Deputy Chief Scientist
I 3	1993	Research Council Institute	Knowledge exchange manager
I 6	2009	Research Council Institute	Head of Business Development & Impact
I 7	1975	PRO affiliated to government department	Director, Science and Commercial
I 8	2011	PRO affiliated to government department	Knowledge exchange coordinator
I 9	1910	Research Council Institute	Head of business development
I 10	1920	PRO affiliated to government department	Head of marketing and business development
I 13	1900	PRO affiliated to government department	Postgraduate Institute director
I 14	1791	PRO affiliated to government department	Chief Scientist
I 15	1914	Research Council Institute	Knowledge Exchange and Commercialisation Manager
I 17	2013	PRO affiliated to government department	Head of business development
I 18	2017	Research Council Institute	Head of Business Development
I 20	1992	PRO affiliated to government department	Principal advisor on science and biodiversity
I 21	1795	PRO affiliated to government department	Head of research, design and innovation
I 22	1795	PRO affiliated to government department	Chief customer officer
I 23	2008	PRO affiliated to government department	Technology commercialisation manager

Note to Table 1: I 21 and I 22 work for the same PRO.

Each interview transcript was subsequently coded using Nvivo. Each transcript was free coded separately by two different coders (Bryman and Bell, 2003) who then agreed on a common coding system in the course of several meetings. For the purpose

[25] These are part of a larger set of 26 interviews with 21 PROs and three funding bodies; however, for the purposes of the present paper, we only consider the interviews with PROs that are part of the sample included in the quantitative analysis.

of the present paper, the focus is on the codes referring to the engagement of PROs in research and KT activities, to develop variables that could be used to capture their performance. The following table (5.7) lists the relevant codes.

Table 5.7. Codes relating to PROs' research and KT activities

Nvivo codes	**Variables**
Licensing of data and other intellectual property	*Licensing IP data*
Spinout companies	*Spinouts*
Delivering training to industry - others	*Delivering training*
Selling products and services (software, testing, analysis, products, services)	*Selling prod services*
Consultancy for external organisations	*Consultancy*
Reports, divulgative materials, booklets	*Reports*
Research contracts with businesses and other organisations	*Research contracts*
Collaborative research	*Collaborative research*
Collaborations with students (supervision, internships)	*Collaboration students*
Providing facilities, equipment, collaboration space to business	*Facilities equipment*
Staff exchanges	*Staff exchanges*
Building relationships with external organisations	*External relationships*
Networking and outreach activities	*Networking outreach*
Conferences	*Conferences*
Scientific publications	*Publications*
Open sharing of data / technology	*Open data tech*
Website or web platform to support KT	*Website KT*
Data repository or platform	*Data repository*

The codes were used not only as a guide to interpret the data, but also as a basis from which to score qualitative variables. For each of the 16 different PROs, variables were created corresponding to each of the codes listed in Table 5.7. In particular the variables were attributed value 1 if the corresponding activity was mentioned as being present, and 0 if it was not mentioned, or if it was explicitly said that the activity was not present. The names of the corresponding binary variables are listed in the right-hand column of Table 5.7.

Another variable named *Breadth of engagement* was then created, which counted the number of different research and KT activities the PRO engaged in; although 18 possible activities were considered, this variable ranged from a minimum of 3 to a maximum of 13 different activities.

Coding the PROs' missions

Considering PRO's heterogeneous nature, this study aims to examine how PROs' different missions are associated with the choice of their KT approach, and how this

impacts their KT performance. UK PROs were classified according to their main mission, based on a careful analysis of these organisations' mission statements as presented in their 2016/17 annual reports. More specifically, content and keyword analysis of each PROs' mission statements were performed, in order to identify which of the following missions were present:

- *Knowledge and technology development mission* if the mission of the PRO included the development and exploitation of new technologies and knowledge assets;
- *Policy support mission* if the mission of the PRO included policy-making and regulatory support to government;
- *Services provision mission* if the mission of the PRO included operational science services to government, business, and society.

For example a PRO whose mission statement mentioned that the PRO engaged in "*licensing intellectual property rights*", *"[serving] customers, partners and markets*" and "*is a trusted adviser to GB Government*", would encompass both technology and knowledge development mission (producing knowledge and technology that generate patents and licensing) and services provision mission (providing services to customers, partners and markets- the commercialisation part) as well as policy support mission that provides information and advice to government. A PRO whose mission statement mentioned that "*we work with government, local councils, businesses, civil society groups and communities*" would be classified as having a services provision mission. A PRO whose mission statements mentioned that they provided "*excellence standards, science to solve critical challenges, recognition of the international work, world's leading technology*" would be classified as having a technology and knowledge development mission. This codification of PROs' mission orientation was then validated through a revision of the transcriptions of PROs' interviews and the relevance of the activities reported in their annual reports.

Based on this analysis, three binary variables were built, one for each mission, which take value 1 when the mission is the PRO's main mission, and zero otherwise (PROs can have more than one main mission). These variables were then clustered using hierarchical clustering (Ward's Linkage method (1963), Canberra distance). This way, two clusters were obtained: one, composed of 11 PROs, whose main mission is

technology and knowledge development; the other composed of 5 PROs, whose main mission is policy support or services provision.

5.3.2. Empirical strategy

In order to describe and measure the PROs' engagement in a variety of KT activities beyond those commonly considered in studies of PROs' performance, the analysis first focused on providing descriptive statistics on PROs' performance according to some indicators that are commonly used in the literature measuring the performance of PROs: the share of private income, the amount of private income per employee, the number of publications per employee, the number of patents per employee, the number of spinouts per employee. The quantitative dataset was used to derive these variables.

The rankings of PROs' performance based on these common but narrow measures were then compared with the outcomes obtained when performance is measured using the broader set of variables derived from the in-depth interviews. Subsequently, the extent to which the PROs' missions affect the findings was investigated by: (i) comparing how PROs with different missions fare, on average, in relation to different performance measures, and (ii) analysing, through qualitative analysis of the interviews, how PROs with different missions evaluate their own performance.

5.4. Findings

5.4.1. PROs performance changes according to the outputs considered

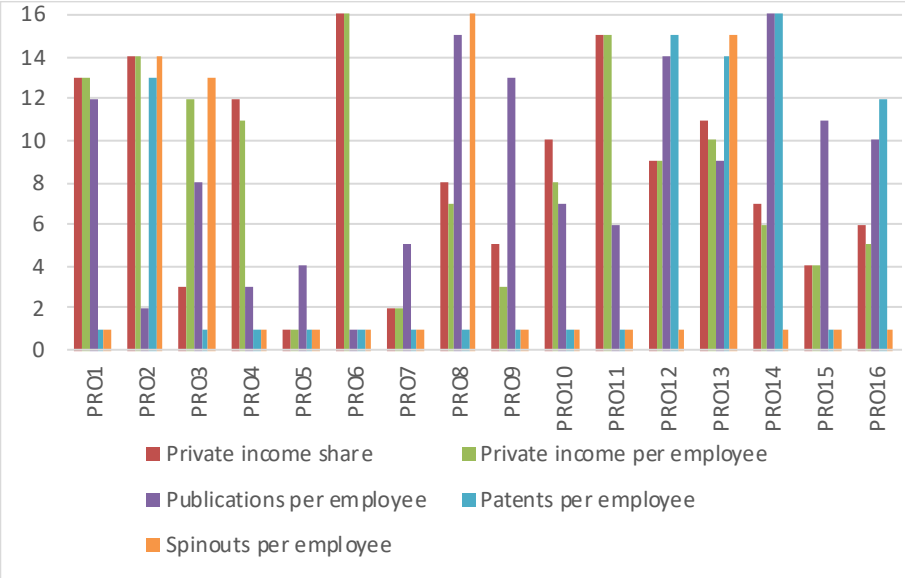
The analysis first considers several variables capturing the research and KT outputs of PROs, that have been widely used to measure their performance:

- Share of private income;
- Amount of private income per employee;
- Number of publications per employee;
- Number of patents per employee;
- Number of spinouts per employee.

It can be noticed that the rankings of PROs in terms of their performance change depending on which output variables are used. Figure 5.2 shows that the rankings

(with 15 for highest rank, 1 for lowest rank) of each PRO change substantially depending on the outcome variable used. For example, some PROs rank very highly on share of private income and amount of private income per employee, and very low on patents per employee; while for other PROs the opposite pattern occurs.

Figure 5.2. PROs' rank according to different performance variables



Additionally, there is a positive correlation between the average rank and the standard deviation of the ranks, suggesting that those that tend to do very well in one performance variables tend to do less well in the others.

When it comes to correlations between rankings, there is a positive and high correlation between the share of private income and the amount of private income per employee, as expected (0.86), and a positive correlation between publications per employee and patents per employee (0.3). Spinouts per employee are positively correlated with patents per employee (0.21) and amount of private income per employee (0.26)

Instead, the share of private income and the amount of private income per employee are negatively correlated with the number of publications per employee (-0.28 and -0.34 respectively).

So even when just the standard performance variables are considered, the outcomes of performance ranking depend strongly on the variable that are chosen.

If the focus is broadened to other forms of engagement beyond those commonly used in the literature, again different results are obtained.

When PROs are ranked in terms of their breadth of engagement, this ranking is found to be negatively correlated to the rankings in terms of share of private income, amount of private income per employee, and number of patents per employee. Instead, the ranking is positively correlated to the ranking in terms of number of publications per employee and number of spinouts per employee.

This means that the PROs that do better in terms of private income tend to have a narrower focus on a smaller range of research and KT activities. Conversely, PROs that have greater research productivity (higher number of publications per employee) produce a broader range of KT outputs, but tend to have lower private income, both in terms of share and amount per employee.

Table 5.8 reports the correlations between the five performance variables that were considered earlier – share of private income, amount of private income per employee, number of patents per employee, number of spinouts per employee, number of publications per employee, and breadth of engagement – and each of the output variables derived from the interviews.

Table 5.8. Correlation between performance variables and output variables

	Breadth of engagement (number of channels)*	Publications per employee	Patents per employee	Spinouts per employee	Private income share	Private income per employee
Breadth of engagement (number of channels)*		0.35	**-0.07**	0.29	**-0.14**	**-0.07**
Research commercialisation outputs:						
Licensing IP data	0.24	0.29	0.09	0.16	**-0.09**	0.03
Spinouts	0.36	**-0.02**	**-0.04**	0.48	**-0.06**	0.07
Research contracts	0.56	0.63	0.30	0.18	**-0.21**	**-0.39**
Collaborative research	0.50	0.27	-0.28	0.19	**-0.02**	**-0.04**
Services outputs:						
Selling prod services	0.23	**-0.34**	**-0.27**	**-0.30**	0.29	0.33
Consultancy	0.42	0.07	**-0.20**	0.32	0.33	0.45
Facilities equipment	0.66	0.27	**-0.10**	**-0.20**	**-0.09**	**-0.01**
Reports	0.24	**-0.31**	**-0.30**	**-0.18**	**-0.05**	**-0.03**
Education outputs:						

Delivering training	0.51	0.44	**-0.15**	0.37	**-0.22**	**-0.30**
Collaboration students	0.01	0.03	0.14	0.21	**-0.11**	**-0.10**
Research dissemination outputs:						
Publications	0.28	0.29	0.12	0.07	**-0.76**	**-0.83**
Conferences	**-0.08**	**-0.10**	0.25	**-0.33**	**-0.16**	**-0.06**
Open data tech	0.54	0.30	0.25	0.28	**-0.40**	**-0.29**
Website KT	0.38	0.19	0.25	**-0.19**	**-0.08**	**-0.21**
Data repository	0.30	**-0.18**	**-0.22**	**-0.13**	**-0.13**	**-0.22**
Relational outputs:						
Networking outreach	0.69	0.24	0.15	0.13	0.08	0.10
External relationships	0.19	0.42	0.30	0.21	0.08	**-0.08**
Staff exchanges	0.42	0.09	**-0.24**	**-0.18**	**-0.08**	**-0.04**

Breadth of engagement is positively correlated to each channel (by construction). The number of publications per employee is also positively correlated with almost all output variables. So it appears that high research productivity is correlated with good performance in many KT and research activities.

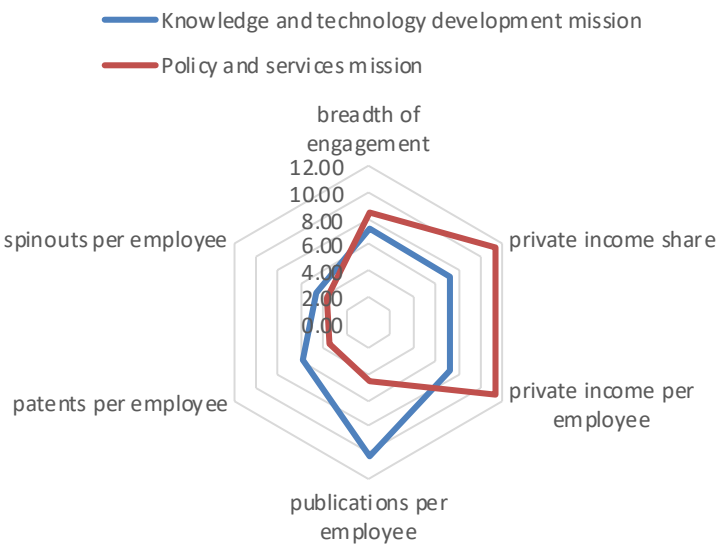
Instead, the situation for number of patents per employee and number of spinouts per employee is more mixed, with some positive and some negative correlations. Private income share and amount per employee tend to be negatively correlated with the majority of outputs (except for Licensing IP data, Selling prod services, Consultancy). So it can be argued that private income is a suitable performance measure only for PROs that engage in a narrow range of channels but does not capture the impact of other channels.

5.4.2. PROs performance and missions

Considering the PROs' missions and how these affect their performance, the analysis returns some relevant differences. The following spider diagram (Figure 5.3) shows the average rankings of the PROs' in the two different mission clusters (technology and knowledge development mission; policy support and services provision mission) according to the six performance variables: breadth of engagement; share of private income; amount of private income per employee; number of publications per employee; number of patents per employee; number of spinouts per employee. While technology and knowledge development mission PROs perform better in terms of

research productivity (number of publications per employee) and research commercialisation (number of patents per employee), policy support and services provision mission PROs perform better in terms of private income.

Figure 5.3. Performance ranking and PRO missions



If the performance of PROs with different missions is computed in relation to each specific type of output, it is possible to also find patterns according to the PROs' missions, although their average breadth of engagement is similar. As Table 5.9 indicates, technology and knowledge development mission PROs perform better in research commercialisation outputs and in the more traditional scientific outputs related to research dissemination and education. Policy support and services provision PROs perform better in services outputs (as could be expected), in relational outputs and in some dissemination outputs, particularly those relating to greater visibility (website, data repository) rather than the dissemination of research outputs (publications, conferences, open data and technology), where instead knowledge and technology development mission PROs perform better.

Considering the structures in support of KT, the analysis shows that technology and knowledge development mission PROs are more likely to have an incubator (36%, vs. 0% of policy support and service provision mission PROs with an incubator) and to have an internal KT office and some KT staff. Instead policy support and service

provision mission PROs are more likely to have an external company to help them with commercialisation and services provision.

These findings are consistent with the expectations presented in the framework developed in section 5.3.

Table 5.9. Output variables and PRO missions

	Technology and knowledge development mission	Policy support and services provision mission
Breadth of engagement (number of channels)*	**7.27**	**8.40**
Research commercialisation outputs		
Licensing IP data	**81.82%**	60.00%
Spinouts	**27.27%**	20.00%
Research contracts	**72.73%**	60.00%
Collaborative research	**63.64%**	60.00%
Services outputs		
Selling prod services	45.45%	**80.00%**
Consultancy	36.36%	**60.00%**
Facilities equipment	36.36%	**40.00%**
Reports	18.18%	**60.00%**
Education outputs		
Delivering training	**36.36%**	20.00%
Collaboration students	**63.64%**	60.00%
Research dissemination outputs		
Publications	**100.00%**	80.00%
Conferences	**63.64%**	60.00%
Open data	**54.55%**	40.00%
Website KT	18.18%	**60.00%**
Data repository	9.09%	**40.00%**
Relational outputs		
Networking outreach	72.73%	**100.00%**
External relationships	54.55%	**60.00%**
Staff exchanges	27.27%	**40.00%**

Qualitative evidence from the interviews confirms that PROs with different missions find different types of KT channels more lucrative in terms of the revenue they derive

from. These channels are exactly those that PROs perform well in, according to the quantitative evidence.

In particular, technology and knowledge development mission PROs mention research commercialisation channels (and their related outputs) as the most lucrative ones for them: IP licensing, commercialisation, collaborative research, and research contracts. Instead, policy support and service provision mission PROs mention the provision of services and consultancies as the most lucrative. The next table (5.10) shows some quotations from interviewees in response to questions about what their most lucrative channels of KT engagement were.

Table 5.10. Qualitative evidence about most lucrative outputs and PRO missions

Type of output	**Quotations**
	Technology and knowledge development mission PROs
Data and IP licensing	*"It would be income generated from analysis of the offshore samples, or the services we provide, or the licencing of varieties of soft foods or potatoes or the working on barley and genetics."* [I8]
Spinouts	*"I suppose the most lucrative way off translating our research is every two stage to take considerable risk and make considerable investment and spin out one of our activities into a company of its own."* [I3]
Research contracts	*"We like also large contract research projects […] spanning maybe several months or several years*." [I6] *"You know, the most lucrative one is when we have an industrial bond they response us research on. They just pay for the research*." [I18]
Collaborative research	*"Collaborative research from funding agencies […]is very lucrative for us because it's very beneficial conditions for us as a research institute to participate because we get 80% of funding, like fully economic costs funded through research collaborations."* [I6]
	Policy support and service provision mission PROs
Services	*"The two strongest ones are what we call our "measurement services", so these were organisations coming to us to buy on a commercial basis, our expertise, and it could be consultancy or it could be, we do quite a lot of calibration services to organisations, there are lots of measurements, then we, we make sure they're doing correctly basically. And they pay us a lot of money for that*." [I13]
Delivering training (paid for)	*"In terms of the most lucrative channels for us, we do trainings. So our training business is about £3 million a year on training is transferring our knowledge to others and people pay us for our time. […] We have books, publications and products, and products are usually software products, software tools."* [I7]

5.4.3. PROs' evaluation of their own performance

The evidence suggests that PROs with different missions particularly engage in certain channels of KT, which they find most lucrative, and which leads them to perform particularly well in relation to the outputs produced through those channels. This is the case for research commercialisation outputs for PROs that have a technology and knowledge development mission, and for service outputs for PROs that have a policy support and service provision mission. However, when it comes to

evaluating what KT channels are more valuable in terms of the impact they generate for society, it is found that the channels that PROs consider most valuable are not necessarily the most lucrative.

First, some PROs expressly state that in practice they use a variety of channels.

> *"You need to use an array of different ways of commercialisation. […] So we are participating in a collaborative research […] We deliver training to academic and industry. We run a lot of events. There would be public engagement events or networking events or information showing events that we also call students. We deliver services and deliver consultantancy, you know, it is a mixture of different models here."* [I6 – Knowledge and technology development mission]

Second, they recognise that channels that are more open and do not imply payment are often most effective to achieve certain outcomes, such as leading to creative interactions. This has been highlighted by PROs with different missions.

> *"But I connect with people through Linkedin sometimes from non-connections or through interactions, and sometimes it's conferences […] I think that the first approach, it's mostly conference season. In that regard, the mostly creative one would be conferences."* [I18 – Knowledge and technology development mission]

> *"So we have that a publication programme. So all of our research publish through review reports. All of our data is openly available. We were advised to make it available anyway, so we don't need to have contracts covering that. We have a very close working relationship with the academic sector."* [I20 – Policy support and service provision mission]

Hence, revenue is not in itself a measure of how effective a KT channel is for PROs. There is awareness on the part of PROs, irrespective of their main mission, that what really matters is the impact of their activities. Accordingly, some PROs are trying to develop ways to evaluate their performance that go beyond revenue only, and even beyond quantitative indicators and towards the use of narratives and qualitative typologies of impact.

"There is a focus of sort of how do we generate more impact? And basically, that's by transferring your knowledge outside of just research communities and academia" [I1 – Knowledge and technology development mission]

"There's been a recognition that it's very difficult to measure return on investment when you're talking about R&D, that goes back to basic research. […] So tracking return on investment is rather difficult in that's kind of framework. So we are more interested in tracking outcomes." [I14 – Policy support and service provision mission]*"An important metric beyond income is some of the testimonies that the stakeholders would offer us on the difference it makes to their business, of our contribution [..] So then articulate through these headings; conceptual, strategic, operational instrumental network development, and those are the headings under which we think about the significance of our impact and how to increase it."* [I8 – Knowledge and technology development mission]

"But the way we measure is not just by revenue. We also measure why the sort of narrative and impact and case studies. So sometimes we might enter into the collaboration which initially is not bringing much revenue to us, but we're building capability. Or we really able to realise some impact". [I6 -– Knowledge and technology development mission]

"at the moment we only measure our IP licensed revenue, but we know that that's not enough. Actually people pay us a license fee, but what they do with the license could be amazing and it can be creating new businesses and jobs, but we're not currently tracking that." [I13 – Policy support and service provision mission]

PROs' use of qualitative instruments and framework for the evaluation of their performance can sometimes be in conflict the guidance received from the government or their own top management, which can appear to be more interested in revenue than in broader societal impact, as well as with the performance indicators requested by their funders, which are usually focused on a narrow set of outputs.

"So I think the director, the Governing Council […] are driven by the commercial benefits of these activities rather than being driven by the wider knowledge exchange and societal type impact agendas. So it's sometimes that

slight conflict between doing activities because they're going to result in a quantifiable societal impact which does not generate revenue as opposed to an area that would lead to a significant economic impact, which would also have associative revenue." [I9 – Knowledge and technology development mission]

"The government […] What they're really looking for is economic benefit. So they care less about whether we're making money as a lab, but more about, well, how are you helping businesses grow? And what's the benefit to the UK and the economy and jobs." [I13 – Policy support and service provision mission]

"The three or four key metrics for all BSSRC funded institutes is revenue brought into the institute, part of this revenue is from public or private organisations, whether there is any in-kind contribution to projects, then a number of new patents, patent applications, or IP." [I6 -– Knowledge and technology development mission]

So it appears that within PROs there are some conflicting tensions between fulfilling the objective to achieve impact on society, and responding to the demands of their key stakeholders – their owners, funders and top management. There is some scope for better alignment between the demands of stakeholders and the PROs' awareness of the importance to engage in a breadth of KT channels of engagement to achieve impact across the board, and of the value of engaging in channels of KT that do not necessarily produce the most revenues, to achieve valuable societal outcomes.

Interestingly, some PROs have been able to embed broader criteria in their performance assessment, which might provide some valuable practices for the sector to learn from:

"What we're interested there is how does that how does that start to move towards a proof of concept? How does that start to move into productisation? But so they were looking at outcomes really, rather than on costs on projects that we want the thing to be, we want to know that the development is leading somewhere. And we want proof that any evidence that things are moving along a pipe by some way." [I14 – Policy support and service provision mission]

"If individuals are identified who had exceptional performance in those areas, then there will be nominated for exceptional performance awards and receive financial rewards for having done that. And that does not have to be connected with the generation of income, more than they have made exceptional contributions to the translation engagement process." [I9 – Knowledge and technology development mission]

"And then externally, similarly; we sort of measure our scientists, part of measuring that performance, if you like, is this element of profile; How are they ensuring that they are interacting with others. And it isn't just for a way, we also use it with individuals to say you need to be open and receptive, to what others can tell us on what we could learn from others as well, actually knowledge transfer it is not just a one way on activity. We want to make sure that we're bringing that knowledge in this crowd." [I7 - Policy support and service provision mission]

5.6. Discussion

PROs tend to be heterogeneous from the point of view of their governance, legal status, accountability to government, as well as the missions that they are expected to fulfill when it comes to innovation support (the types of stakeholders they are supposed to transfer knowledge to, the type of knowledge they are expected to provide). When analysing the performance of PROs in KT, this heterogeneity needs to be taken into account. Particularly the heterogeneity of missions of PROs is important, as it can be expected that the different missions will drive PROs to set up their KT processes differently, which will affect their performance. To the authors' knowledge, no studies have analysed the KT performance of PROs taking into account their heterogeneity.

The systematic overview of the literature performed in the contect of this study confirms the growing importance of developing a deeper understanding of the role PROs play for government and overall, to wider society and assessing their performance with respect to their heterogeneous missions. The limited body of work measuring PROs' performance represents fragmented methods for applying limited and outdated (with respect to the significance of new ways of transferring and commercialising research outputs) measures for assessing the multiple perspectives

on PROs' heterogeneous missions, KT activities and performance. This calls for a more contextualised understanding of the way PROs' output and performance develop over time and an emergent contribution from scholars to the field where extensive government spending goes towards and expectations are high due their role in testing, setting standards, providing emergent solutions and consultancy as well as suggesting national and international advice to policy makers for taking timely, comprehensive and futuristic decisions. Improvement in performance measurement relies on a collective understanding of the role and missions of PROs and how their performance should be measured in line with the PROs' missions and streams of income (either public funding or private from licensing and contracts, etc) as well as their effective KT channels. Lack of understanding of PROs' missions defined by government and affiliated organisations (in the UK government departments and research councils), theoretical insights explicitly linked to performance assessment, and using de-contexualised performance assessment measures, lead to over-reliance on systematic reviews (Eva et al., 2019) and performance analyses methods with quantifiable inputs and outputs e.g. DEA that are unable to capture full breath of PROs' KT activities and therefore to demonstrate how those activities translate into PROs' performance. Thus, there are increasing calls for empirical work which seeks to explain the contextualised performance indicators that reflect the PROs' range of research and KT outputs. and bringing clarity to the questions what performance indicators can better reflect the PROs' heterogeneity and influential missions as well as how these performance indicators should be assessed. To answer these questions, the in-depth qualitative approach combined with the systematic review of extent literature on performance and quantitative data, provide a clear conceptual framework of how PROs mission is correlated to their performance and highlight new indicators revealed from interviews not able to be explained otherwise.

In particular, support is found for the argument that technology and knowledge development mission PROs tend to perform the role of market creators. They focus on research and development, enhancing existing or developing new technologies, products, services, and other knowledge assets (models, methods, procedures), in fact they engage more in the traditional research dissemination (publications, conferences) and education-based channels (delivering training, collaborations with students) compared to policy support and services mission PROs. They perform better in all

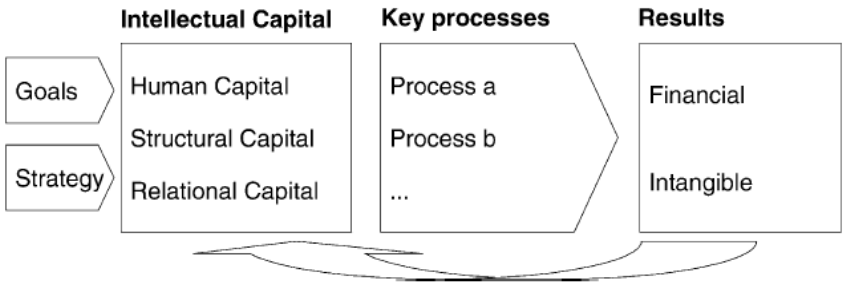
kinds of research commercialisation outputs - Licensing IP data, Spinouts Research contracts and Collaborative research. They are more likely to set up infrastructures like incubators to help them grow spinoff companies, and to have internal KT staff and KT offices in order to build relationships with key actors, with the view to shape markets in the future.

Support is also found for the argument that policy support and services mission PROs perform the role of market fixers, helping companies and other partners with their current challenges. In fact, compared with technology and knowledge development mission PROs, they perform better in all kinds of outputs that involve the provision of services, with a more transactional approach - Selling products and services, Consultancy, Facilities and equipment, Reports. They also engage relatively more than technology and knowledge development mission PROs in activities that enhance their visibility with external stakeholders, such as having a website showcasing their KT activities, as well as in activities of networking and outreach, and staff exchanges. In terms of infrastructures for KT they rely more on external companies to help them with commercialisation and services provision .

Consequently, there is a need to conceptualise KT in broader terms to take into account the different missions of PROs. When measuring the efficiency with PROs, it is necessary to develop different models that use different variables for measuring outputs appropriate to the PRO's mission.

Therefore this study suggests that a more general model for PROs' KT performance, while still based on an input-output framework (Paul et al., 2010), would be appropriate to capturing the heterogeneity of PROs' missions (Figure 5.5 is taken from Laliene and Sakalas, 2014, which in turn cite Leitner and Warden, 2004). This model recognises that different goals and strategies affect the inputs and outputs of the KT process; it also recognises that the processes of transformation of inputs into outputs can be of many types, and that the outputs can also be very diverse in nature, comprising both tangible (financial) and intangible outputs.

Figure 5.5. A more general approach to measure the efficiency of PROs



Source: Laliene and Sakalas (2014)

Additionally, the qualitative evidence from interviews suggests that the traditional quantitative indicators (patents, spinouts, income) do not adequately capture all KT activities of PROs. Many PROs engage in further activities (see Table 5.9). To properly communicate the value they create, PROs should put more emphasis on these activities.

5.7. Conclusions

The findings of this study make a novel contribution to knowledge about PROs' KT engagement and related performance measurement. The extensive bibliometric review for this study includes a systematic investigation of the literature on the performance of PROs and their relevant role in five European countries' public research systems (Germany, France, Italy, Spain, UK) and leading articles on PROs' efficiency. The findings indicate that most of the literature measure PROs' performance using typical measures for outputs with limited indicators, neglecting the full breadth of KT activities that PROs are engaged in. By taking an exploratory approach and thanks to a careful examination of 16 PROs in the UK, this study remedies the above research deficiencies by taking into account the most significant and used forms of KT actors channels: researchers, graduate education as part of research output measurements, most effective and lucrative KT channels of PROs. Furthermore, this approach extends understanding of what is considered KT efficiency and PROs' performance in the sense that what KT managers and scientists believe is *lucrative,* e.g., licensing and contracts, or *effective,* e.g., workshops, conferences, and training programs. This information is not accessible in secondary data; at the same time, it potentially impacts PROs' innovation efforts, performance, business growth, and success (Hult et al., 2004).

Similarly, this study deepens current research on PROs' performance, assuming all PROs are engaged in similar KT activities, take identical approaches, produce similar output, and use the same typical performance measurements without considering their different production functions. This case reveals the need for further research by extending and broadening the analysis of PROs performance. To do so, access to a comprehensive dataset would be an ideal starting point. An initiative that can require an in-depth study of PROs and the collection of additional data in new forms and typologies that comprise the broader scope of determinants of PROs' performance and KT engagement corresponding to their prominent missions. In the same vein, scholars are encouraged to extend the model developed in this study and form generalisable typologies and indicators reflecting PROs' heterogenous missions and research output in the broader geography.

This study offers rich implications for PROs and policy makers. Drawing on insights from previous research, the government's proposed classification PROs' missions in the UK (2022), and Mazzucato's (2018) terminologies, this study extends an existing review of PROs' heterogenous missions.

PROs with technology and knowledge development missions tend to perform the role of market creators and pursue long-term objectives in technology and research development, and PROs with prominent policy support mission and service provision missions tend to perform the role of market fixers by providing vital research information, monitoring- surveillance and scientific advice to contribute consultancy to government and policy makers.

What clearly emerged from the conceptual framework contributes to a better understanding of PROs' performance measurements derived from their KT activities, research outcomes, and their relevance to their mission. In this sense, PROs classified as *technology missions* deliver new technologies, products, and services, focus on longer-term objectives, and create markets. Consequently, these PROs require substantial managerial planning and improved forecasts and methods to fortify infrastructure, set up incubators, and foster spin-offs. In addition, building solid relationships with commercialisation offices is vital for these PROs to obtain high-quality research contracts reflecting the true value of their research and IP rights in collaboration with key actors. Other PROs with *policy support* and *service provision missions* deliver vital research information based on their monitoring and standard-

setting capabilities. These PROs provide policymakers with data and scientific advice and advocate government, society, and businesses to overcome current challenges by providing operational science services and acting as market fixers. The managerial implications for these PROs involve developing consultancy and provision services that are derived from in depth understanding of the context the PROs are operating in and monitoring their performance by applying relevant qualitative and quantitative performance indicators.

Ultimately, the results of this study provide managers and policymakers with an overview of the implications of PROs' mission and performance. Furthermore, the findings help managers realise particular managerial practices, methods, and models that can lead to desired performance concerning PRO's mission. That can enable managers to set up their KT activities differently by having access to performance measurements that are both measurable/quantifiable and descriptive/qualitative, as well as multi-dimensional (economic-cultural and social parameters). Such measures should consider the PRO's interaction with various stakeholders and be characterised according to the organisation's context and the mission it is obliged to fulfill. This study can take a broader approach to generalise the findings so that policymakers set up strategies and establish policies that better support quality research, forecast research funding, and calibrate research relevance to their mission.

Although this study bridges several gaps in the management of KT literature and practices, it has several limitations. First, underdeveloped theoretical standpoints on the implications between PROs' performance and mission in the extant literature have been partially addressed in this study. However, that requires exceptional attention in the future research agenda. Second, the generalisability of the study is limited due to its geographical focus (UK PROs) and limited sample size of 16 PROs. That calls for further research to detect different contexts PROs operate in and more fine-grained categorisations of their KT activities in a broader geography to develop generalisable concepts and performance measures suitable to a broader scope of PROs from different sectors and locations.

Chapter 6. Conclusion

6.1. Contribution

This PhD thesis aims to highlight the intricacies of KT within PROs by formulating three key research questions and addressing them more precisely through three separate research papers. The broader research gap that this PhD thesis has highlighted includes:

(i) How do PROs organise their KT activities? in particular, what factors are associated with different ways to organise their KT management functions?

(ii) What managerial practices are associated with PROs' KT activities within the open innovation paradigm?

(iii) How well do PROs' performance measurements reflect the specificities of their heterogeneous missions and KT engagement?

Drawing on different strands of literature, this PhD thesis establishes new conceptual frameworks, complements the establishing theories, and identifies and integrates gaps in the literature to target a niche gap in each paper. The background and framework of this thesis are established mainly through the overview of the literature on the role, and missions of PROs, their contributions to UK innovation and economic growth, organisational literature on firm theories, open innovation, and performance.

The point of departure of this PhD thesis is the significant role PROs play in providing high-quality applied scientific research, technical consulting, professional advice, and emergency measures in various critical fields. These facts, in turn, reveal PROs' substantial potentiality to promote the commercial exploitation of their research outputs and engage with a broader range of stakeholders to enhance their contribution to the overall economy (Maxwell-Jackson, 2011). At the same time, there is significant government spending on public R&D to cover many calls on emergency needs from government, deliver public service and promote policy development, and carry out ad hoc research to tackle major regional and global challenges (Nurse, 2015). This has led to growing concerns about utilising government R&D spending to ensure the utmost performance and maximise value from PROs' tremendous assets of scientists and engineers and their massive infrastructure. This thesis sheds light on PROs' KT activities and the factors associated with their KT management strategies. Due to the involvement of public

and private actors in innovation processes, and the growing importance of cooperation between PROs and the private sector in stimulating regional economies and strengthening national innovation systems (Guerrero and Urbano, 2017; Vick and Robertson, 2017), PROs need to better position themselves in the interaction with both public and private stakeholders in facing challenges and finding solutions for the government (Kankanhalli et al., 2017). At the same time, there has been a tendency for public organisations to employ strategies that have their locus in a *closed form* of innovation and provide solutions that are restricted within the boundaries of the organisations (Torfing, 2019). The insufficient capacity of the closed form of innovation model to address current and emerging social and policy challenges (Bommert, 2010) on the one hand, and the widespread emergence of OI approaches in the private sector, on the other hand (Gassmann et al., 2010; Ye and Kankanhalli, 2013; Cervantes and Meissner 2014), caused a growing number of PROs chose to adopt OI initiatives in their organisational practices (Bommert, 2010; European Commission, 2017).

However, limited research has focused on PROs' adoption of OI practices. In addition, despite the importance of the performance of public research, there remains a paucity of research on the specificities of PROs' KT engagement and their performance assessment.

Each paper addresses the intricacies of PROs' KT management by targeting specific research questions. The identified research questions are addressed by developing a conceptual framework, drawing on established theories in management, applying inductive and deductive approaches that best fit best the research's purpose, and analysing the purposefully collected data and producing results that contribute to practice and policy.

Paper I explores what drives PROs to vertically integrate or outsource KT management. By extending the theory of firm boundaries to the case of PROs, this paper investigates the conditions under which it is more effective for PROs to vertically integrate KT management or to outsource it to specialist suppliers. In this context, two types of complementarity are defined: *intrinsic complementarity* (when the KT process requires unique tacit knowledge) and *strategic complementarity* (when the knowledge recipients' nature matters to the PRO). The results demonstrate

that the extent of intrinsic and strategic complementarity with core research capabilities determines whether to outsource or vertically integrate KT management. In that sense, the more intrinsically and strategically complementary KT is to research, the more likely KT management will be performed in-house. Furthermore, the results contribute to PROs' managerial and strategic planning in bundling KT with the core activities (research) or unbundling KT through contacting specialised suppliers.

Paper II investigates PROs' engagement in various OI activities and explores to what extent they organise their KT activities within the OI paradigm, as defined in the OI literature. This paper extends the boundaries of OI in management theories to be applied in the PROs context. It provides practical evidence for the underdeveloped definition of *desorptive* capacity initially introduced by Lichtentather and Lichtentather (2009) in outbound OI. In particular, this paper offers insights on organisational capabilities that underpin the successful use of outbound OI in PROs and how and to what extent they apply OI concerning their heterogeneous organisational mission, governance, and managerial strategies. Drawing on a thematic analysis of 26 in-depth interviews, this study suggests that there are two different OI business models for PROs. One OI business model focuses on the commercialisation of knowledge through multiple channels, and the other focuses on the open dissemination of knowledge. Each business model has a different value proposition, organisation of activities, cost-revenue structure, and different organisational capabilities underpin it. This paper provides implications for developing literature on OI business models in the public sector.

Paper III explores the specificities of PROs' missions and KT engagement and the related performance measurement of public research. Building on government's proposed classification of UK PRO's missions (2022) and the terminology of Mazzucato (2018), this paper conceptually distinguishes between two main PROs missions: a) technology and knowledge development mission PROs tend to perform the role of market creators with long-terms objectives, focus on research and development, enhancing existing or developing new technologies, products, services, and other knowledge assets, b) Policy support mission and service provision mission PROs provide crucial research, information, monitoring/surveillance capabilities, data, and scientific advice to inform government policy and they provide operational

science services to government, society, and businesses. Relying on an extensive bibliometric review on performance of PROs, the paper shows that the most prominent literature on PROs' KT engagement and efficiency measures PROs' performance using limited indicators and typical measures for outputs. At the same time, they overlook the full breadth of KT activities that PROs are engaged in. By undertaking an inductive-qualitative approach based on a combination of quantitative data from public sources and in-depth interviews with 16 PROs, this paper provides a novel contribution to performance management literature and extends the understanding of what elements should be considered when measuring PROs' performance. The results suggest that the traditional quantitative indicators (patents, spinouts, income) do not sufficiently capture all the KT activities of PROs. Moreover, the findings suggest that the channels that KT managers and scientists consider *lucrative*, e.g., licensing and contracts, are not the same as those that are considered most *effective*, such as workshops, conferences, and training programs. Notably, the information about effective channels is not accessible in secondary data. The deficiencies in measuring performance call for more contextualised indicators, new forms, and typologies that comprise the broader scope of determinants of PROs' KT engagement and performance measures proportional to their prominent missions.

The results from the individual papers enhance the understanding of the PROs' KT engagement in the following areas: management of PROs' KT activities, the extent to which they have adopted OI practices, and the underlying organisational capabilities for successful outbound OI in line with their heterogeneous missions, as well as intricacies of PROs' missions and KT engagement and the related performance measurements.

6.2 Implications

The results offer important implications for practice and policy. For practice, the results of paper I, provide useful insights for PROs' outsourcing choices in relation to their KT management, and this, in turn, provides a better understanding of those of other types of public and private organisations that have research as their core activity, such as universities and private research institutes. The results imply that the

more intrinsically and strategically complementary KT is to research (the core activity of the PROs), the more likely it is that the KT management to be performed in-house.

This allows the institution to perform its institutional mission (which is benefiting its stakeholders) more effectively. The findings can be applied to PROs in different national settings.

In terms of policy, the findings suggest that the governments should take into account the heterogeneous nature of PROs mission, governance, and the type of knowledge they produce when outlining guidelines for improving their KT management with a wide range of stakeholders.

Paper II contributes to practice by focusing on organisational capabilities that promote successful outbound OI and are particularly appropriate for PROs' business model, where managers can develop components of each organisational capability that boost commercialisation of public research output. For managers, the findings of this study imply management strategies for coordinating practices and allocating resources for improving PROs' performance in OI, which can reinforce the national innovation system. In addition, for policy aiming at promoting OI in PROs, it should consider PROs' different business models when setting targets and evaluating their OI performance.

The results in Paper III make major contributions to practice and policy by highlighting the importance of an in-depth understanding of the context PROs operate, their missions, and the type of performance measurement they apply for assessing the efficiency of their KT activities. Particularly, the study demonstrates that the current performance indicators are limited and do not fully reflect the PROs performance. A better understanding of the PROs' different missions and performance measurements will help managers to set up appropriate strategies for monitoring PROs' KT activities and applying relevant quantitative and qualitative performance indicators that are up-to-date and more calibrated in assessing the research outputs. In addition, effective performance measurement for PROs should be able to evaluate their KT activities in association with their missions. This, in turn, can support a more accurate allocation of resources concerning the PROs' missions, improve their R&D performance, and enable policymakers to set up guidelines, allocate budgets, and design innovation prospects.

6.3. Future research

This PhD thesis sheds light on some aspects of major topics on KT, OI and performance measurement in management literature, which have been underdeveloped, particularly in the public research sector. The present PhD thesis is developed based on a limited number of PROs in the UK and is replicable on a larger scale of PROs in different countries. For example, the variables used in paper I, indicating intrinsic and strategic complementarity developed for this study, are limited to publicly available data sources. Possible areas for future research would be to extend the pattern used in this study and investigate more thoroughly the possible ways to organise in-house KT management in PROs, and their strategic choices that can lead to adopting specific models.

Since most PROs are in their early stages of adoption of open innovation (Ham, et al., 2015), a better understanding of how PROs position themselves in this paradigm and create indicators for assessing PROs performance associated with their OI engagement. This is particularly important as most literature has focused on the private sector, where the aim is to achieve a competitive advantage, while PROs are primarily engaged in innovation to enhance public value and broader impact in society (Konsti-Laakso et al., 2008). Furthermore, the model used in paper II can be applied to other public research systems with a larger number of PROs, less heterogeneity (compared to PROs in the UK), and different institutional frameworks in relation to the central government. This PhD thesis also encourages further research to develop new performance indicators that measure PROs' research output and KT activities concerning their specific missions, the context they are operating, and new KT activities they are expected to practice.

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Appendices

Appendix 3.1. Correlation matrix

	In_house	Government_control	External_interests	Share_journals_applied_	Employees	Age	Health	Agrifood	Environment_protection
Government_control	0.41***	1.00							
External_interests	0.40***	0.44***	1.00						
Share_journals_applied	0.19***	0.31***	0.17**	1.00					
Employees	0.29***	0.19***	0.08	0.10	1.00				
Age	-0.31***	0.05	0.17*	0.28***	-0.25***	1.00			
Health	-0.03	-0.06	-0.11	-0.31***	-0.03	-0.44***	1.00		
Agrifood	-0.09	-0.17**	-0.20***	-0.15**	-0.23***	-0.16***	0.27***	1.00	
Environment_protection	0.05	0.03	-0.15**	-0.11	-0.18**	0.08	-0.36***	-0.14*	1.00
Defense_space	0.26***	0.25***	0.11	0.17**	0.12	0.07	-0.31***	-0.29***	-0.07

Appendix 3.2. Robustness checks

VARIABLES	(a1) In_house	(b1) In_house	(c1) In_house	(d1) In_house
gov_control3	5.507***	6.548***	4.426***	8.579***
	(1.926)	(1.638)	(1.436)	(1.560)
External_interests	5.921+	6.738*		
	(3.832)	(3.826)		
Share_journals_applied	17.252	20.742+		
	(14.054)	(13.251)		
Board_members			0.141	0.048
			(0.530)	(0.531)
Nopatents			9.895***	9.381***
			(3.271)	(3.184)
Employees	-6.886*	-5.445	-2.939	
	(3.792)	(5.408)	(3.453)	
sqempl	1.049+	0.055	0.620	
	(0.669)	(1.131)	(0.725)	
Income_public_funding				-0.033+
				(0.023)
sqIncome_public_funding				0.00003
				(0.000)
Age	-0.118***	-0.134***	-0.085***	-0.144***
	(0.029)	(0.028)	(0.022)	(0.021)
Health_sector	0.748	-3.070	-4.259	-7.651**
	(4.459)	(3.783)	(3.511)	(3.763)
Agrifood_sector	-6.214*	-2.868	0.740	-6.814*
	(3.567)	(3.864)	(3.347)	(3.608)
Sustainability_sector	6.460	4.314	3.698	4.467
	(4.552)	(4.502)	(3.518)	(4.206)
Security_space_sector	19.367***	19.194***	8.277**	8.707**
	(5.209)	(4.981)	(3.865)	(3.935)
T2	-1.961	-2.147	-0.680	-0.737
	(3.620)	(3.442)	(2.774)	(3.022)
T3	0.181	0.219	0.040	-0.202
	(3.853)	(3.726)	(3.115)	(3.333)
T4	2.186	2.233	5.201+	5.732*
	(3.624)	(3.422)	(3.237)	(3.367)
T5	7.026*	6.795*	5.815*	6.393*
	(4.044)	(3.857)	(3.256)	(3.360)
T6	7.387*	7.408*	5.379*	6.200*
	(3.936)	(3.805)	(3.172)	(3.246)
Constant	-5.255	-7.630	-5.340	-0.181
	(8.952)	(8.768)	(6.393)	(7.242)
lnsig2u	5.890***	5.795***	5.345***	5.869***
	(0.591)	(0.551)	(0.659)	(0.553)
Observations	186	174	198	198
Number of ID	31	29	33	33

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In italics: p<0.15

Appendix 4.1. Questions outline used in the interviews

General questions about PRO's infrastructure and funding

- 1.1 How has this PRO's R&D centre been funded? Has been there any changes in the pattern of R&D centre's funding through recent years, do you receive specific funding for your KT activities (since 2011)?

KT activities

- 2.1 What managerial strategies does this PRO apply for its KT activities?
- 2.2 What KT channels does this PRO generally use? What are the most effective channels of knowledge transfer and commercial exploitation of knowledge between PROs and industry?
- 2.3 What KT channels are considered more lucrative? How does this PRO measure its KT activities/ revenue/ outcome?
- 2.4 Does this PRO prefer a specific channel to transfer its knowledge output and commercialise it?
- 2.5 Are there any preferences in terms of which sector they collaborate with? Any specific customer groups? In terms of sector/ size/ region, etc?
- 2.6 Do you customise your KT strategy and research output for a specific customer order? Do you have the capacity for mass production if required by specific customer?
- 2.7 Does this PRO work together with the outside community to meet mutual needs? Does this PRO analyse and interpret changing market demands promptly? Do new opportunities to serve clients are understood rapidly by this PRO? Does this PRO thoroughly grasp the opportunities new knowledge offers to the market?
- 2.8 What type of technology do you often commercialise? Those technologies that are not used internally? Is external technology commercialisation is restricted to relatively mature and proven technologies? Or to non-core technologies.

Open innovation

- 3.1 Has this PRO adopted any concepts or ideas of Open Innovation to be congruent with industry and EU guidelines to governments to improve KT engagement and commercialisation strategies?
- 3.2 Since when have you started complying your KT strategies with Open Innovation framework?
- 3.3 What are the main drivers to adopt Open Innovation in your KT activities?
- 3.4 Do you organise any workshop/ conferences/ training program for your staff to get familiar with the concepts and ideas prominent in open innovation paradigm?
- 3.5 Is there any specific group specialised for learning, adopting and boosting open innovation strategies to improve commercialisation of research output in this PRO? How do they perform this task? (number of staff/ percentage/ in any department engaged with KT)
- 3.6 Is there any incentives for staffs engaged in commercialisation through open innovation paradigm, due to their extra effort and performance or for taking initiatives?
- 3.7 Do teams/groups revise their thinking as a result of group discussions or information collected? Do these lessons learned available to all employees?

- 3.8 What are the main constraints this PRO encounter in terms of open innovation activities?
- 3.9 Do you have any specific strategy if competition becomes heavier and profit margin becomes lower in your main market? what actions do you take to compete? (Competition related to Open Innovation)

Third parties

- 4.1 Does this PRO use KTOs or other type of third parties to commercialise its research output?
- 4.2 What is the role of intermediaries (if any)? Do they have an effective role in transferring knowledge from PRO to other sectors/Parties?

Learning process

- 5.1 Does this PRO organise any type of activities in terms of workshops/ conferences/ training courses for its employees to: encourage KT and update the latest and effective strategies applied in other sectors or market to boost KT engagement?
- 5.2 How do you organise/structure/update your KT activities to comply with the latest changes in the market and demand? Is there a group of people who decided how and when it is appropriate to take on a new strategy?
- 5.3 Are employees clearly aware of how the KT activities should be performed? Do they share a common understanding of commercialisation of research output? Do employees in this PRO meet periodically to discuss consequences of market trends and new product development and best strategy to commercialise the new output?
- 5.4 Are people/staff rewarded for learning in this PRO? What about leaders?
- 5.5 Does this PRO analyze and interpret changing market demands promptly? Do new opportunities to serve clients are understood rapidly by this PRO? Does this PRO thoroughly grasp the opportunities new knowledge offers to the market?
- 5.6 Does this organisation constantly review how to better exploit its knowledge output?
- 5.7 Is the PRO CEO or equivalent monitored on the PRO's commercialisation performance?

Collaboration with firms

Firms usually seek linkage to PROs to substitute their innovative activities rather than to complement their in-house innovation, and PROs are not always paid for these knowledge interactions. What are general drivers of firms that collaborate with this PRO(firms' knowledge capabilities, benefiting from the provision of services or PROs' infrastructures, etc.?)

- 6.1 Does this PRO collaborate with SMEs?
- 6.2 How does PRO create contact with SMEs?
- 6.3 How SMEs create contact with this PRO?
- 6.4 Is there any specific dstepartment responsible for marketing and commercialising of PRO's research output with SMEs?
- 6.5 Does it have any specific strategy to approach SMEs in terms of SMEs' financial and infrastructure constraints?
- 6.6 How does this PRO comply itself with high tech SMEs with higher flexibility in terms of KT governance, contracts, skills, etc,…

- 6.7 How does this PRO comply itself with low tech SMEs with limited technology, IP knowledge, etc,…?

The following questions were emailed to each PRO after the interview in the form of a follow-up questionnaire

Constraints to OI:

- 7.1 Did your organisation encounter any of the following constraints in the last 8 years?

    - Lack of market demand (Low purchasing power of customer),
    - Lack of skilled manpower,
    - Too expensive manpower,
    - Lack of quality management personnel,
    - Problems with administrative regulations,
    - Problems with infrastructure (e.g., electricity, gas, communication, etc.)
    - High interest rates
    - Problems with access to finance (other than interest rates)
    - Lack of knowledge in implementing new form of technology
    - Lack of knowledge in implementing new form of organisation
    - Difficult to protect intellectual property
    - Did not have any open innovation plan

- 7.2 What was/were the main constraints you think in terms of open innovation activities in your organisation during last 8 years?

    - High cost of open innovation
    - Lack of financing
    - High economic risk
    - Organisational rigidities
    - Government regulations
    - Lack of customers' responsiveness
    - Lack of knowledge to use new technology
    - Lack of information on market
    - Did not have any innovative plan
    - None of the above

- 7.3 If competition becomes heavier and profit margin becomes lower in your main market, what actions do you take to compete? (Select more than one)

    - Increase quality of product/service
    - Increase product differentiation
    - Look for market niches (demand)
    - Increase marketing activity
    - Reduce costs of production
    - Forming strategic partnerships
    - Reduce prices (prices of products/services)
    - Increase working hours
    - Look for other foreign markets

    - Reduce production

- 7.4 What percentage of this PRO's customers does comprise SMEs? What percent of PRO's income comes from SMEs?

Non-financial impact

- Number of knowledge transfer opportunities and invention disclosures communicated to Technology Transfer Office, Industrial Liaison Office, Innovation Hubs and Contract Offices or their equivalent
- Number of collaborative research projects
- Do you carry out any research through informal agreements? Y/N
- Do you carry out any research through formal agreements? Y/N
- Number of collaborative projects (only complete if the answer to at least one of the previous questions is "Yes")
- Business/community engagement -number of revenue generating agreements with commercial and non-commercial organisations to exploit the research carried out by the Public Sector Research Organisation
- Number of agreements with commercial organisations, new in year
- Cumulative portfolio of agreements with commercial organisations
- Number of agreements with non-commercial organisations, new in year
- Cumulative portfolio of agreements with non-commercial organisations
- Could you please estimate the percent of turnover (annual sales) coming from new or significantly improved products or services (those you consider that falls under open innovation category) in the last------- years?
- The above questions are mainly aimed at providing a "snap shot" of knowledge transfer activities in PROs. To help us develop a better understanding of the long-term impact of PROa we are interested in any assessments you have carried out of the long-term impact of your knowledge transfer activities. We would therefore be grateful for a short summary (max 300 words) of any such assessments that you have carried out.