# Measuring and Evaluating the Economic Impact of Publicly funded Research Centres

by

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The author hereby declares that except where duly acknowledged, this thesis is entirely his own work and has not been submitted for any degree in the National University of Ireland, or in any other University.

This thesis is dedicated to the memory of Lorna Brosnan,

always loved, never forgotten, forever missed.

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# Abstract

The aim of this thesis is to develop and test frameworks and tools to measure and evaluate the economic impact of publicly funded research centres, thus addressing calls from policymakers for greater accountability and justification for investment of public funding towards research activities. In addition to developing impact measurements tools, the Research Impact Index (RII) is tested using a Science Foundation Ireland (SFI) funded research centre. Testing the tool facilitates the identification of strengths and weaknesses of the framework and tools before large scale roll-out of the RII.

The development of robust tools and frameworks to measure and evaluate the economic impact of publicly funded research centres requires conceptual clarity on research impact. Research impact can mean different things to different people. Therefore, this thesis offers conceptual clarity on what constitutes an impact through a thematic analysis exploring the meanings and conceptualisations of research impact across the research sector in Ireland.

Following this, the thesis contributes to the development of a novel framework for measuring the economic impact of publicly funded research centres. The IMPACTS framework (**I**mpact **M**easurement and **P**erformance **A**ssessment of **C**entres for **T**echnology and **S**cience) adopts a systems-based approach to research impact assessment which views research centres as important cogs within an innovation system. An important new, and to date underappreciated, element in this framework is the inclusion of a research centre's contribution to the overall innovation system, while simultaneously identifying the strength of the system is an important input and platform for a research centre's success.

The study uses data generated though two survey instruments, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire. The questionnaires were designed to facilitate the assessment of research centre impact that minimises common methodological challenges, such as issues of attribution, additionality and time lags. The quantitative and qualitative data from the questionnaire will be combined to construct a multidimensional index to measure and evaluate research centre impact.

The development of the IMPACTS framework and Research Impact Index (RII) will result in a step change in measurement of the performance of publicly funded research centres, enabling them to optimise structures and ways of working to maximise economic impact. In addition, it will help funding bodies select and oversee funded centres to increase the efficiency in conversion of investments into impact for industry partners and the regional and national economy. Findings will be disseminated to science policy practitioners, funding bodies and research centres management teams.

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# Chapter 1: Introduction – Thesis Rationale, Objectives and Motivations

## 1.1 Research Aims and Objectives

The central aim of this thesis is to develop robust frameworks and tools to measure and evaluate the economic impacts of publicly funded research centres, thus addressing the demands from policymakers, funding bodies and the public for greater accountability when allocating public funding for research activities. Three main research questions are set out to provide a framework to study research centre impact.

1. What is meant by research impact?
2. How does research impact occur?
3. How can research impact be measured?

The key objectives of this thesis will be discussed briefly in relation to the central theme and research questions outlined above. The first objective aims to provide conceptual and methodological clarity in relation to the term research impact. In recent years, the impact agenda has gained considerable traction amongst academic and policymaking circles. However, impact can mean different things to different people. The lack of conceptual clarity surrounding research impact limits policymaker's ability to develop and implement effective policies to maximise the impact generated through research activities. This thesis addresses these issues by developing robust and flexible frameworks and tools to measure and evaluate the economic impact of publicly funded research centres, thus minimising the likelihood of research impacts being overstated or overestimated.

The second objective addresses the second research question related to understanding the research impact process. The aim is to develop a multidimensional, systems-based framework to assess the economic impacts of publicly funded research centres, the **I**mpact **M**easurement and **P**erformance **A**ssessment of **C**entres of Technology and **S**cience (IMPACTS) framework. The framework aims to address key conceptual and methodological challenges research impact assessment by offering a unique approach to measuring and evaluating the economic impacts of publicly funded research centres.

The final two objectives address the third research question related to measuring research impact. The availability of data has been identified as a key challenge when conducting research impact assessments (Barge-Gil and Modrego 2011, Guthrie et al. 2018). Therefore, the third objective of this thesis is to develop survey instruments that may be used to collect data. The systems-based approach adopted in this thesis requires data collection across two actors in innovation systems, research centres and industry partners. Therefore, two questionnaires were developed in this thesis to measure the impact of publicly funded research centres, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire.

Finally, the fourth objective of this thesis aims to test the feasibility of the IMPACTS framework through the development of a novel benchmarking tool, Research Impact Index (RII). This tool may be used by funding bodies, evaluators and research centres to measure and evaluate the performance of research centres across several impact dimensions.

The rest of the introductory chapter is organised into six sections. Section 1.2 presents the motivation and focus of this study. Section 1.3 discusses the importance of understanding the policy context. Section 1.4 presents the research methods and methodology. Section 1.5 the conceptual, methodological and policy contributions of this thesis. Section 1.6 outlines the structure of this thesis.

## 1.2 Motivation of the research

Publicly funded research has been identified as a key mechanism for enhancing economic growth, competitiveness and innovation at national (Guellec and Potterie 2000, Schildt, Keil, and Maula 2012), regional (Hewitt-Dundas and Roper 2011), industrial (Beise and Stahl 1999, Arundel and Geuna 2001), and firm (Roper, Hewitt-Dundas, and Love 2004) levels. However, during the last thirty years publicly funded research has become subject to increasing accountability (Martin 2011). The impact agenda refers to the shift in research policy from delivering scientific excellence towards demonstrating broader economic and societal impacts that have real-world impact. This agenda has placed accountability and justification for public funding at the forefront of research policy, both in Ireland and internationally.

While various research identifies the benefits of publicly funded research to the broader economy (Buxton et al. 2008, Donovan and Hanney 2011, Guthrie et al. 2013, Ofir et al. 2016, Guthrie et al. 2018), the importance of investment in other areas, such as education and healthcare may be considered more immediate and more politically attractive. As such, policymakers are increasingly stressing the importance of accountability and the need for researchers and research centres to provide justification for the allocation of public funds for research activities. Kearnes and Wienroth (2011, p.157) argue

> "research policy has been broadly reframed emphasising notions of 'value for money', democratic oversight and accountability" and that "[p]ublic research funding is … increasingly understood as a strategic investment where state economic and regulatory strategies are oriented towards maximising returns" (p.157).

This shift in research policy was initially met with much scepticism amongst the academic community. Several authors highlighted the potentially negative unintended effects of the impact agenda including an infringement on academic autonomy (Chubb and Reed 2017), intensification of neoliberalist political agenda (Holbrook 2017), rewarding short-termism (Ma and Ladisch 2019), and emphasising commercially-driven research at the expense of scientific quality (Jones, Manville, and Chataway 2017).

Furthermore, the rise of the impact agenda, coupled with increased competition for scarce public resources, provides a perverse incentive for researchers and research centres to overestimate, or at least overstate the likely short- and medium-term impact of research, in their enthusiasm to justify its importance (Molas-Gallart et al. 2002). This issue is accelerated by the ambiguity around suitable frameworks and tools developed to measure and evaluate the impacts of publicly funded research.

The rationale for choosing the research centre as the unit of analysis was threefold. Firstly, research centres play significant roles in the Irish and European Innovation Systems, yet what they do is, to a large extent, undocumented and misunderstood (Arnold, Clark, and Jávorka 2010). While much research has explored the private and public returns of universities research (Mansfield 1991, Beise and Stahl 1999, Cohen, Nelson, and Walsh 2002, Zucker, Darby, and Armstrong 2002, Perkmann et al. 2013), studies on the impact of research centres are more rare (Hallonsten 2017).

Research centres are “a sector of organizations that undertake research and development but are not part of either the academic or the private sector” (Hallonsten 2017, p.2). These organisations typically comprise non-academic, publicly owned R&D organisations that complement universities and private-sector firms and are typically called research institutes. Arnold et al (2010) define research centres broadly as organisations “which as their predominant activity provide research and development, technology and innovation services to enterprises, governments and other clients”. This distinguishes them from universities, whose primary mission is education, and from enterprises that produce goods and many types of services.

While universities, for the most part, focus on fundamental research and teaching, research centres generally focus on more applied research activities. However, the activities of universities cannot be neatly differentiated from research centre activities as there is increasing overlap in activities between the two institutions. Research centres and universities are strongly linked through joint research projects, doctoral training, co-publications, joint appointments and in some cases, co-location (OECD 2016). In Ireland, many research centres are embedded within universities and have shared staff, students and resources, such as knowledge transfer offices.

Secondly, the majority of research impact assessment (RIA) frameworks adopt the project or programme as the unit of analysis. However, RIA at the project level may not be sufficient when exploring the impact of the total sum of research activities (Greenhalgh et al. 2016). It may not be possible to simply aggregate the impacts from individual projects into an overall research impact as synergy effects, multiple funding sources and difficulties in attributing research impact to a project may prove extremely problematic.

Thirdly, the research centre landscape in Ireland is in its relevant infancy yet is developing rapidly. SFI Research Centre Centres were established in 2013, with seven research centres receiving public funding. Five more centres were established in 2015, with a further four additional research centres announced in 2017. SFI invested €355 million to set up the initial twelve research centres with a further €190 million generated from industry partners. (Indecon 2017). Therefore, the significant investment of public funding into the SFI Research Centre Programme requires robust tools to measure the research centre impact to ensure accountability and provide justification for public funding.

While there is a consensus that publicly funded research provides many benefits, ambiguity exists in identifying robust tools and frameworks to measure research impact, suitable indicators and metrics to capture the broad range of impacts generated through research activities and the opportunity cost associated with various methodological approaches. Despite the broad range of channels through which knowledge is exploited and commercialised, in most countries, the statistical infrastructure for gauging the effectiveness of these channels remains limited (OECD 2013, p.26).

## 1.3 Policy Context

This section traces research policy in Ireland from its early developments towards the most recent developments in Innovate2020 (DJEI 2015). Research policy in Ireland was significantly underdeveloped relative to other developed economies in Europe during the 1980s and 1990s. It was only in 1996, following the publication of the White Paper on Science, Technology and Innovation that the Irish Government first made focused efforts on developing a knowledge-based economy. In 2000, the production of the *National Development Plan 2000-2006* (Government of Ireland 2000), set out an ambitious development strategy for the country over the period. The economic conditions in the country during the formulation of the document were much different from those evident during previous National Development Plans (NDPs), which were constrained by budget deficits and high levels of unemployment.

The NDP 2000-2006 committed to investing €51.5 billion, of which some € 2.5 billion was allocated to research, technology, development and innovation (RTDI). Under the NDP 2000-2006, unlike previous NDPs, one of the key objectives was to promote basic research as a means of increasing innovation and competitiveness in the economy. Third-level and state institutes, primarily focused on basic research as opposed to applied research, were allocated €698 million. The funding was provided to increase the human potential in research, science and technology and to strengthen the research and science capability of higher education institutions. These actions were taken to facilitate an increase in university-industry collaboration and to develop a research and development (R&D) culture to all sectors of the economy. A central part of the additional investment went to Science Foundation Ireland (SFI), which was established in 2000.

Initially, SFI launched six Centres for Science, Engineering and Technology (CSETS) across key strategic areas. The initial grants ranged from €1 to €5 million per year for a five-year period. CSETS were established to increase public-private collaborations across the innovation system in Ireland. The aim was to deliver several economic impacts including fostering new start-up companies, attracting foreign direct investment and increasing education, training and career opportunities in science and engineering fields.

In 2006, the Irish Government followed up on the success of the NDP 2000-2006 by publishing the *Strategy for Science, Technology and Innovation 2006-2013* (SSTI 2006). The SSTI 2006-2013 ambitiously set the objectives of “creating a knowledge-based economy, internationally renowned for excellence in research, and at the forefront in generating and using new knowledge for economic and social progress, within an innovation-driven culture” (SSTI 2006, p.8). The document highlighted the need for Ireland to achieve recognition as a world leader in the area of Science, Technology and Innovation (STI). Under the plan, success is measured by

> “increased participation in the sciences, increased numbers of people with advanced qualifications, enhanced contribution by research to economic and social development, transformational change in the quality and quantity of research, increased output of economically relevant knowledge, increased trans-national research activity, an international profile for Ireland and greater coherence and exploitation of synergies nationally and internationally” (SSTI 2006, p.8).

SSTI (2006) aimed to increased R&D investment to 2.5% of GNP by 2010, in line with EU targets, with two-thirds of this investment coming from industry. The plan identified several deficiencies in the research sector including “in the areas of awareness, identification, evaluation, capture, protection and commercialisation of ideas”. As such, enhancing knowledge transfer from public research institutes to private enterprises was identified as a key policy challenge.

In response to this report, SFI stated that its target would be to “initiate centres, institutes and teams that establish research links between Irish research institutions and industry, attract or substantially increase the RDI investments of at least 10 foreign-owned firms in Ireland and produce at least five significant research collaborations between research institutions and indigenous companies” (Science Foundation Ireland 2009).

Since 2012, policymakers have adopted a more focused approach to public funding of research and innovation activities. Ireland’s Research Prioritisation Strategy aims to focus most competitive funding to areas deemed likely to yield the greatest economic and societal impact. The Prioritisation Strategy focuses on 14 Priority Areas[1] and in six underpinning technology platform areas that are adjudged to generate the highest potential economic and societal impact.

The Government highlighted networking, linkages and clustering as essential mechanisms to improve the efficiency and effectiveness of research and technology centres. The development of standardised key performance indicators and metrics and associated targets for measuring and evaluating the economic impact of publicly funded research centres have been identified as a key policy objective.

The SFI Research Centre Programme was launched in 2012. To date, sixteen research centres have been established through a combination of funding from Science Foundation Ireland and industry partners. The activities of the funded centres align closely with strategic areas outlined in Research Prioritisation Strategy. Initially, seven research centres received funding from SFI. An additional five centres were funded in 2014 and began operations in 2015. In 2017, four additional centres were funded. The National Development Strategy 2018-2027 has set out the objective of scaling up both

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[1] Future Networks, Communications and Internet of Things; Data Analytics, Management, Security, Privacy, Robotics and Artificial Intelligence (including Machine Learning); Digital Platforms, Content and Applications, and Augmented Reality and Virtual Reality; Connected Health and Independent Living; Medical Devices; Diagnostics; Therapeutics; Food for Health; Smart and Sustainable Food Production and Processing; Decarbonising the Energy System; Sustainable Living; Advanced and Smart Manufacturing; Manufacturing and Novel Materials; Innovation in Services and Business Processes

SFI and Enterprise Ireland (EI) research centres. The aim is to support up to twenty SFI Research Centres.

*Innovate2020* (DJEI 2015) aims to increase the commercialisation of publicly funded research, using available commercialisation and technology transfer programmes. The strategy highlights the importance of developing new impact metrics for commercialisation of publicly funded research and has set targets for both outputs and impacts commensurate with increased public investment. The new metrics aim to move beyond traditional measures such as counting licences and spinouts towards measuring the quality and longer-term economic impact of these outputs.

However, limitations centred on ambiguity and a lack of clarity surrounding specific targets exist. While the key objective of government targets is ideally focused on research impact, the actual targets are more specifically focused on research outputs and outcomes. For example, the government has targeted the establishment of 40 spin-out companies. However, the number of spin-offs reveals very little about impact generated by a spin-off. In order to capture research impacts, as opposed to outputs, information regarding the number and quality of jobs created, the life span of the spin-off and financial information such as sales, turnover, profits and value-added would need to be gathered.

## 1.4 Contributions of this Thesis

The rapid development of the impact agenda coupled with the lack of consensus surrounding suitable definitions, frameworks, tools and indicators to measure and evaluate the impacts generated through research and innovation activities points to a clear research agenda. This thesis contributes to the research agenda by developing robust tools and frameworks to measure and evaluate the economic impact of publicly funded research centres.

The four main contributions include:

- A thematic analysis of meanings and conceptualisations of research impact across research sector in Ireland.
- The development of the IMPACTS framework, a systems-based framework which traces the process of research impact, from initial investments to economic and societal impacts.
- The development of two survey instruments used to gather data on key metrics and indicators of impact across research centres and their industry partners
- The construction and feasibility testing of the Research Impacts Index (RII), a multidimensional index to measure the economic impacts of publicly funded research centres.

### 1.4.1 Thematic Analysis of Meanings and Conceptualisations of Research Impact across Research Sector in Ireland

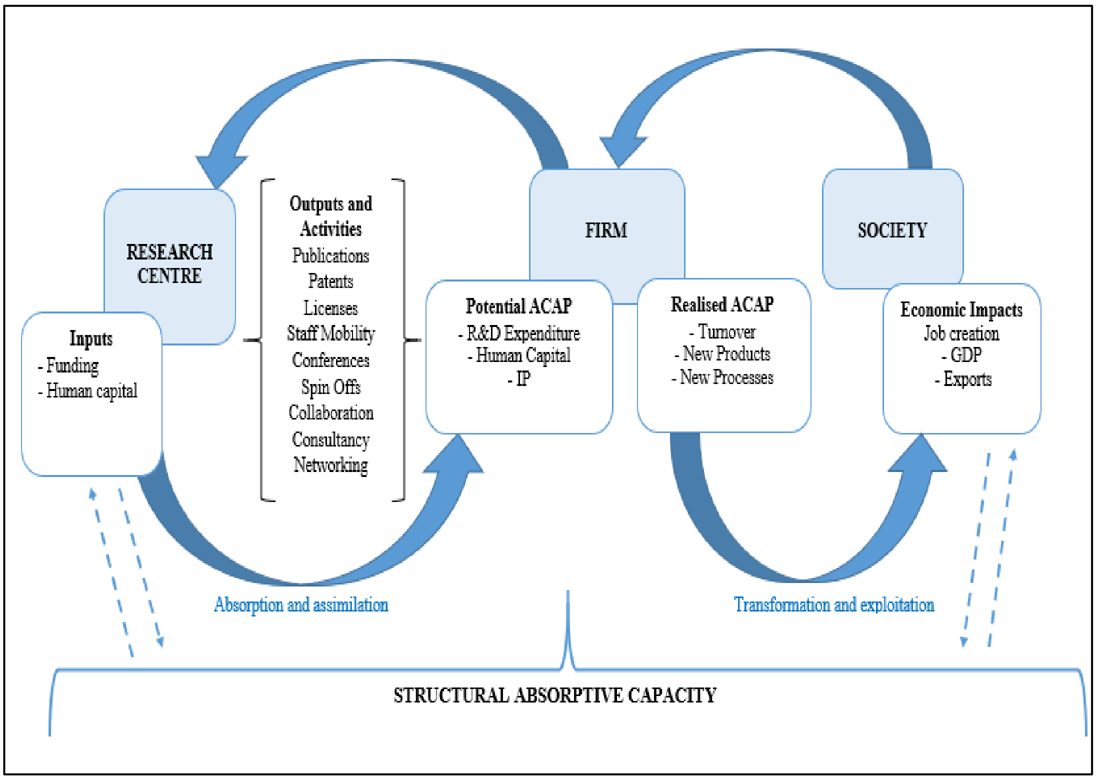
The first contribution of this thesis is a thematic analysis exploring the meanings and conceptualisations of research impact across the research sector in Ireland. The thematic analysis aims to gain an understanding of what constitutes 'impact' amongst key stakeholders across the Irish research system, identify indicators and metrics to measure research impact and assessing whether formal impact strategies have been developed across the research sector.

Thirteen semi-structured interviews with key stakeholders across the Irish research sector system were conducted to gain an insight into different perspectives on 'impact'. Following a detailed thematic analysis of the interview transcripts, two overarching themes were identified. The themes highlight significant opportunities and challenges facing funding bodies and research centres in the drive towards the research impact agenda. The themes identified are i) Meanings and conceptualisation of research impact ii) System-level effects of research impact agenda.

### 1.4.2 Development of the IMPACTS framework

The second contribution of this thesis is the development of the IMPACTS framework presented in Chapter 5. The framework is grounded in a systems-based approach to RIA, viewing research centres as important actors within an innovation system which complement private businesses and universities in generating new knowledge, innovation and research impacts. An important new, and to date underappreciated, element of the framework is the inclusion of a research centre's contribution to the overall innovation system, while simultaneously identifying the strength of the system is an important input and platform for a centre's success. The IMPACTS framework is presented diagrammatically in Figure 1.1.

**Figure 1.1 IMPACTS Framework**




A detailed discussion of the theoretical and conceptual underpinnings of the IMPACTS framework is outlined in Chapter 5. The framework offers a unique methodology for measuring and evaluating the economic impacts of publicly funded research centres. The framework adopts a mixed-methods approach to research impact assessment (RIA) based on a combination of primary and secondary data. The primary and secondary data will be combined to generate a Research Impact Index (RII).

The RII may be used to benchmark research centres against each other or to generate reporting indicators to enhance management processes, funding decisions and monitoring mechanisms for research centres and funding bodies. The development of a flexible, robust framework comparable across a range of research centres, technological readiness levels (TRLs), economic sectors and countries will provide greater transparency and comparability in assessing research impacts and reduce the likelihood research impact being overestimated or overstated.

### 1.4.3 Development of Survey Instruments

The third contribution of the thesis is the development of two questionnaires, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire. The questionnaires were designed to facilitate assessment of research centre impact that minimises the issues of attribution, additionality and time lags inherent in RIA exercises. The data from the questionnaires will be combined to construct a multidimensional index to measure and evaluate research centre impact.

### 1.4.4 Development and Feasibility Testing of the Research Impact Index (RII)

The fourth contribution of the thesis is the development of a multidimensional index to measure and evaluate the economic impacts of publicly funded research centres, the RII. Following construction, the RII is tested using a Science Foundation Ireland (SFI) funded research centre. Testing the tool facilitates the identification of strengths and weaknesses of the framework and tool before large scale roll-out of the RII. The development of a flexible, robust tool comparable across a range of research centres, which considers objectives, research activities and technological readiness levels (TRLs) will provide greater transparency in RIA exercises.

The RII measures and benchmarks the economic impacts generated by research centres through four composite sub-indices:

i) RII input sub-index
ii) RII impact sub-index
iii) Overall RII score and
iv) Impact-efficiency ratio (IER).

The primary objective of the RII is to measure the economic impacts of publicly funded research centres. However, the generation of economic impacts from research activities are often constrained by the issues of time lags and uncertainty, particularly for basic research, where projects may take much longer to achieve impact – sometimes many decades (Mansfield 1991, Salter and Martin 2001, Toole 2012, Haskel and Wallis 2013). As such, we include a taxonomy of research impacts to capture impacts at different stages of the research process.

The IMPACTS framework categorises research impacts into four categories:

- Scientific impacts contribute to world-class scientific excellence based on traditional measures such as bibliometric and scientometrics indicators.
- Technical impacts contribute to intellectual property outputs including patents, licenses, prototype development etc.
- Human Capital impacts contribute to the training and development of world-class talent and researchers, mobility of researchers into the private sector.
- Economic impacts contribute to the development of new products and services, increased productivity, job creation and foreign direct investment (FDI).

The classification of impact into the four dimensions allows evaluators to identify short, medium- and long-term impacts which reduce the issue of time lags, since the time lag associated with basic research is much longer than commercially-driven research. As such, when evaluating research centres at lower technological readiness levels (TRLs), decision-makers will perhaps weight scientific and technical impacts more heavily as these may be achieved in the short term and may provide an indication of potential future economic impacts.

However, metrics-based approaches to research evaluation suffer from many limitations including they may be easily gamed, difficulties measuring intangible impacts and ability to identify unexpected impacts. Several authors have cautioned against an overreliance on metrics-based approaches for research impact assessment. For example, Hicks et al. (2015) assert "quantitative evaluation should support qualitative, expert assessment". As such, a recommendation stemming from this thesis is that the results of the RII should be combined with qualitative impact statements before informing funding decisions, guiding strategic decision-making and enhancing learning processes.

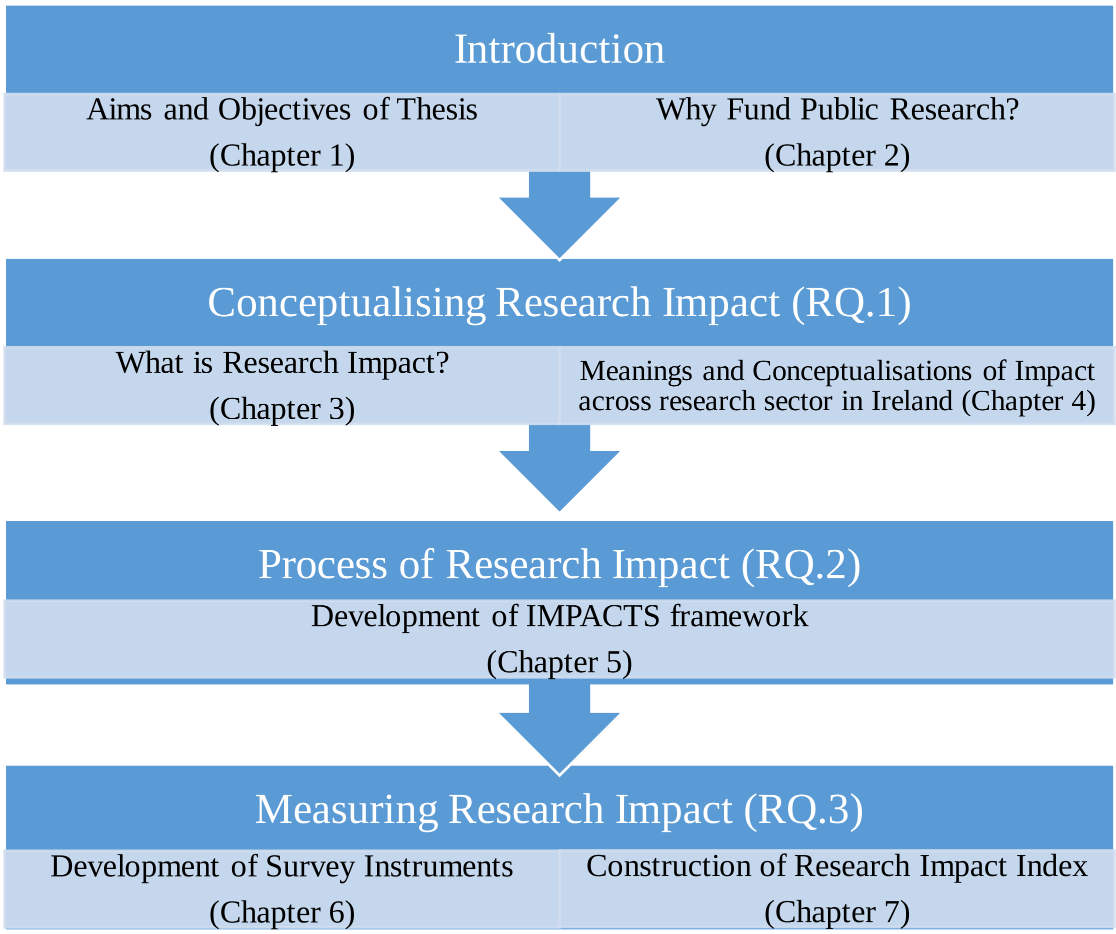
The impact statements allow research centres to provide rich and detailed information on specific topics or events, as well as related and contextual conditions. An advantage of the impact statements is research centres are already familiar with the tool as a method of demonstrating and communicating the impact of their research. SFI-funded research centres are required to provide evidence of impacts generated through research activities from a list of eleven impact statements. Each research centre is required to rank at least one, and up to five, research impacts. Furthermore, in-depth impact narratives are required to provide support for the impact statements selected.

The combination of quantitative and qualitative methodologies provides a novel approach to research impact assessment (RIA). This approach provides a robust measurement tool that allows funding bodies to benchmark research centre across several impact categories considering context-specific factors such as objectives of the centre, research discipline, life cycle of research centre, technological readiness levels.

## 1.5 Structure of this Thesis

The main structure of this thesis is set out in Figure 1.2. The contributions of the thesis and how they relate to the aims and objectives are outlined.

**Figure 1.2 Main Structure of Thesis**

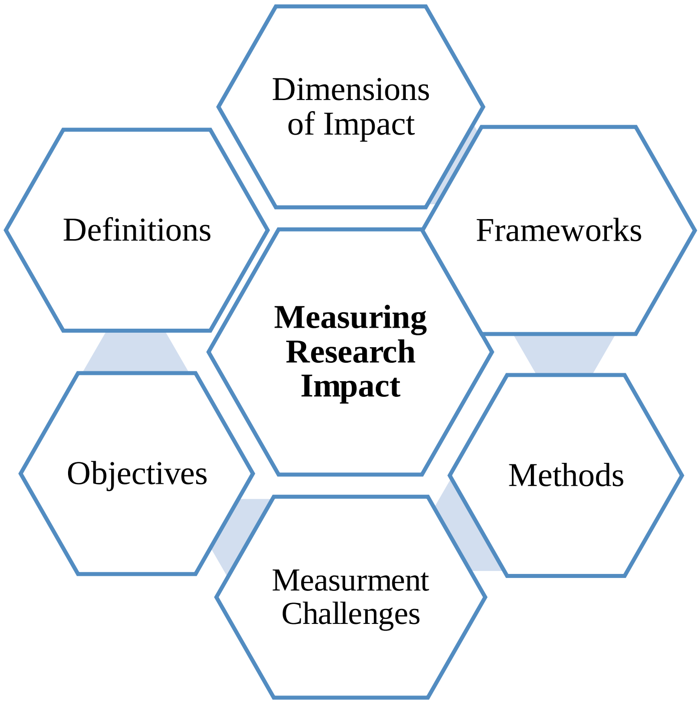


The rest of this thesis is structured as follows. Chapter 2 outlines the theoretical considerations on the topics of research, innovation and publicly funded research centres. The chapter discusses the relationship between knowledge, research and economic growth, presents the rationales for investing in publicly funded research centres and explores whether public funding for research complements or substitutes for private investment in research activities. The findings highlight key factors that may influence a research centre's ability to deliver economic impacts.

Chapter 3 provides a detailed analysis of the literature on research impact assessment including outlining the diverse definitions of research impact, methodologies available for measuring research impacts, channels through which impacts may be generated and current frameworks used to conceptualise the process of research impact. Furthermore, the conceptual and methodological challenges facing evaluators and practitioners when measuring and evaluating the impact of investments in research activities are presented.

This chapter also discusses the methodological tools available to measure and demonstrate impacts from research activities. A comprehensive review of the current RIA frameworks available to measure research impact is conducted. The aim of the literature review is to identify the strengths and weaknesses of current RIA frameworks to inform the development of the IMPACTS framework. Figure 1.3 highlights the key factors that must be considered when measuring and evaluating the impacts of publicly funded research.

**Figure 1.3 Measuring Research Impact**




Source: Compiled by Author

Chapter 4 presents a qualitative analysis of the meanings and conceptualisations of research impact across the research sector in Ireland. The aim is to assess how the diverse conceptualisations of research impact is driving the research sector in Ireland. The research method focused on a thematic analysis of qualitative data collected via thirteen semi-structured interviews with key stakeholders across the research sector in Ireland.

Chapter 5 presents the development of the novel framework to measure the economic impacts of publicly funded research centres, the IMPACTS framework. The theoretical and conceptual underpinnings of the IMPACTS framework are presented. The IMPACTS framework adopts a holistic, systems-based approach to RIA, the framework viewing research centres as important elements within an innovation system. As such, the impact capacity of a research centre will be influenced by both the absorptive capacity of their external partners and the strength of the innovation system which it is embedded within. The chapter concludes the presentation of the IMPACTS framework and discusses future steps in implementation and operationalisation.

Chapter 6 outlines the fieldwork undertaken in the development of two survey instruments. The survey instruments were constructed to gather data required to test the IMPACTS framework. The process of designing, piloting and testing of the survey instruments is outlined. Furthermore, descriptive statistics from the testing of the two questionnaires is presented. While the descriptive statistics don't provide evidence of impact in themselves, they do provide a useful overview of these elements of the innovation system.

Chapter 7 presents the process undertaken in the formulation of the multidimensional index to assess and benchmark research centre performance, the Research Impact Index (RII). This chapter makes a key contribution to the literature on RIA by demonstrating how composite indicators may improve our understanding of measuring impacts generated by publicly funded research centres. The RII is a novel tool used to test and operationalise the IMPACTS framework outlined in Chapter 5. The tool is tested on an SFI-funded research centre to verify its suitability and usefulness for measuring and evaluating the economic impact of publicly funded research centres.

Chapter 8 provides a summary of the findings of this thesis, identify strengths and limitations of the research findings and propose some fertile ground for future research in the area. Furthermore, the implications of these findings on the future directions of Irish research policy are considered.

# Chapter 2: Knowledge, Growth and Public Investment in Research

Chapter 2 surveys the science, technology and innovation literature to determine the factors that have been found to influence research impact. These factors were important considerations for the development of the IMPACTS framework and Research Impact Index (RII) outlined in Chapter 5, 6 and 7. This chapter is comprised of six sections and is structured as follows. Section 2.1 considers the relationship between knowledge, innovation and economic growth. This section highlights the importance of generating new, economically useful knowledge for understanding and explaining economic growth, competitiveness and innovation at national, regional, sectoral and firm levels. It is argued that, from an economics perspective, the production of the knowledge is important to the extent to which it drives economic growth, fosters innovation, and contributes to improvements in the standard of living.

Section 2.2 outlines the economic rationale for investment in publicly funded research centres. The traditional justification for government investment in publicly funded research is related to market failure associated with knowledge production. This section discusses how the characteristics of knowledge contribute to suboptimal production levels by private businesses. Therefore, the neoclassical perspective argues that government investment in publicly funded research is required to increase knowledge production to the socially optimal level.

The neoclassical economics perspective influenced the development of the linear model of innovation to illustrate the process of transforming initial investments in research into economic and societal impacts. However, Section 2.2.1 outlines the limitations of the linear model of innovation. These limitations coupled with the changing nature of science and technology has led to the emergence of alternative perspectives on knowledge production and innovation.

Section 2.3 presents the evolutionary perspective of innovation, which highlights the complex, dynamic, interactive nature of the innovation process. This section argues that the evolutionary perspective provides a more satisfactory explanation of the processes through which publicly funded research contributes to innovation and economic growth. The objective of this section is to identify and incorporate the key features of evolutionary models of innovation into the novel framework developed in this thesis to measure and evaluate the economic impact of publicly funded research centres.

Section 2.4 presents the literature on the relationship between public and private investment in research activities. This section discusses whether public funding for research activities complements or substitutes for private investment. Section 2.5 concludes the chapter and outlines the next steps involved in the thesis. The theoretical literature highlighted in this chapter provides the theoretical underpinnings of the IMPACTS framework outlined in Chapter 5, the development of the two survey instruments presented in Chapter 6 and the construction of the Research Impact Index (RII) in Chapter 7.

## 2.1 Knowledge as a Driver of Economic Growth

### 2.1.1 Models of Economic Growth

Knowledge is increasingly recognised as a driver of economic growth at national, regional and local levels. However, Penrose (1959, p.77) noted, that "economists have, of course, always recognized the dominant role that increasingly knowledge plays in economic processes but have, for the most part, found the whole subject of knowledge too slippery to handle with even a moderate degree of precision".

Early neoclassical models of economic growth emphasised the role of capital accumulation, as opposed to knowledge, as a driver of economic growth and productivity. Under the Solow-Swan model, economic output is produced by the amount of capital, the amount of labour and labour productivity. Economic growth is achieved through increases in labour productivity and output per capita assumed to grow at an exogenously given rate of technical progress.

Solow (1956) uses a growth accounting framework to provide an estimation for the rate of technological progress. Total Factor Productivity (TFP), or the Solow residual, is often regarded as a measure of technological progress. TFP refers to the amount of economic growth that cannot be attributed to increased labour or capital accumulation. As such, since Solow (1956) assumes that TFP is exogenous to the model, the framework is limited in providing an explanation of the underlying force driving economic growth. Solow (1956) estimated that TFP accounted for 88% of growth in per capita income. However, given the limited explanatory power of TFP under the

Solow model, this measure represented a "measure of our ignorance" of the growth process (Abramovitz 1956) rather than explaining underlying determinants of economic growth.

Barro, Mankiw, and Sala-i-Martin (1992) develop an 'augmented Solow model' by incorporating human capital, proxied by educational attainment, into their growth model. The findings highlight the usefulness of the Solow model for explaining differences in income levels across countries, even more so when human capital is incorporated into it.

The seminal work of Romer (1986) led to the development of endogenous growth models, which sought to explain the lack of convergence between rich and poor countries and provide explanations for these growth rates. To answer this question, endogenous growth models relied on the existence of externalities, increasing returns and the lack of inputs that cannot be accumulated (Sala-i-Martin 1996). The main point of contrast between neoclassical growth models and endogenous growth models is that the latter does not assume diminishing returns to capital (which should be understood in a broad sense to include human capital) which are a prerequisite for neoclassical growth models and furthermore, technological progress is endogenised within the model.

Romer (1986) developed a model of long-run growth in which knowledge is assumed to be an input into the production process that has increasing marginal productivity. Essentially, Romer develops a competitive equilibrium model which endogenises technological change. Under Romer's model, endogenous technical change is primarily driven by the accumulation of knowledge by forward-looking, profit-maximizing agents. Romer (1986) modelled endogenous growth due to knowledge externalities, i.e. a given firm is more productive the higher the average knowledge stock of other firms. Romer (1986) initially modelled knowledge as a generalised spillover dependent on the level of human capital accumulation however later knowledge was modelled as a spillover from partially non-rivalrous knowledge accumulation with explicit innovation decisions by monopolistically competitive firms with patenting.

Lucas (1988) identified human capital as a key driver of economic growth. Lucas (1988) argued that human capital externalities may explain differences in income per capita across countries. Aghion and Howitt (1990) develop a model of endogenous growth where the rate of economic growth is dependent on the amount of research in the economy. The amount of research in this period depends negatively upon the expected amount next period, through two effects – one based on creative destruction (Schumpeter 1942) and another on the general equilibrium wage of skilled labour.

The process of creative destruction refers to the development of new products, which in turn replace existing products. Thus, the system is in a constant state of destruction and renewal. Aghion and Howitt (1990) argue that current research is determined by expected future research. The payoff for research in the current period is expected monopoly rents in the next period. As such, the prospect of more future research discourages current research by threatening to destroy the rents created by current research.

New Growth Theory (NGT) models emphasise the importance of knowledge spillovers to stimulate economic growth and competitiveness. While few researchers would argue that knowledge spills over, ambiguity exists amongst economists and economic geographers surrounding the nature and dynamics of knowledge spillovers, the degree to which spillovers are spatially bound and suitable indicators to measure knowledge spillovers. The next section presents the theoretical literature on knowledge spillovers with the aim of addressing these issues.

### 2.1.2 Knowledge Spillovers

Knowledge spillovers refer to the benefits of innovative activities of one firm that accrue to another firm without following market transactions. From neoclassical economic theory, knowledge is considered ubiquitous or as Rosenberg (1990, 165, p.165) puts it "on the shelf, costlessly available to all comers". As such, the existence of knowledge spillovers, or positive externalities, provides a rationale for government investment in R&D activities as the nonrival and nonexcludable properties of knowledge lead to suboptimal levels of investment by the private sector in R&D activities. As a result, R&D activity is undersupplied relative to the social optimum. Thus, it is argued, governments ought to subsidise or otherwise encourage R&D in order to promote social welfare.

An extensive literature has developed within the field of economics which analyses the influence of knowledge spillovers on economic growth (Romer 1986, Lucas 1988, Aghion and Howitt 1990), innovation (Cohen and Levinthal 1989, Audretsch and Feldman 1996, Bottazzi and Peri 2003, Ponds, Van Oort, and Frenken 2010), firm performance (Zucker, Darby, and Armstrong 2002, Belderbos, Carree, and Lokshin 2004) and firm competitiveness (Malmberg, Sölvell, and Zander 1996). Furthermore, the concept has become ingrained within studies focused on agglomeration, clusters (Porter 1990, 1998, Porter 2003), industrial districts (Marshall 1890) and localisation economies. These theories illustrate the importance of knowledge spillovers for enhancing economic growth and competitiveness of firms within a geographically proximate location.

Krugman (1991, p.53) questioned not only whether knowledge spillovers were spatially bound but also suggests that measuring knowledge spillovers is complicated because “knowledge flows are invisible, they leave no paper trail by which they may be measured or tracked”. However, many studies have attempted to measure knowledge spillovers using patents (Jaffe, Trajtenberg, and Henderson 1993, Jaffe 1989); skilled labour (Malecki 1997, Zucker, Darby, and Brewer 1998) and staff mobility (Breschi and Lissoni 2006).

The geographical concentration of knowledge spillovers has been a source of debate within the economics literature. Many studies have identified knowledge spillovers as being inherently local, particularly the greater the tacitness of knowledge being transferred. Tacit knowledge refers to knowledge embodied within an individual that is difficult to transfer via codification. The most commonly used example to illustrate tacit knowledge is teaching someone to ride a bike. This form of knowledge sharing is facilitated best through face to face communication and informal contacts in geographically proximate areas.

Audretsch and Feldman (2004) assert “geographic concentration matters in transmitting knowledge, because tacit knowledge is inherently non-rival in nature, and knowledge developed for any particular application can easily spill over and have economic value in very different applications”. Furthermore, Glaeser, Scheinkman, and Shleifer (1995) famously remarked “intellectual breakthroughs must cross hallways and streets more easily than oceans and continents”. However, Breschi and Lissoni (2001) insist that there is no reason why knowledge spillovers are intrinsically local in nature.

Marshall (1890) is credited as laying the foundations for much of the theorising surrounding knowledge spillovers and economic agglomeration. Marshall identified three drivers of industrial agglomeration, namely access to skilled labour (labour market pooling), supplier specialisation (shared inputs) and knowledge spillovers. According to Marshall, industrial agglomeration provides the environment for the diffusion of knowledge through the concentration of similar firms and specialised labour in a particular area. Marshall's insights led to the concept of "industrial atmosphere" in contemporary accounts, which refers to, "… the collective aspect of knowledge creation and diffusion, which is the hallmark of the Marshallian industrial district" (Amin 1994, p.65).

Marshall asserts that the benefits of agglomeration lie not in firms' locational decisions, but in the external economies available to firms from proximity to other firms and suppliers of services. Marshall describes economies which are industry-specific and largely positive, and once this is taken into account "the mysteries of the trade become no mysteries, but are as it were in the air" (Marshall 1890, IV, X, p.271).

Pigou (1932) advanced Marshall's concept of external economies further by reconceptualising the concept into two subsets: negative and positive externalities. Hoover (1937) identified different types of agglomeration economies: large-scale economies, localisation economies and urbanisation economies. Large scale economies obtain upon the expansion of the scale of production of a firm in a given location. Localisation economies follow Marshall's three sources of agglomeration and as such are related high output of all firms in a given location. Finally, urbanisation economies accrue as a result of a reduction in production costs for firms located in a large, diversified geographic area.

The identification of different types of agglomeration economies provided an important foundation for later debates which "sought to penetrate the black box of geographic space by addressing limitations inherent in the knowledge production function" (Audretsch and Feldman 2004). While studies generally support the existence of knowledge spillovers and their positive relationship with innovation, growth and competitiveness, a lack of consensus exists on whether specialised or diversified externalities facilitate greater regional growth and innovation.

Based on Marshall (1890), Arrow (1962), and Romer (1986), Glaeser, Scheinkman, and Shleifer (1995) formalised Marshall-Arrow-Romer (MAR) externalities. MAR externalities identify the specialisation of specific industries in regions as facilitating knowledge spillovers, as it allows for knowledge to spill over between similar firms. Saxenian (1994) notes "this specialisation encourages the transmission and exchange of knowledge, of ideas and information, whether tacit or codified, of products and processes through imitation, business interactions, inter-firm circulation of skilled workers, without monetary transactions".

Diversification externalities identify knowledge spillovers across different industries within close geographical proximity, usually cities, as facilitating greater knowledge spillovers, which leads to increasing regional innovativeness. Jacobs (1969) identified a diversified local production structure as a means of increasing returns as "the greater the sheer number of and variety of division of labour, the greater the economy's inherent capacity for adding still more kinds of goods and services" (Jacobs 1969, p.59).

According to Jacobs (1969), diversified regions tend to be more innovative as complementary knowledge spills over across industries, which contributes to the cross-fertilisation of knowledge. The combination of knowledge across industries may contribute to the generation, assimilation and exploitation of new ideas, techniques and methodologies which firms may utilise to create new products and processes. These products and processes may not have been possible without the combination of knowledge from different industries.

The third type of externality refers to Porterian externalities, which follow the Marshallian tradition in identifying intra-industry spillovers as the main source of knowledge externality. Porter (1990) developed the concept of the 'cluster' defined as "geographic concentrations of interconnected companies and institutions in a particular field" (Porter 1998, p.78). However, Porter identified competition rather than a monopolistic industry structure as the key source of economic growth, competitiveness and innovation. This view corresponds with the ideas inherent in the work of Jacobs (1969), which opposes Marshall's view of monopolistic competition structures facilitating greater knowledge spillovers. According to Porter (1990), local conditions and context influence how firms organise and contribute to the nature of the domestic rivalry. Intense local rivalry, Porter (1990) argues, is essential for increasing regional competitiveness.

The next sub-section discusses the characteristics of knowledge as an economic good.

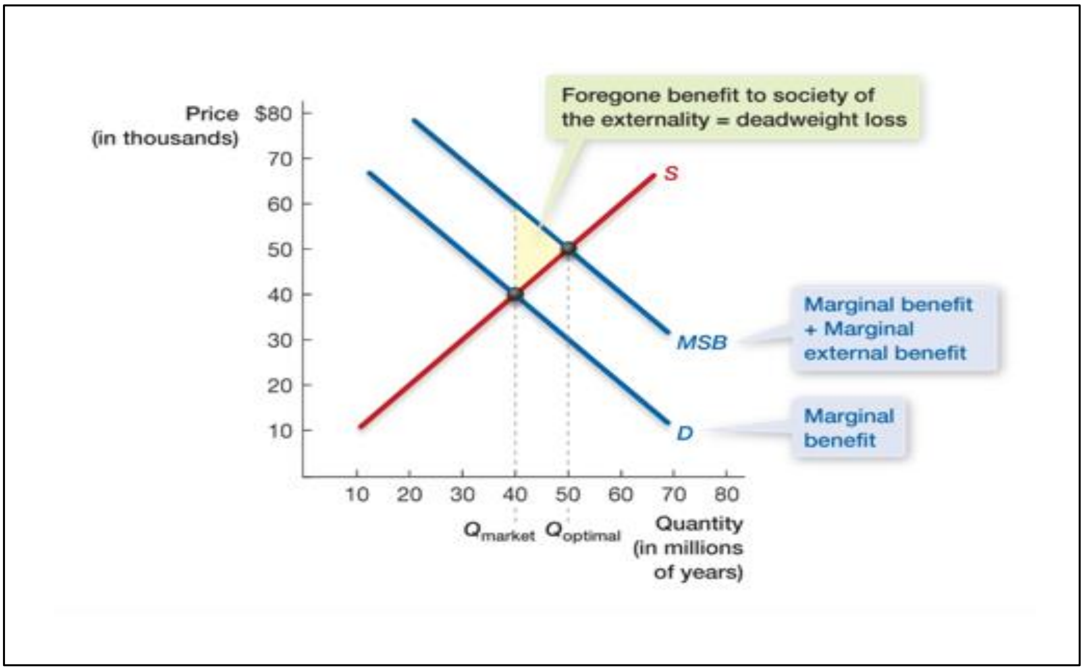
## 2.2 Neoclassical Perspective: Public Good Nature of Knowledge

The traditional starting point with discussions around the economics of knowledge is the observation that knowledge is a public or quasi-public good. The seminal work of Nelson (1959) and Arrow (1962) provide the foundation for much of the economic analysis on knowledge production that would follow. Nelson (1959) was concerned with identifying the socially optimum level of resource allocation to research under uncertain conditions. The socially optimum level of investment in research is equal to the level whereby net social benefit, or social profit, is maximised. Social profit is equal to social benefits which would not have been produced had the research had not been conducted minus social costs including opportunity costs of future benefits not realised as a result of investing in research over other areas of the economy, for example, healthcare.

Nelson identified scientific research as a public good, thus providing justification for government investment in scientific research. Public funding of scientific research is required when the marginal value of a good to society exceeds the marginal value of a good to the individual who pays for it as the socially optimal level of resource allocation will not be achieved through market mechanisms.

Figure 2.1 illustrates graphically the effect of public funding of research on the level of research, and thus knowledge production.

**Figure 2.1 Positive Externalities associated with Publicly Funded Research**




Source: Acemoglu, Laibson, and John (2016, p.235)

Following Nelson (1959), Arrow published the '*Economic Welfare and the Allocation of Resources for Invention*' which addressed the question of optimum allocation of resources under uncertainty. Arrow (1962) highlighted three of the classical reasons for the possible failure of perfect competition to achieve optimality in resource allocation: indivisibility, inappropriability and uncertainty. Arrow shows all three of the reasons given above will result in a failure of the competitive system to achieve an optimal resource allocation in the case of invention. Arrow (1962) identifies information as a commodity which is non-rival, non-excludable and cheap to reproduce.

Knowledge is considered inappropriable in the sense that once it is produced, it is very difficult for the producer of the information to keep the information to themselves. Although suitable legal measures, such as patents and trademarks, may allow for the appropriability of information, once used in a productive way it is bound to be revealed, at least partially. Furthermore, if knowledge were to contain a greater degree of appropriability on the part of the producer, this would lead to greater economic inefficiency in the allocation of resources.

Arrow (1962) asserts “the central economic fact about the processes of invention and research is that they are devoted to the production of information”. Moreover, both the production of information and the process of invention face uncertainty. Arrow suggested that due to the risky and uncertain nature of invention broadly and research, in particular, larger firms are better able to minimise this risk by conducting many projects, each small in scale compared to net revenues. Nelson (1959, p.300) also highlights this uncertainty in the activity of invention, stating an actor has alternate paths of invention which he may pursue. However, the absorptive capacity of an individual actor, built up through prior knowledge and knowledge of relative fields, lowers the expected cost, and uncertainty, of making an invention.

Arrow (1962, p.619) shares the sentiments of Nelson (1959) that suboptimal levels of resources will be allocated to research and invention through market mechanisms as

> “it is risky because the product can be appropriated only to a limited extent, and because of increasing returns in use. This underinvestment will be greater for more basic research. Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an underutilization of that information as compared with an ideal allocation”.

The next sub-section presents the linear model of innovation which is influenced by the neoclassical perspective on knowledge.

### 2.2.1 Linear Model of Innovation

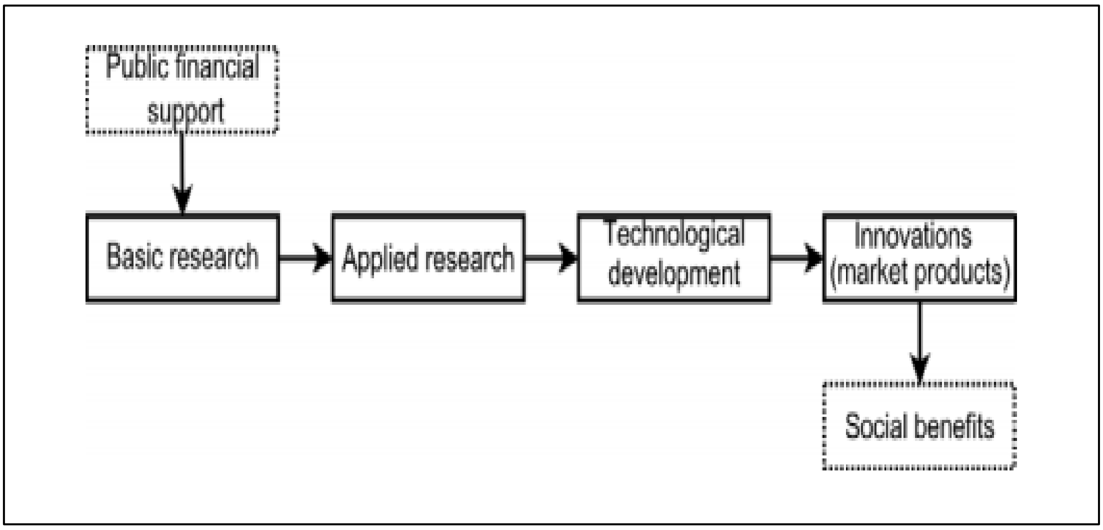
Traditionally, the linear model of innovation has been used to illustrate the process of transforming investments in research into economic and societal impacts. Much of this discussion can be traced back to the influential work of Vannevar Bush during World War II, although others assert its origins were established much earlier (Godin 2006). During World War II, Bush was appointed the director of the wartime Office of Scientific Research and Development, which was founded to develop technology which may be used to enhance the United States war efforts. This has been identified as a key development for the future of science and research as it was one of the first concerted efforts of publicly funded scientific research.

The principle focus of Bush's famous text '*Science, the Endless Frontier*' is the importance of basic research. Bush (1960, p.viii) describes the process of transforming basic research into wider economic and societal impacts

> "Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. Today, it is truer than ever that basic research is the pacemaker of technological progress".

Bush (1960) emphasised the importance of publicly funded basic research while considering the private sector as the main funder of applied research. Bush (1960, p.5) identified the flow of new scientific knowledge as an essential driver to material and technical progress through "new products, new industries, and more jobs require continuous additions to knowledge of the laws of nature and the application of that knowledge to practical purposes". This process is presented graphically in Figure 2.2.

**Figure 2.2 Linear Model of Innovation**




Source: Gust-Bardon (2014)

Much of the model's appeal is related to its simplicity. However, it is widely agreed that the linear model is subject to substantial limitations. Firstly, the linear model represents a 'science-push' model and underplays the possibility of generating impacts through a 'demand-pull' model, in which new technologies lead to advances in scientific knowledge and understanding. The innovation process is complex, nonlinear, and highly uncertain where 'science-push' and 'demand-pull' processes occur in tandem. Secondly, linear models exclude many important inputs such as 'trial and error', accumulated experience and tacit knowledge as well as non-technical inputs. Thirdly, while research inputs are primarily national, the impacts from the research are international. Furthermore, innovation is increasingly international in scope. Fourthly, there are limits to the extent to which impacts from research may be quantified. Research impacts are often "indirect, partial, opaque and long-term" (Martin 2011, p.250). Moreover, there is a lack of consensus around suitable indicators to capture the wide range of research impacts. Finally, the model overlooks the need for capabilities and absorptive capacity of industry partners to absorb, assimilate, transform, and exploit knowledge and technologies produced through publicly funded research.

Despite more sophisticated insights, the linear model continues to influence thinking. The linear model was very influential in the development of the OECD's Frascati Manual, first published in 1963. While the Frascati Manual was initially written by and for experts interested in collecting and issuing national data on R&D, its impact has been on contextualising different definitions, meanings and terminology used in the discussion of research. These definitions, conceptualisations and terminologies have significant influence on national evaluation systems, research impact assessment exercises, grant proposals and funding decisions.

However, many studies have questioned the usefulness of the distinction between basic and applied research, and the role basic research plays in the innovation process (Stokes 1994, Gibbons et al. 1994, Calvert 2006). These studies highlight the blurring of the boundaries between research typologies and the increasing importance of interaction and overlap between different types of research. Therefore, it is important to consider the usefulness of these definitions in current research environment.

The most recent edition of the Frascati Manuel defines basic research as:

> "Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view."
>
> (OECD 2002, p.77)

while applied research relates to:

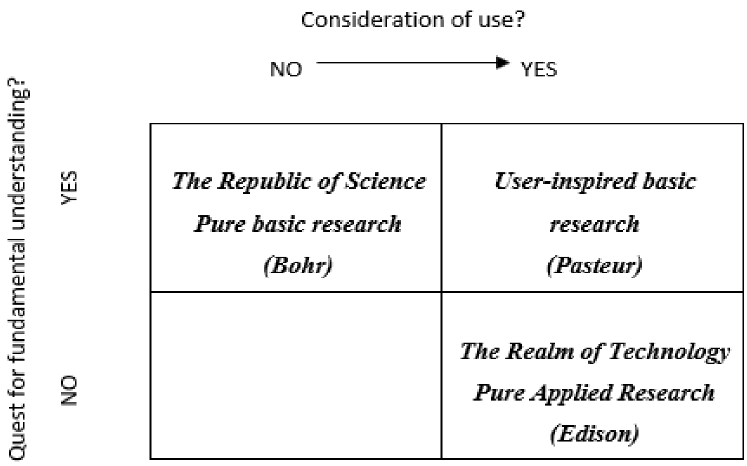
> "Original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective."
>
> (OECD 2002, p.78).

Furthermore, the third type of research 'Oriented basic research' may be distinguished from pure basic research as follows:

> "Pure basic research is carried out for the advancement of knowledge, without seeking long-term economic or social benefits or making any effort to apply the results to practical problems or to transfer the results to sectors responsible for their application. Oriented basic research is carried out with the expectation that it will produce a broad base of knowledge likely to form the basis of the solution to recognised or expected, current or future problems or possibilities."
>
> (OECD 2002, p.78).

Stokes (1994) developed a framework for understanding the distinction between basic and applied research which challenges the view of Bush (1960). Stokes (1994) argued the distinction drawn between basic and applied research advocated by Bush (1960) was inconsistent with real-world problems, and in order to rebuild the relationship between science and policy we must understand the limitations of this view. Figure 2.3 shows the different forms of research highlighted in Pasteur's Quadrant.

**Figure 2.3 Pasteur's Quadrant**




Source: Stokes (1994)

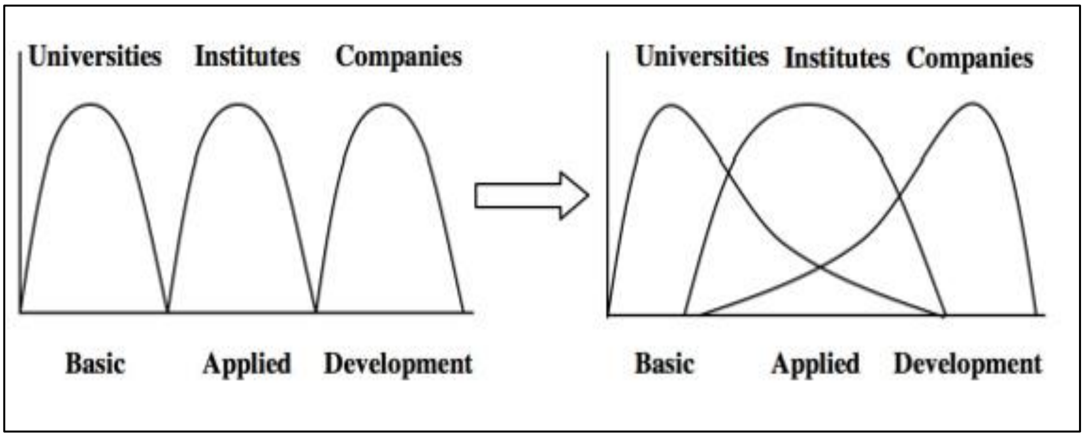
Stokes (1994) illustrates the motivations for conducting various forms of research in quadrant form. Three types of research activities can be identified:

- Pure basic research is represented by Bohr's Quadrant. Pure basic research is curiosity-driven research concerned with fundamental understanding. As such, pure basic research does not have any commercial application.
- Applied research is represented by Edison's Quadrant. Applied research is conducted with the aim of increasing the economic and commercial impacts of research, including the creation of new products and processes, increasing sales and turnover and creation of new jobs and spin-offs.
- User-inspired research which is concerned with both fundamental understanding and consideration of use is labelled Pasteur's quadrant.

Stokes (1994) asserts an important distinction is made when defining basic and applied research which perhaps oversimplifies the relationship between the concepts by overlooking overlapping and interrelated elements. Basic research can lead—either directly or indirectly—to future discoveries that have useful applications. Many of these applications will have prospects for commercial success and will attract private sector investment.

Similarly, Arnold, Clark, and Jávorka (2010) highlight the breakdown of the traditional 'three-hump model', outlined in Figure 2.4.

**Figure 2.4 Breakdown of the "Three-Hump Model"**




Source: Arnold, Clark, and Jávorka (2010)

Under the three-hump model, universities conduct curiosity-driven 'pure' basic research; research institutes conduct applied research and companies develop the knowledge generated by universities and research institutes to develop new products and services. However, this traditional three-hump model underplays the interaction and overlap between the various groups and the types of research they conduct. Today, universities and research centres are increasingly conducting research, which is more applied in nature, which has led to a considerable body of work on subjects such as academic entrepreneurship, academic engagement and commercialisation and university-industry relations. As such, Arnold, Clark, and Jávorka (2010, p.30) stress that "it is increasingly recognised that if the old 'three-hump model' ever worked, it has now broken down".

Calvert (2006, p.207) discusses the response of scientists and policymakers to the issue of the relationship between basic and applied research. According to Calvert, basic research often relates to the intentions of the researcher and as such, is flexible and ambiguous. Researchers can be carrying out the same research with different intentions, and these intentions lead to the research being classified as either basic or applied. Calvert (2006, p.204) asserts "the significance of the intentional definition of 'basic research' is that if the intentions behind the research are to produce something that will result in an application, no matter how fundamental the research may be in an epistemological sense, the research will no longer be classified as basic".

Calvert argues that researchers themselves are uninterested in the distinction between the terms and mainly make these distinctions when applying for research funding. Hughes and Martin (2012, p.9) stress "a substantial portion of publicly funded research may, therefore, lie in Pasteur's Quadrant, while individuals and research groups may move between quadrants in the course of research projects".

In recent years, it has been argued that the research impact agenda aims to shift all research, including basic research, towards application (Watermeyer 2016). Researchers and research centres are increasingly expected to demonstrate an ability to secure external funding, engage in knowledge transfer and commercialisation activities, develop intellectual property and apply research findings to industrial and societal needs. As such. the distinction between the different types of research advocated by Pasteur's Quadrant may no longer be appropriate, with an increased blurring of the boundaries between research typologies.

Ranga, Debackere, and Tunzelmann (2003) evaluate whether research conducted at universities has shifted to a 'perceived' applied research end because of an increasing focus of business needs. The findings indicate that growth in both basic and applied research have generally risen together. The paper does not find evidence of a shift towards a more applied research end and indicates that basic research tends to be the more dominant form of research, both in absolute terms and in terms of growth. The author's caution against considering basic and applied research as substitutes for each other and instead insist that they must be viewed as complementary for firms to achieve their optimum R&D potential.

Despite the limitations associated with of the concepts of basic and applied research, I would argue that they are still useful distinctions for research impact assessment exercises. The concepts provide a well-established, widely-accepted, commonly used language across academic and policymaking circles. Gulbrandsen and Kyvit (2010) conducted interviews with 64 researchers from diverse scientific disciplines across Norwegian universities and research institutes. The findings suggest that for most researchers the concepts are meaningful and easily elaborated. The authors assert that although the meanings may differ, the language offered by the traditional terms basic and applied research may constitute a communication platform that unites researchers from fields which in most respects have very little in common in daily practices.

The limitations associated with the linear model of innovation coupled with the changing nature of science and technology has contributed to the development of alternative models to explain the process of innovation and research impact. These models aim to overcome the weakness in the linear model by highlighting the complexities, collaborative and evolutionary nature of the research impact process. Section 2.3 outlines the evolutionary perspectives of innovation and research impact. This perspective offers significant advantages compared to the linear model when analysing the innovation process.

## 2.3 Evolutionary Perspective

From the evolutionary perspective, the focus of attention ceases to be "market failure *per se* and instead becomes the enhancement of competitive performance and the promotion of structural change" (Metcalfe 1995, 6, p.6). Two points are fundamental to the argument using an evolutionary economics perspective. Firstly, institutions outside of the firm are critical for supplying knowledge and skills necessary to conduct innovative activities. This is termed the systems perspective on innovation (Nelson

1993). Secondly, innovation and the diffusion of knowledge should not be considered in isolation but rather in its interrelation to one another.

From an evolutionary perspective, the impact of publicly funded research is "substantially affected by the capacity of other actors in the economic and innovation system to access, understand and use the research outputs produced with public sector support" (Hughes and Martin 2012, p.12). As such, "private-sector research and the publicly funded research base, therefore, represent two complementary systems of activity, in the sense that each is specialised in a particular aspect of the innovation system" (Foray and Lissoni 2010).

Salter et al. (2000, p.28) highlight the key features of this approach:

- Innovation as an evolutionary process
- Research as a capability
- The absorptive capacity of industry
- The new mode of knowledge production and
- Creating social and technological variety

The next sub-section discusses these features in more detail, highlighting their importance when measuring and evaluating the economic impact of publicly funded research centres.

### 2.3.1 Innovation as an Evolutionary Process

From an evolutionary perspective, generating research impacts is a complex, dynamic, interactive process involving multiple stakeholders. Research centres are viewed as a vital cog within the innovation system, which are interrelated and interact with other entities within the system such as firms, universities and government agencies. As such, a simple linear model of research impact does not capture the true extent of the dynamics of research impact.

Salter et al. (2000, p.29) assert "firms do not innovate in isolation". Similarly, research centres do not produce impacts in isolation. Similarly, research centres do not provide 'impacts' in isolation. The impact of publicly funded research will be "substantially affected by the capacity of other actors in the economic and innovation system to access, understand, and use the research outputs produced with public sector support" (Hughes and Martin 2012, p.12). From this perspective, firms are the main drivers of innovation and the objective of publicly funded research centres is to provide knowledge outputs which can be absorbed, transformed and exploited by firms generating economic and societal impacts.

### 2.3.2 Research as Capability

The evolutionary approach views research as a capability embedded in specific researchers and/or collaborative networks. The neoclassical perspective undervalues the 'tacitness' of knowledge i.e. the extent to which knowledge is embodied within individual researchers and institutional networks which is not easily transferable, as often "we can know more than we can tell" (Polanyi 1966). Salter and Martin (2001, p.512) assert "the development of tacit knowledge requires an extensive learning process, is based on skills accumulated through experience and often years of effort". As such, the neoclassical perspective is limited in assessing the potential and realised impacts of publicly funded research centres.

### 2.3.3 Absorptive Capacity

The evolutionary economics perspective emphasises the role of the specific researcher or firm as an embodiment of scientific knowledge. This contrasts with the view of the neoclassical economists who view knowledge as "on the shelf, costlessly available to all comers" (Rosenberg 1990, p.171). From the evolutionary perspective, knowledge alone is considered a necessary though not sufficient condition to achieve competitive advantage. But rather, it is the *capacity* of an individual researcher, firm or government to make the best use of available information which provides unique opportunities to increase productivity and innovation capacity.

Rosenberg (1990) questions why firms should perform basic research with their own money when knowledge, under the neoclassical economics perspective, is considered non-rival and non-excludable. The study indicates that businesses engaging in private R&D may benefit from a wide range of advantages. Firstly, the firm may benefit from 'first mover advantages' such as acquiring valuable assets or consolidating their market position. Secondly, conducting private R&D may be thought of as "a ticket to an information network" which provides benefits such as knowledge spillovers and the building of potentially lucrative relationships. Thirdly, to 'plug in' to the research community, private firms must have some form of in-house capabilities as a firm is of much less use to research institutions if it does not conduct research itself. This final point refers to a firm increasing its absorptive capacity to identify, understand and make the best use of the information available to them.

Absorptive capacity refers to “the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends” (Cohen and Levinthal 1990, p.128). However, many authors have highlighted ambiguity in definitions, measurement and conceptualisation associated with the term (for example Zahra and George 2002, Van Den Bosch, Van Wijk, and Volberda 2003).

Van Den Bosch, Van Wijk, and Volberda (2003) question the appropriateness of the use of ‘information’ rather than ‘knowledge’ in Cohen and Levinthal (1989) definition of absorptive capacity, as they assert that the two terms have different meanings. They instead suggest a definition of absorptive capacity as “the ability to recognize the value of new external knowledge, assimilate it, and apply it to commercial ends” (Van Den Bosch, Van Wijk, and Volberda 2003, p.5).

The limitations of initial conceptualisations of absorptive capacity have led to many authors reconceptualising the concept. Kalkstein (2007) asserts “the concept of absorptive capacity, while at first glance intuitively appealing and seemingly easy, becomes problematic with attempts to pinning it down and operationalization”. The most cited reconceptualisation of absorptive capacity was provided by Zahra and George (2002) who suggest that absorptive capacity exists as two subsets of potential and realised absorptive capacity.

Potential absorptive capacity (PACAP) is related to a firm’s capabilities in the acquisition and assimilation of knowledge while realised absorptive capacity (RACAP) refers to the transformation and exploitation of knowledge. Zahra and George (2002, p.187) define absorptive capacity as “a set of organizational routines and processes by which firms acquire, assimilate, transform and exploit knowledge to produce a dynamic organizational capability”. The authors label the ratio of PACAP and RACAP, the efficiency ratio. The efficiency ratio is a relative measure that determines how successful firms are in exploiting knowledge absorbed from external partners.

Lane and Lubatkin (1998) introduced the concept of *relative absorptive capacity* which relates to the notion that the transfer of knowledge is not only dependent on the ability of firms to absorb the knowledge but also depends on the characteristics of the partner in a 'student-teacher-like' relationship. Similarly, Dyer and Singh (1998) suggest another conceptualisation of absorptive capacity, *partner-specific absorptive capacity,* which is the ability to identify and assimilate knowledge from a specific collaborative partner, rather than the ability to absorb and assimilate knowledge as a whole.

Van Den Bosch, Van Wijk, and Volberda (2003) highlight the importance of the level of aggregation when studying absorptive capacity. They identify absorptive capacity as a multilevel construct. The lowest level of analysis takes place at the *individual level* where the link between absorptive capacity and learning is most evident. The next level is the *organisational level;* however, this does not equal simply adding up the absorptive capacity of all individual members. This overlooks the aspects of absorptive capacity which are distinctly organisational.

Cohen and Levinthal (1990) focus on the level of the organisation; however, more recent studies have identified *inter-organisational levels* with the literature on networks, clusters and economic agglomeration playing an important role in conceptualising absorptive capacity. Kalkstein (2007) insists that if one wishes to contribute to and advance on the seminal work of Cohen and Levinthal (1989), all three levels must be taken into consideration, i.e. individual, inter-organisational and organisational.

An extensive literature exists empirically examining the relationship between business R&D and innovation outcomes. Beise and Stahl (1999) analysed the impact of publicly funded research institutes on industrial innovations of 2,300 manufacturing firms in Germany between 1993 and 1995. The findings suggest that business investment in R&D increases their ability to absorb knowledge from public research institutions and transform and exploit this knowledge into industrial innovations. Similarly, Arundel and Geuna (2004), using data from the 1993 PACE survey of Europe's largest R&D-performing firms find higher levels of R&D investment are associated with higher likelihood of collaboration with public research institutes.

Studies conducted at an inter-organisational level typically examine the impact of clusters, networks and alliances on a firm's absorptive capacity. Roper, Hewitt-Dundas, and Love (2003) develop an ex-ante framework to measure the impact of publicly funded research centres. The findings suggest that the magnitude of impacts are dependent on the strength of the innovation system of the host region. Roper, Hewitt-Dundas, and Love (2003, p.498) assert "the industrial composition and absorptive capacity of local firms and the strength of local knowledge dissemination networks are all important synergies between the research focus of the R&D centre and the needs of the regional economy".

### 2.3.4 New mode of knowledge production

Section 2.2.2 highlighted the changing nature of science and technology from traditional conceptions of innovation based on the linear model of innovation towards evolutionary models of innovation which attempt to incorporate the complex, dynamic and nonlinear features of the innovation process. The evolutionary perspective emphasises a shift in knowledge production from traditional knowledge production characterised by theoretical or fundamentally driven-research towards production towards a new form of knowledge production which was "socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities" (Nowotny, Scott, and Gibbons 2003, p.179).

Gibbons et al. (1994) introduced the concepts of Mode 2. According to Gibbons et al. (1994, p.VII)

> "The new mode operates within a context of application in that problems are not set within a disciplinary framework. It is transdisciplinary rather than multi-disciplinary. It is carried out in non-hierarchical, heterogeneously organised forms which are essentially transient. It is not being institutionalised primarily within university structures. Mode 2 involves the close interaction of many actors throughout the process of knowledge production, and this means that knowledge production is becoming more socially accountable".

Table 2.1 highlights some of the key differences between Mode 1 and Mode 2 knowledge production.

**Table 2.1 Mode 1 and Mode 2 of knowledge production**

| Mode 1 | Mode 2 |
|---|---|
| Problems of knowledge are set and solved in a context governed by the academic interests of a specific community. | Knowledge is produced and carried out in a context of application. |
| Based on the disciplines | Cross/trans-disciplinary |
| Homogeneity | Heterogeneity |
| Hierarchical structure, and tends to preserve its form | Hierarchical and transient |
| Quality control by peer review judgements | Socially accountable and reflexive |

Source: Tjeldvoll (2010, p.430)

Nowotny, Scott, and Gibbons (2003) addressed some of the initial criticisms of their thesis on knowledge production. Nowotny, Scott, and Gibbons (2003) identify three trends are generally accepted to be significant within research systems and have contributed to new discourses in the research and innovation literature. These are:

- 'steering' of research priorities – supranational, national and systems policies
- the commercialisation of research – industry funding and intellectual property
- the accountability of science – effectiveness and justification of public funds.

These trends are closely aligned to trends in research policy resulting from the development of the impact agenda.

### 2.3.5 Creating Social and Technological Variety

The fifth element of the evolutionary approach to the impact of research on innovation focuses on the role of public funding in supporting social and technological variety. Salter et al. (2000, p.37) note “many social and technical issues involve choices between competing technical options. Publicly funded research can help support improved social decision-making, providing new evidence and ideas for how to resolve or consider technical and social problems”. A primary function of publicly funded research centres is the production of new useful knowledge which can contribute to economic and societal impacts.

This sub-section outlines the key features of the evolutionary perspective of innovation. The evolutionary approach provides a more satisfactory approach for measuring and evaluating research impact as it highlights the complex, nonlinear, multidimensional nature of the research impact process. The next sub-section presents evolutionary models of innovation. These models were developed in efforts to overcome weaknesses inherent in the linear model of innovation.

### 2.3.6 Evolutionary Models of Innovation

The limitations associated with the linear model of innovation have contributed to the development of evolutionary models of innovation which attempt to capture the complexities and dynamics of the innovation process. These models are characterised by the key features highlighted in Section 2.3.1 to Section 2.3.5. Perhaps the most popular conceptualisation of the process of innovation was developed by Kline and Rosenberg (1986), outlined in Figure 2.5. Unlike the linear model of innovation which presents one major path of activity, the chain-link model identifies five paths.

The linear model of innovation is presented as a ‘science-push’ model with the chain of causation running from left to right. The science push model begins with “scientific discovery, passing through invention, engineering and manufacturing activities and ending with the marketing of a new product or process” (Dodgson 2000, p.17). The chain link model does not identify the generation of new knowledge as a driver for innovation, rather the first step involves identifying potential market for the new product.  Kline and Rosenberg (1986, p.275) state “successful outcomes in innovation thus require the running of two gauntlets: the commercial and the technological”. Therefore, commercial viability and applicability must be considered prior to research and development phases of the process. Thus, the path begins with a design and continues through development and production to marketing.

**Figure 2.5 Chain Link Model of Innovation**

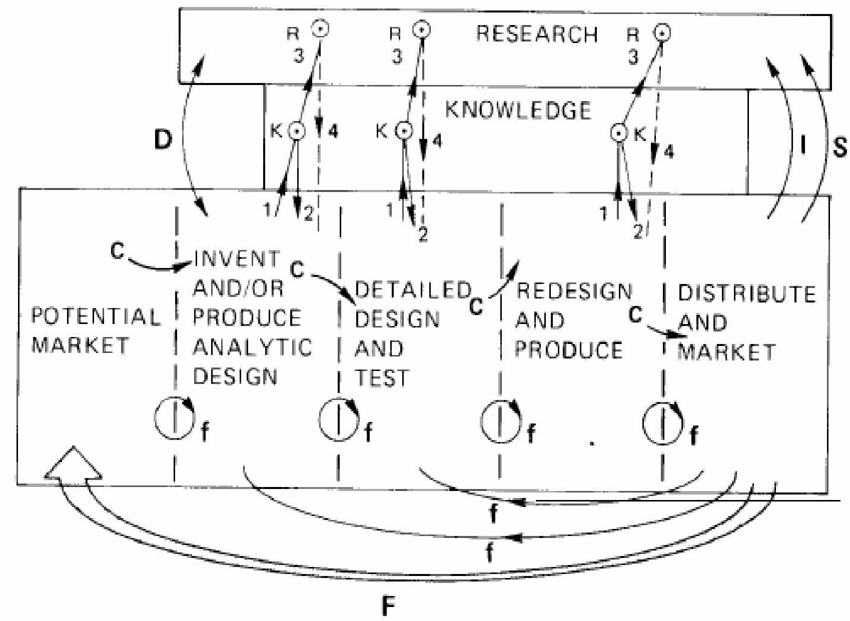



FIGURE 3 Chain-linked model showing flow paths of information and cooperation. Symbols on arrows: C = central-chain-of-innovation; f = feedback loops; F = particularly important feedback.

Source: Kline and Rosenberg (1986, p.290)

The central chain of innovation in the model is represented by the label ‘C’. In an ideal market, with omniscient people and perfect knowledge, the design and optimisation of innovation could be done in the first attempt. In this world, the process of innovation would resemble the linear model of innovation of innovation where identification of a potential market is followed by invention and/or product design through to redesign and production towards distribution and marketing. However, in the real world with high degrees of uncertainty and the absence of perfect knowledge, nothing like this occurs. Therefore, the chain link model incorporates feedback loops into the research process, represented by ‘f’ and ‘F’ in Figure 2.5.

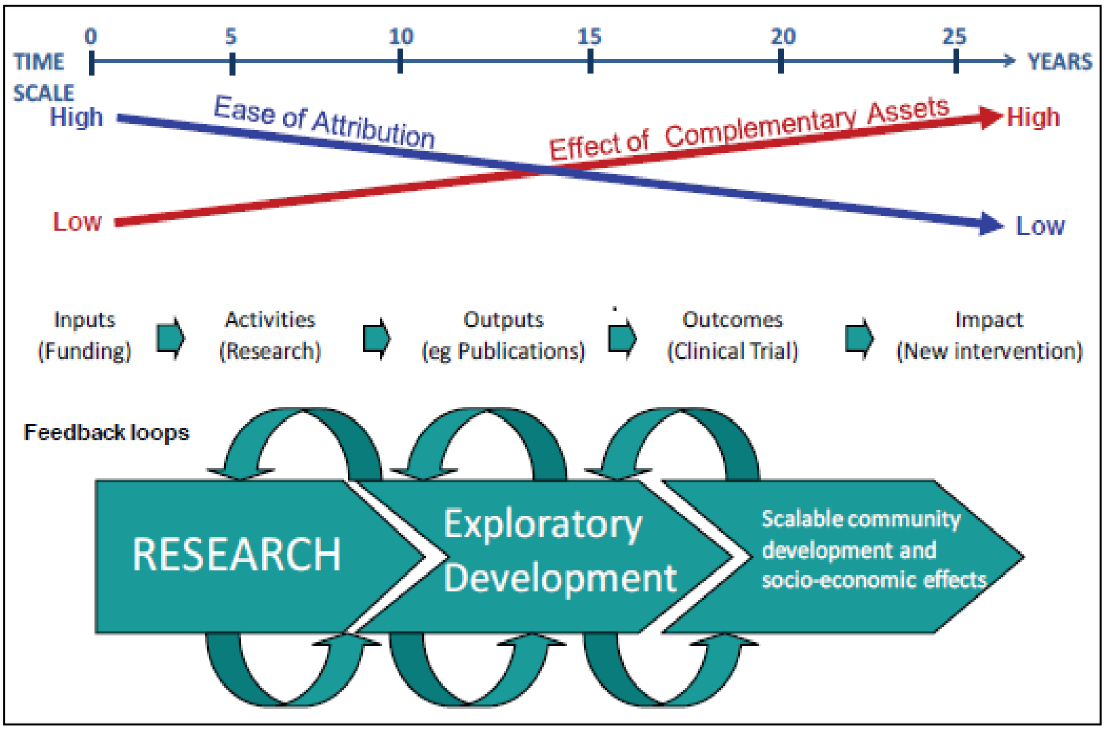
The chain-link model presents the process of innovation as complex, dynamic and highly uncertain involving multiple feedback loops throughout the innovation process. While the linear model places research activities at the beginning of the innovation process, the chain-link model represents research activities as occurring continuously throughout the process guided by “feedback signals” from both users and the market.

These feedback loops provide direct response from perceived market needs and users to potential improvements of product and service performance in the next round of design. Kline and Rosenberg (1986, p.187) state “in this sense, feedback is part of the cooperation between the product specification, product development, production processes, marketing, and service components of a product line”.

The chain-link model acknowledges that knowledge and technology are important, but not sufficient, components of innovation. The labels ‘K’ and ‘R’ represent the two-stage process outlined to overcome technological problems throughout the innovation process. Firstly, researchers should make efforts to draw on accumulated knowledge to solve scientific and technological problems. This is represented by arrow ‘1’ in Figure 2.5. If the problem may be solved following this step then researchers should move to the next stage of the research process, represented by arrow ‘2’. However, if the technological problem cannot be solved using the stock of existing knowledge within the organisation, further research is required, represented by arrow ‘3’ in Figure 2.5. Finally, if the problem is solved through further research then researchers may move on to the next stage of the research process, represented by arrow ‘4’. Arrow 4 is a broken line which implies that a solution to the problem may not be possible given current knowledge.

Hughes and Martin (2012) develop an evolutionary model of innovation to illustrate the process of generating economic and societal impacts from research activities. This process is embedded within a wider systems or evolutionary context. This model addresses three issues that have hampered innovation and evaluation studies: attribution, complementarities, and time lags. As well as feedback loops between stages, the model includes a timescale across the top to indicate the estimated time it takes to transform initial inputs into the research process into outputs towards outcomes and wider economic and social impacts. These time lags may be discipline, project or sector-specific but studies have indicated it can take up to seventeen years to deliver impacts from research (Morris, Wooding, and Grant 2011).

**Figure 2.6 Evolutionary Model of Research Impact**




Source: Hughes and Martin (2012)

The two arrows sloping upwards and downwards highlight the inverse relationship between degree of attribution and the importance of complementary assets when demonstrating economic and social impact from research activities. The generation of impacts from research activities is a complex, dynamic process involving multiple stakeholders. The ability of a researcher or research centre to deliver economic and societal impacts is dependent on the identification, uptake and use of the research by external actors in the research system. It is often difficult to disentangle the overall contribution of the researcher and/or research centre from the external actors when evaluating economic and societal impacts. This is known as the 'attribution problem'.

Figure 2.6 shows that the degree of attribution decreases as the number of stakeholders involved in innovation process increases. This issue becomes more problematic when evaluating the longer-term economic impacts of researchers and/or research centres as typically the three earlier stages of the process i.e. inputs, activities and outputs are typically shorter-term and involve less stakeholders which reduces the issues of attribution, complementarities, and time lags.

The next section discusses the relationship between public and private investment in research activities, namely whether public investment acts as a complement or substitute for private investment in research activities.

## 2.4 Crowding in or Crowding out?

Much research has been carried out investigating whether public investment in R&D 'crowds in' or 'crowds out' private investment, yet the results of these studies tend to be ambiguous. Comparisons across studies have been hampered by differences in methodologies, levels of aggregation, regions and explanatory variables included in estimations. As such, there is a lack of consensus on the impact of public investment in R&D on the decision of private firms to invest in R&D. This section highlights the most significant contributions in the literature on the impact of public R&D investment on private R&D. Caution must be exercised when drawing comparisons across nations as differences in the goals of governance and institutional structures responsible for the creation and implementation of science, technology and innovation policies can contribute to differences in outcomes.

Table 2.2 highlights studies carried out at the national level which analyses the relationship between public and private R&D while Table 2.3 shows studies focused on relationship between public and private R&D investment at a microeconomic level.

**Table 2.2 Relationship between public and private R&D investment at Macroeconomic Level**

| National Macro | Regions | Sources of Data | Type of Funding | Methodology | Dependent Variables | Independent Variables | Findings |
|---|---|---|---|---|---|---|---|
| Levy and Terleckyj (1983) | United States | National Accounts | Government Contracts | Generalized Least Squares (GLS) | Government R&D | Private R&D, output of the private business sector, corporation taxes, lagged one-year unemployment in millions | Complementary (0.27) |
| Terleckyj (1985) | United States | National Accounts | Government Contracts | GLS | Private R&D expenditure | Private R&D, Private Sector Output, Sales | Complementary (0.24) |
| Lichtenberg (1987) | United States | National Accounts | Federal R&D funding | Time Series Cross Sectional | R&D expenditure | Federally funded R&D, Sales (GOV), Sales (Other) | Complimentary (0.11) |
| (Robson 1993b) | United States | National Accounts | Federal R&D funding | Ordinary Least Squares (OLS) | Private inv basic research | Public inv. Basic research, Private inv applied, Public inv applied, Gov purchases of G&S, Non-gov purchases of G&S | Complimentary (1.00) |
| Diamond Jr (1999) | United States | National Science Foundation | Federal funding of basic research | OLS First Differences (FD) | Privately funded basic research | publicly funded basic research, GDP | Complementary Universities (0.08), Non-profit (0.03) Industry (0.62) |

Source: Compiled by Author

**Table 2.3 Relationship between public and private R&D investment at Microeconomic Level**

| Micro-level | Regions | Source of Data | Type of Funding | Method | Dependent Variables | Independent Variable | Findings |
|---|---|---|---|---|---|---|---|
| Blank and Stigler (1957) | United States | Survey data | Government Contracts | OLS | Private R&D expenditure | The ratio of scientific workers to total workers | Substitute |
| Howe and McFetridge (1976) | Canada | National Accounts and Tax returns | Government grants for three industries | Pooled panel | Private R&D investment | Public Subsidies, Profits, Sales, Government grants, Foreign-owned, Locally owned | Complementary for one industry out of three (electrical) |
| Lichtenberg (1984) | United States | National Science Foundation (NSF) database | Government Contracts | OLS Pooled | Private R&D (expenditure and personnel) | Public R&D (expenditure and personnel), Industry dummies Time dummies | Insignificant |
| Lichtenberg (1988) | United States | NSF Database | Firm's competitive contracts, Firm's non-competitive contracts | OLS IV | Private and non-private competitive contracts | Public R&D expenditure | Complementary effects for competitive contracts (0.54) but larger negative effects for non-competitive contracts. Net effect is substitute (-0.48) |
| Wallsten (2000) | United States | Small Business Innovation Research (SBIR) data | R&D grants | OLS 3SLS | R&D Expenditure Employment | Subsidy, Firm Age, Employment 1991, Patents awarded, Industry Dummies, Type of Firm dummy | Substitute (-0.82) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lach (2002) | Israel | Survey of Research and Development questionnaire | Subsidies for manufacturing firms | DID estimator | Firm investment in R&D | Public subsidies, Employment, Sales | Substitute at time t (-0.28), Compliment at t+1 (4.2), Compliment for smaller firms but substitute for larger firms. |
| Yla-Anntila et al. (2005) | Finland | Companies' Financial statements | R&D spending | OLS Pooled IV | Private R&D | Public R&D, Debt, Debt Squared, Profit | Complementarity (0.616), Complementarity (0.864) |
| Toole (2007) | United States | U.S. National Institutes of Health data | R&D investment in the Pharmaceutical industry | 2SLS | Industry R&D investment | Public inv. Basic research, Public inv clinical research, Previous year's sales, Hospital admin rate, Mortality rate | Complementary in first period (0.60); substitute in second period (-0.37); complementary in final period (0.04) |
| Görg and Strobl (2007) | Ireland | Forfás Dataset | Government Grants | PMS estimator | Private R&D spending | Public Subsidy | Complementarity for small domestic firms (0.72), Substitute for large domestic firms (-1.27) |
| Hussinger (2008) | Germany | Mannheim Innovation Panel (MIP) dataset | Subsidies | Two-Stage Parametric Approach Probit and Tobit Models | R&D per employee New Sales | Firm Size, Patents, Previous subsidies, Eastern German | Complementarity (0.56) |
| Afcha and López (2014) | Spain | Survey on Business Strategies | Government subsidies | Multinomial Logit model | Private R&D | Central government subsidies, Regional government subsidies, subsidies from other agencies | Complementary across all levels but particularly for firms conducting internal R&D |

Source: Compiled by Author

Most studies suggest complementarities between public and private investment in R&D, however substitution effects can be found, particularly at the firm level. The findings suggest that the level of investment, the type of funding i.e. contract or subsidy, the nature of research activities and the size of the firm are important determinants of whether public R&D leads complementary or substitute effects for private R&D. Furthermore, results are sensitive to differences in methodologies, regions and level of analysis.

## 2.5 Conclusion and Next Steps

The chapter provides an economic rationale for public investment in science, technology and research. Publicly funded research is widely considered as a key determinant of economic growth, competitiveness and innovation at national, regional and firm levels (Buxton et al. 2008, Donovan and Hanney 2011, Guthrie et al. 2013, Ofir et al. 2016, Guthrie et al. 2018). However, policymakers and funding bodies are faced with an opportunity cost when making public investment decisions. Therefore, accountability and demonstrating value for money are considered key criteria for awarding public monies for research activities. The justification for public investment in research centres is fourfold.

Firstly, knowledge is recognised as a driver of economic growth at national, regional and local levels. Section 2.1.1 outlines the literature on the relationship between knowledge and economic growth. An important contribution of the IMPACTS framework outlined in Chapter 5 is that the impact capacity of research centres is influenced by the strength of the innovation system which it is embedded within. Therefore, it is hypothesised that ceteris paribus, research centres embedded within innovation systems with higher stocks of knowledge have a higher impact capacity than research centres located in innovation systems with lower stocks of knowledge.

Secondly, the neoclassical perspective (Nelson, 1959; Arrow, 1962) provides the tradition justification for public investment in research and research centres. The neoclassical perspective views knowledge as a public or quasi-public good i.e. nonrival, nonexcludable and highly uncertain. Therefore, perfectly competitive markets will under-produce knowledge relative to the socially optimal level, as social benefits of knowledge production outweigh private benefits.

Thirdly, the presence of knowledge spillovers, or positive externalities, contributes to the market failure hypothesis outlined above. Section 2.1.2 discusses the literature on knowledge spillovers in the science, technology and innovation literature. An extensive literature has developed within the field of economics which analyses the influence of knowledge spillovers on economic growth (Romer 1986, Lucas 1988, Aghion and Howitt 1990), innovation (Cohen and Levinthal 1989, Audretsch and Feldman 1996, Bottazzi and Peri 2003, Ponds, Van Oort, and Frenken 2010), firm performance (Zucker, Darby, and Armstrong 2002, Belderbos, Carree, and Lokshin 2004) and firm competitiveness (Malmberg, Sölvell, and Zander 1996). The presence of knowledge spillovers, or positive externalities, provides further justification for the investment of public funding for research activities.

Fourthly, public investment in research is often complemented by private investment. Section 2.4 presents an overview of empirical studies analysing whether public funding 'crowds in' or 'crowds out' private investment. Most studies suggest complementarities between public and private investment in R&D, however substitution effects can be found, particularly at the firm level. The analysis suggests that results of empirical studies are sensitive to differences in methodologies, regions and level of analysis.

The neoclassical perspective is closely aligned with the linear model of innovation, outlined in Section 2.2.1. However, the limitations associated with the linear model of innovation coupled with the changing nature of science and technology has contributed to academics and policymakers to look towards more sophisticated models to explain the innovation process. The evolutionary perspective offers a more satisfactory explanation of the research impact process. From the evolutionary perspective, the focus of attention ceases to be "market failure *per se* and instead becomes the enhancement of competitive performance and the promotion of structural change" (Metcalfe 1995, 6, p.6).

The IMPACTS framework presented in Chapter 5 adopts an evolutionary perspective to explain the process of research impact. The IMPACTS framework incorporates several key features outlined in this chapter, which provide a holistic approach to research impact assessment (RIA) including:

- Innovation as an evolutionary process
- Research as a capability
- The absorptive capacity of industry
- The new mode of knowledge production; and
- Creating social and technological variety

Under this perspective, research centres are viewed as a vital cog within the innovation system, which are interrelated and interact with other entities within the system such as firms, universities and government agencies. Therefore, the ability of research centres to generate economic and societal impacts is influenced by how knowledge is absorbed, assimilated, transformed and exploited by actors in their external environment.

The next chapter introduces the concept of research impact including a discussion on the diverse meanings and conceptualisations of the concept of research impact, theoretical and empirical challenges facing evaluators when evaluating the impacts of publicly funded research and current frameworks and tools available to measure the range of impacts generated through investments in research activities.

# Chapter 3: Measuring the Economic Impact of Publicly funded Research: Conceptual and Empirical Challenges

In recent years, the impact agenda has gained strong traction across both academic and policymaking circles. Governments and funding bodies are increasingly stressing the importance of accountability and demonstrating value for money when making funding decisions. This has led to a shift in the primary goals of research policy from the development of scientific excellence towards the generation of broader economic and societal impacts. Notwithstanding the growing popularity of the impact concept, ambiguity surrounding definitions, robust measurement tools, and practical policy recommendations have contributed to a lack of conceptual and methodological clarity on research impact.

Stevens, Dean, and Wykes (2013, p.17) insist that the goal of standardising definitions, conceptions, measure and indicators of impact is unlikely to be achieved in the near-term. This chapter takes up this challenge by detailing the diverse meanings and conceptualisations of research impact to provide conceptual clarity, at least for the purpose of this study, on what is meant by impact, the main challenges facing evaluators, policymakers and research centres conducting research impact assessment (RIA) exercises, and frameworks and tools developed to measure and evaluate research impacts.

The rest of the chapter is structured as follows. Section 3.1 highlights the diversity of definitions of impact in the literature. Defining research impact is complicated as impact is often context-specific, meaning different things to different people. Section 3.2 presents the conceptual and methodological challenges facing evaluators and practitioners when measuring and evaluating the impact of investments in research activities. Research impact assessment (RIA) is complicated by well-known issues, such as estimating the degree of attribution, time lags and additionalities.

Section 3.3 presents the methodological tools available to measure and demonstrate impacts from research. There are numerous tools available to measure research impacts, both quantitative and qualitative. While each approach is illuminating, neither is complete. Research impact is a complex, multidimensional, iterative process. Therefore, combining methodological tools is often considered the best way to capture the tangible and intangible, expected and unexpected, short- and long-term impacts of research.

Section 3.4 presents a comprehensive review of the current frameworks available for measuring research impact. The aim of the literature review is to identify the strengths and weaknesses of current RIA frameworks and trade-offs considered when informing the development of the IMPACTS framework. Section 3.5 concludes the chapter with a discussion on the next steps involved in the thesis.

## 3.1 Defining Research Impacts

Measuring the impacts of publicly funded research has generated an extensive and evolving literature (Buxton and Hanney 1994, Salter and Martin 2001, Grant 2006, Spaapen and Van Drooge 2011, Hughes and Martin 2012, Harland and O' Connor 2015). While many definitions of impact exist, it is "surprisingly often left without a definition" (European Science Foundation, 2012, p.5). The development of a universal definition of research centre impact is complicated by conceptual and methodological issues associated with the term.

### 3.1.1 Definitions of Research Impact

Despite the growing popularity of the research impact concept, a universally accepted definition of impact has yet to be established. As Reinhardt (2013, as cited in Stevens, Dean, and Wykes 2013) states

> "Eskimos are said to distinguish 50 words for snow. In contrast, European research agencies talk about impact, impact and impact, but they all mean different concepts, attach different importance to it and implement it in different ways."

Stevens, Dean, and Wykes (2013) warn that the scale of the definitional challenges should not be underestimated as the size and diversity of the research community mean consensus in conceptualisation is unlikely. Research centres are differentiated by their aims and objectives, organisational structure, funding sources and research discipline. Furthermore, the nature of research activities conducted – from pure basic research to commercially driven applied research- will have a significant influence on the outcomes and impacts generated by the research centre. As such, developing an all-encompassing definition for research impact is challenging.

A possible explanation for the lack of suitable definitions of research impact is that impact in itself is complicated by conceptual and methodological issues which make its assessment very difficult. Martin (2011, p.247) asserts "impact comes in numerous forms; however, so its assessment is far from straightforward…various forms of research assessment have been developed, each more complicated, burdensome and intrusive than its predecessor".

Martin (2011) identifies multiple challenges associated with measuring research impacts. Firstly, impact may mean different things to different people depending on their profession or research discipline. For example, an engineer is likely to have a different conceptualisation of impact than that of a medical researcher. Secondly, differing magnitudes of impact – from extremely large to more moderate cases – make evaluation difficult. Thirdly, impact is not always positive. Furthermore, Martin (2011, p.250) describes RIA as being hindered by the fact that impacts are "indirect, partial, opaque and long-term".

Table 3.1 summarises some of the diverse range of definitions of research impact used in RIA frameworks.

**Table 3.1 Definitions of Research Impact**

| Approach | Year | Definition | Impact Categories |
|---|---|---|---|
| Research Impact Framework (RIF) | 2006 | "Health impacts are defined as the generation of new knowledge using the scientific method to identify and deal with health problems" | Policy, health services, societal - including economic, environmental, cultural, and social capital. |
| Research Excellence Framework (REF) | 2011 | "An effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia" | Economic, academic, societal, cultural, policy, health and wellbeing, environment |
| SIAMPI | 2011 | "Measurable effects of the work of a research group or program or a research funding instrument in a relevant social domain. The effect regards the human well-being ('quality of life') and or the social relations between people or organizations" | Economic, environmental, health, technological, societal |
| Canadian Academy of Health Sciences (CAHS) | 2011 | "Social impacts are changes that are broader than simply those to health and include changes to working systems, ethical understanding of health interventions, or population interactions". | Economic, commercial, health and wellbeing, research activity, Societal |
| European Science Foundation (ESF) | 2012 | "The consequences of an action that affects people's lives in areas that matter to them" | Economic, scientific, technological, societal, political, environmental, health, cultural, training |
| Contributions Framework | 2015 | "Changes in awareness, knowledge and understanding, ideas, attitudes and perceptions, and policy and practice as a result of research". | Policy and practice |
| Science Foundation Ireland (SFI) | 2015 | "The direct and indirect 'influence' of research or its 'effect on' an individual, a community, or society as a whole, including benefits to our economic, social, human and natural capital". | Economic, health and wellbeing, environmental, public policy, human capital, societal impact. |
| Research Councils UK (RCUK) | 2015 | "The demonstrable contribution that excellent research makes to society and the economy" | Economic, health and wellbeing, environmental, public policy, human capital, societal impact. |

Source: Compiled by Author

***Attribution or Contribution-based Approaches***

A popular definition of research impact was developed by the Research Excellence Framework (REF) in the United Kingdom. The REF was one of the first RIA frameworks to assess the broader impacts of research beyond academia. This represented a shift away from traditional evaluations of research based on bibliometrics and scientific quality towards metric-based approaches focused on broader economic and societal impacts. The REF defines impact as “an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.” (Higher Education Funding Council United Kingdom 2010).

Similarly, the initial definition of research impact adopted by the leading science funding body in Ireland focused on an attribution-based approach. Harland and O' Connor (2015, p.5) defined impact as “the direct and indirect ‘influence’ of research or its ‘effect on’ an individual, a community, or society as a whole, including benefits to our economic, social, human and natural capital.”

However, there has been a gradual shift in the conceptualisation of research impact from attribution-based definitions towards contributions-based approaches. Recently, Science Foundation Ireland (2018) followed the Research Council UK by adopting a contributions-based definition of research impact. Research impact is defined as “demonstrable contribution that excellent research makes to society and the economy”. This shift in the conceptualisation of impact is the result of difficulties associated with estimating attribution rates. As Morton (2012, p.202) emphasised the idea of “a contribution to an outcome rather than direct control over outcomes and acknowledges outside issues over any issue that will affect the same outcome”. These issues are discussed further in Section 3.2.2.

***Impacts may be generated across multiple categories***

Some of the difficulties associated with defining and conceptualising impact is that research impact may be generated simultaneously across many diverse categories – both public and private. Common categories of impact include but are not limited to - economic, health, environmental, public policy, human capacity, technological, societal, academic, cultural impacts. The measurement of research impacts is complicated by methodological issues associated with different categories of impact.

Table 3.2 highlights the multiple categories though which research impacts may be generated.

**Table 3.2 Categories of Research Impacts**

| Impact Category | Examples |
|---|---|
| Economic | contribution to the sale price of products, a firm's costs and revenues (micro-level), and economic returns either through economic growth or productivity growth (macro-level). |
| Societal | contribution to community welfare, quality of life, behaviour, practices and activities of people and groups. |
| Political | contribution to how policymakers act and how policies are constructed and to political stability. |
| Technological | contribution to the creation of product, process and service innovations. |
| Cultural | contribution to the understanding of ideas and reality, values and beliefs |
| Health | contribution to public health, life expectancy, prevention of illnesses and quality of life |
| Environmental | contribution to the management of the environment, for example, natural resources, environmental pollution, climate and meteorology. |
| Training | contribution to curricula, pedagogical tools, qualifications |

Source: European Science Foundation (2012, p.7)

The definition of research impact is often based on the category of impact which the research is concerned. For example, Kuruvilla et al. (2006, p.3) consider research impacts specifically in relation to health impacts, defining impacts as "the generation of new knowledge using the scientific method to identify and deal with health problems". However, impact categories are not necessarily mutually exclusive and cannot be differentiated neatly. As such, practitioners and policymakers should be cautious in setting definitions of impact too narrow. Research impact is a dynamic, uncertain, complex process involving multiple stakeholders and as a result, focusing on narrow criteria of impact may potentially overlook substantial unexpected impacts generated from the research.

As Jones and Grant (2013, as cited in Stevens, Dean, and Wykes 2013, p.20) note "we are at the beginning of a collective journey exploring the feasibility of developing impact indicators" and identify the "real challenge" for impact is "understanding what kinds of impact categories and indicators will be most appropriate, and in what contexts."

For example, the European Science Foundation (2012, p.5) defines impact as "consequences of an action that affects people's lives in areas that matter to them". This definition suggests that research impacts are subjective and what constitutes an impact lies in the eye of the beholder. This definition underappreciates unintended impacts that users may not be directly interested in, although they may be important. The assessment of research impacts should consider both intended and unintended impacts in order to provide a more robust evaluation of the overall impacts.

***Impacts may be both Positive and Negative***

Most definitions of impact suggest a change, effect or influence an individual, group, or society as a result of research activities. Furthermore, most definitions of impact assume these changes, effects or influences to be positive. For example, negative impacts related to increasing pollution and environmental effects, adverse health impacts or potential legal issues are often overlooked when formulating definitions of impact. However, it is important to consider these negative impacts when evaluating the impact of publicly funded research.

Derrick et al. (2018) introduced the concept of 'grimpacts' to measure and evaluate the negative impacts of research activities. The authors highlight the negative impact of research activities by using a case study approach. The authors identify three well-known examples of grimpacts from research. Firstly, Wakefield et al. (1998) asserted a link between the measles, mumps and rubella (MMR) vaccine and a "new syndrome" of autism and bowel disease. These findings contributed to a drop-in vaccine rates globally (to a vaccination level of 80% in the UK, well below the WHO 95% level for herd immunity). However, the study was eventually retracted due to lack of scientific rigour, evidence of data falsification, and lack of reproducibility of findings. Therefore, the research findings negatively impacted the lives of many children that did not receive essential vaccinations.

Secondly, the Cambridge Analytica scandal is a well-known controversy that emerged into public consciousness in early 2018. The controversy related to research into the app "thisiyourdigitallife" developed by Dr Aleksandr Kogan. Using Kogan's app, participants consented for their data to be used for academic purposes only. However, Facebook allowed data to be collected, not just on the participants, but also all people within the participant's social network. As a result, an estimated 70 million profiles were collected and, through Kogan's affiliations with CA, allowed to be used for commercial purposes. The use of this data has been since linked to unduly influencing the US elections since 2014, including the 2016 Presidential election, the 2016 UK/Europe referendum, and the 2013 and 2014 Kenyan elections.

Thirdly, the authors link the economic and financial crisis in 2008 to laissez-faire, free-market economic research which dominates the academic landscape in economics. Derrick et al. (2018, p.1202) assert "although the direct causes of the global financial crisis cannot be attributed to economists alone, it seems that their impact on economic and financial policies, in the US and other places, was crucial for allowing a general climate of deregulation of dangerous activities".

The standard form of data collection in research impact assessment methods is self-reported data provided by researchers, groups or centres. Therefore, it is unlikely that these stakeholders will provide evidence of negative impacts from their research activities given the importance of impact scores on future funding opportunities. Thus, assessing negative impacts falls on the part of the evaluator or funding body. However, identifying these grimpacts is a difficult task as much of research activities are protected by intellectual property, trade secrets and confidentiality. Therefore, identifying and evaluating Grimpacts outside of the more well-known examples is a challenging task requiring significant investment in time and resources that is often unavailable.

***Impacts are often in the eye of the beholder***

Another difficulty with defining and conceptualising research impacts is that stakeholders may be affected differently from the results of a research grant, project or programme. The generation of positive impacts for specific individuals or organisations may subsequently be considered negative impacts by others. Schumpeter's concept of 'creative destruction' is useful to illustrate this. Creative destruction refers to the "process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (Schumpeter 1942, p.82-83). For example, recent work by Frey and Osborne (2017) found increasing automation – associated with product and process innovations – may result in a reduction in as much as 47% of future employment. Similarly, Crowley and Doran (2019) find that two out of every five jobs are at risk as a result of automation in Ireland. This suggests that there will be winners and losers resulting from automation and both will have different views on whether the impact of automation is positive or negative.

***Definition of Research Impact developed in this thesis***

Research impact is a complex, iterative, multidimensional process involving multiple stakeholders. Therefore, definitions of research impact must be flexible and robust to the indirect, opaque, partial nature of impact. The definition of research centre impact developed in this thesis is

> "the contribution of research centres, either direct or indirect, short or long term, intentional or unintentional to society and the economy".

This definition of research centre impact identifies the complex and multidimensional nature of research impact process and provides the foundation for the construction of the Research Impact Index (RII). The next sub-section discusses the methodological challenges facing evaluators and practitioners in efforts to measure and evaluate the impact of publicly funded research.

## 3.2 Measuring the Economic Impact of Publicly funded Research Centres: Methodological Challenges

This section presents some well-known methodological challenges facing research centres, funding bodies and evaluators when conducting RIA exercises including availability of data, attribution problems, additionalities, nonlinearities and absorptive capacity of collaborative partners. These issues must be overcome before presenting robust estimates of the economic impact of publicly funded research centres.

### 3.2.1 Data availability

The process of generating impacts through research is complex, dynamic and non-linear involving multiple stakeholders. Although consensus exists as to the nature of the research process, research is often still portrayed as basic research transforming into applied research that then translates into technological development in forms such as devices, systems, drugs, and therapies that then exert an impact on the world. Therefore, measuring and evaluating research impacts requires data collection from multiple stakeholders. The most common approach to data collection is the self-reported survey data. However, self-reported impact data provided by stakeholders must be treated cautiously. Research impacts are often in the 'eye of the beholder' thus positive impacts from the perspective of one stakeholder may be considered negative impacts from the perspective of the other. Also, stakeholders may not be disinterested in the assessment of impact as future or continued funding may rely on emphasising positive impacts and downplaying negative ones.

### 3.2.2 Attribution

The attribution problem has been identified as a key challenge facing evaluators when measuring and evaluating the impact of publicly funded research (Martin and Tang 2007, Penfield et al. 2013, Harland and O' Connor 2015). The OECD (2010, p.17) defines attribution as

> "The ascription of a causal link between observed (or expected to be observed) changes and a specific intervention. … Attribution refers to that which is to be credited for the observed changes or results achieved. It represents the extent to which observed development effects can be attributed to a specific intervention ...".

As such, attribution refers to the extent to which observed changes may be caused by a single intervention. However, this presents a number of challenges for evaluators aiming to attribute a specific portion of economic or social impact results from a research project, programme, or centre. Firstly, the complexities of the research impact process make it difficult to directly attribute the portion of overall impacts resulting from a specific piece of research or research centre. The generation of research impacts requires the combination of knowledge, skills and capabilities from multiple stakeholders and it is not always possible or desirable to attribute the outcome to a single intervention or stakeholder. As Penfield et al. (2013, p.26) state "the exploitation of research to provide impact occurs through a complex variety of processes, individuals, and organizations, and therefore, attributing the contribution made by a specific individual, piece of research funding, strategy, or organization to an impact is not straight forward".

Secondly, the generation of economic impacts from research activities are often constrained by the issues of time lags and uncertainty, particularly for basic research, where projects may take much longer to achieve impact – sometimes many decades (Mansfield 1991, Salter and Martin 2001, Toole 2012, Haskel and Wallis 2013). As such, estimating robust attribution involves making a number of truly heroic assumptions that are open to challenge" (Hughes and Martin 2012, x-xi). These challenges have led to many evaluation systems utilising shorter-term research inputs, e.g. leveraged funding and cash investments and outputs, publication and patent counts for assessing the impact of publicly funded research. The rationale for selecting these metrics is that they are typically achieved at an early stage of the research process, usually between 1 to 3 years. As such, research centres have a high degree of control over the production of research outputs which makes estimating attribution rates more straightforward.

However, evaluators must be cautious when interpreting outputs as 'impacts' in and of themselves. Godin and Doré (2004, p.8) highlight an important distinction between research outputs and impacts: "while output is the direct result or product of science – production or mere volume of output as economists call it – impact is the effects that this output has had on society and the economy". Research outputs may be considered short-term, direct results of research that may lead to potential impacts in the future. However, the process of transforming outputs into impacts remains highly uncertain. These underlying concerns were summarised by Fielding during the early stages of the impact agenda

> "My sense is that it valorises what is short-term, readily visible and easily measurable. My sense is also that it has difficulty comprehending and valuing what is complex and problematic, what is uneven and unpredictable, what requires patience and tenacity. My sense is that it finds difficulty in distinguishing between levels of change, between what is fairly superficial and what is, to coin another already over-used, increasingly presumptuous phrase 'transformational', between what, in the management literature, is second-order rather than first-order change" (Fielding, 2003, p. 289).

Thirdly, disciplinary differences have been identified as a key issue when assessing the impacts generated by publicly funded research centres. The generation of economic impacts is demonstrated more easily across STEM (Science, Technology, Engineering and Maths) disciplines compared with arts, humanities and social science

(Meagher and Martin 2017, Rau, Goggins, and Fahy 2018). Penfield et al. (2013) assert that research impact assessment in these disciplines need to do more (compared to applied disciplines) to reflect the cumulative nature of intellectual advances underpinning research impact.

These challenges associated with the ‘attribution problem’ have led to many authors recommending a shift in research impact assessment towards a contribution-based approaches rather than an attribution-based approaches (Morton 2015, Ofir et al. 2016, Joly et al. 2015). These approaches suggests research ‘contributes’ to research outcomes and impacts, rather than implying causation. These approaches acknowledge the complexities, uncertainties and time-lags associated with the research process, particularly for basic research and allow researchers and research teams to identify how their research influenced impacts without requiring them to provide robust estimates.

### 3.2.3 Time Lags

The issue of time lags can make conducting research impact assessments challenging. If conducted too early, the full benefits from investments in research activities will likely not yet have emerged. If conducted too late, the challenges of recall, data collection and tracing the pathway from investment to outcomes become increasingly significant (Guthrie et al. 2018). Research outputs and impacts are often associated with considerable time lags from initial investment to final impact, often up to 17 years (Morris, Wooding, and Grant 2011).

While some research projects will have an immediate impact, others take much longer to achieve impact – sometimes many decades (Harland and O' Connor 2015). For example, in a seminal study, Mansfield (1991) finds that 10% of innovations would not have been possible without academic research. The findings suggest the average time lag between initial research and industrial innovation was seven years. However, results tend to vary across sectors. Toole (2012) studying the pharmaceutical sector in the USA finds that on average the lag between public investment and new applications is seventeen to twenty-four years.

### 3.2.4 Non-linearity of Research Process

There is a consensus that the process of generating research impacts is complex, dynamic, interactive, involving multiple stakeholders. However, research is often still portrayed as basic research transforming into applied research that then translates into technological development and broader research impacts. Non-linearity makes modelling the research and innovation-to-impact process difficult, and developing a set of metrics that is comprehensive and appropriate, yet comparable and feasible to collect, is extremely difficult (Jones, Manville, and Chataway 2017).

### 3.2.5 Additionality

Additionality relates to questions surrounding the extent to which additional innovation activity is stimulated by public support (Georghiou, Clarysse, and Steurs 2004) (Hyvärinen and Rautiainen 2007, Roper and Hewitt-Dundas 2016). This approach is grounded in the neoclassical economics perspective which provides the traditional justification for government investment in research resulting from market failures associated with knowledge production. This approach how the characteristics of knowledge contribute to suboptimal production levels by private businesses. Therefore, the neoclassical perspective argues that government investment in publicly funded research is required to increase knowledge production to the socially optimal level.

However, many studies have investigated whether public investment in R&D ‘crowds in’ or ‘crowds out’ private investment (Blank and Stigler, 1957, Lach 2002, Yla-Anntila et al., 2005, Toole 2007, Görg and Strobl 2007, Hussinger, 2008, Afcha and López, 2014). The findings of these studies are presented in Table 2.2 and Table 2.3. While the results of these studies tend to be ambiguous, most studies suggest complementarities between public and private investment in R&D. However, substitution effects can be found, particularly at the firm level. The findings suggest that the level of investment, the type of funding i.e. contract or subsidy, the nature of research activities and the size of the firm are important determinants of whether public R&D leads complementary or substitute effects for private R&D. Therefore, evaluators must be cautious when determining additionalities associated with investments in research activities.

Additionality has been applied widely to evaluation studies focused on measuring the impact of publicly funded research (Hyvärinen and Rautiainen 2007). Traditionally, additionalities resulting from publicly funded research have been categorised across two areas:

- Input additionalities: refers to how a firm's own R&D investment behaviour changes when it receives public R&D funding.
- Output additionalities: refers to the portion of overall outputs that would not be achieved without public funding.
- Behavioural additionalities: refers to changes in the behaviour of firms resulting from investment of public funding.

However, measuring additionalities is considered a difficult, if not impossible, task (Mosselman and Prince 2004). Self-reporting is a common approach to overcoming issues of additionality (Nason et al. 2008, Morton 2015). Barge-Gil and Modrego (2011) address the issue of additionality through a self-administered questionnaire. The authors suggest a taxonomy of impacts including economic impacts, technical impacts, impact on inputs, intangible impacts and 'other' impacts including measures of customer satisfaction and additionalities offered related to improvements in the speed and efficiency of research projects.

Alternatively, studies aimed at measuring input, output and behavioural additionality have utilised control groups (Aerts and Schmidt 2008, Czarnitzki and Licht 2006). These studies aim to create a counterfactual situation which involves comparing the outcomes of interest of those having benefitted from an intervention (the "treated group") with those of a group similar in all respects to the treatment group (the "comparison/control group"), the only difference being that the control group has not been exposed to the intervention (European Commission, 2020).

### 3.2.6 Absorptive Capacity

Section 2.3.3 presents the theoretical and empirical work on absorptive capacity. Therefore, this section will discuss the concept briefly in relation to challenges it presents to research impact assessment exercises. Absorptive capacity is defined as the ability to "ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal 1989).

The evolutionary models of innovation are outlined in Section 2.3.6. These models characterise innovation and research impact as a complex, iterative, dynamic process involving multiple stakeholders. Under these models, the production of new knowledge and technology is a necessary but not sufficient component of generating economic impacts. Instead, these models emphasise the importance of knowledge translation, uptake and use by external actors in the innovation system, usually firms, before economic impacts from research may be maximised. As such, the ability for industry partners to absorb, assimilate, transform and exploit knowledge from their external environment will influence the magnitude of impact generated by research centres.

The range of challenges associated with RIA has contributed to numerous methodologies and tools attempting to measure and evaluate research impacts. The next section discusses the quantitative and qualitative tools available for measuring and evaluating research impacts.

## 3.3 Established Approaches for Measuring Research Impact

This section provides an overview of the tools and methods available to measure and evaluate research impacts. Sampat and Azoulay (2011, p.11) caution against policymakers overselling what performance measures can do as evaluators are faced with trade-offs when choosing methods to measure and evaluate the impacts of research activities. The strengths and limitations of each approach are outlined in Table 3.3.

**Table 3.3 Available methods for evaluating research impacts**

| Method | Pros | Cons |
|---|---|---|
| **Surveys** | • provides qualitative analysis of outcomes and impacts<br>• can identify outputs and outcomes associated with research<br>• potential to treat attribution problem<br>• generalisability and reduces bias<br>• cost-effective | • poor response rate may contribute to bias<br>• dependent on the availability of contact details<br>• lack of flexibility to control for individual and/or institutional specific contexts |
| **Case Studies** | • provides an in-depth analysis of the research process<br>• identifies 'Pathways to impact.'<br>• useful information for a range of purposes<br>• allows for the inclusion of multiple impact categories | • potential selection bias: may not be representative<br>• cherry-picking best cases<br>• recall bias<br>• resource-intensive<br>• generalisability of results |
| **Econometric Studies** | • allows for counterfactual | • Requires database<br>• Does not capture qualitative elements of impact |
| **Economic analysis** | • allows for comparative analysis<br>• quantitative<br>• applied across a wide variety of sectors | • difficulties monetising impacts<br>• heavily reliant on assumptions<br>• difficult to identify attribution<br>• involves subjective decisions |
| **Bibliometrics** | • can indicate volume and quality of output<br>• suitable for analysis over time<br>• inexpensive<br>• allows for comparability<br>• quantitative<br>• transparent and reproducible results<br>• database availability | • research fields and disciplines need to be considered<br>• only suitable peer-review publications<br>• incentives for gaming<br>• citations do not necessarily imply the quality<br>• highly skewed distributions.<br>• citations need time to accumulate. |

| | | |
|---|---|---|
| **Peer Review** | • widely accepted within the research community<br>• credibility with the academic community<br>• rigorous | • time-consuming<br>• cost and burden<br>• lack of transparency<br>• may be less valid when assessing ‘impacts’ compared to scientific outputs. |
| **Logic Modelling** | • identify stages of the research process<br>• easily understandable<br>• provide a systematic structure to aid thinking<br>• visualisation<br>• shared understanding | • quantification is difficult<br>• the research process is non-linear<br>• oversimplified<br>• may change over time<br>• does not capture the counterfactual |

Source: Compiled by Author

### 3.3.1 Surveys

Surveys offer a useful approach for assessing the economic impacts of publicly funded research. Surveys provide a broad overview of the current status of a programme, project or body of research (Guthrie et al. 2013). Surveys offer significant advantages beyond quantitative methodologies, such as metrics-based approaches, for conducting RIA including providing detailed information about the relationships between various stakeholders within an ecosystem, the processes by which a variety of impacts occur and the variety of forms of engagement between the research community and industry.

Currently, there is a lack of databases available to conduct RIA exercises using secondary data. Therefore, surveys provide a valuable approach for collecting a large quantity of data on the processes and outcomes of research projects in a time and cost-efficient manner. Furthermore, surveys provide an advantage over other methods (e.g. case studies) in that they can be administered over long distances using phone, mail and web-based surveys. Section 6.2 presents the different modes of data collection available to researchers when administering survey instruments.

Surveys are a useful tool for tackling the 'attribution problem' that has plagued research impact assessment exercises. Barge-Gil and Modrego (2011) develop a questionnaire to estimate the impact of research and technology organisations in Spain. The authors adopt a two-stage approach to deal with the attribution problem. Firstly, they asked firms about their relationships with their main collaborative partner and following this ask firms explicitly how their companies would have evolved in the absence of this relationship. A similar method is employed in this thesis and is outlined in Section 6.2.2.

However, survey methods are not without limitations when assessing the impacts of research activities. Firstly, surveys are often labour intensive, requiring significant resources and expertise. Survey instruments require careful construction and administrative oversight and even well-designed studies can quickly fall apart. Survey instruments are inflexible in that the initial design generally remains unchanged throughout the course of the study as any changes may potentially reduce comparability across respondents.

Secondly, surveys often address only part of the impact equation as it may be challenging to explore the results of the survey beyond a particular project or company under study. Survey respondents may have a bias toward internal activities of their own business and limited knowledge of their sectors and technologies (Salter and Martin 2001). Furthermore, surveys may be impacted by self-selection bias as people that choose to respond may be different from those that do not respond. Thirdly, surveys containing yes/no questions make "it impossible to quantify these impacts" as it is constructed (Guellec and Pattinson 2001).

Fourthly, surveys and questionnaire are generally completed by one point of contact, and therefore, it is necessary that the contact person has all relevant information being requested. Vie, Stensli, and Lauvås (2014) suggest businesses are very dependent on the capabilities of the contact person for collaborations with public research organisations. The contact person may have a negative effect on knowledge transfer between business and research organisations. Furthermore, there may be potential for a contact person to provide incorrect information, suffer memory gaps and try to provide answers that impress the investigator, rather than the correct information.

Despite these limitations, surveys have been used extensively to measure the impact of publicly funded research on productivity and growth. Mansfield (1991) conducted one of the most well-known studies using this approach. The study surveyed R&D managers from 76 U.S. firms to estimate the percentage of their products or processes that could not have been developed in the last ten years without academic research. The findings suggest 10% of innovations would not have been possible without academic research, although significant differences between sectors existed.

Evaluators often favour a mixed-methods approaches to RIA by combining survey methods with more in-depth qualitative tools, such as narratives and case studies. Guthrie et al. (2013) note that case studies and narratives are useful tools for providing context and exploring reasoning behind survey responses. The next sub-section discusses the strengths and limitations of adopting case studies as a research impact assessment (RIA) tool.

### 3.3.2 Case Studies

Case studies are a widely used RIA tool to evaluate the economic and societal impacts of publicly funded research. Case studies provide rich and detailed information on specific topics or events, as well as related and contextual conditions. The aim of case studies is to provide an exploratory rather than a prescriptive approach to research impact assessment. As such, the approach offers flexibility to evaluators as it offers a creative and innovative approach which supports analysis of multiple topics and subjects (Guthrie et al. 2013).

RIA is a rapidly developing discipline; however, its origins are recent. As such, there is a lack of standardised and widely accepted definitions, frameworks and tools for assessing the impact of publicly funded research projects, programmes and centres. The lack of consensus about theoretical and methodological underpinnings of 'impact' is identified as one reason for case studies being the preferred approach to RIA. Furthermore, Martin (2011) asserts that although case studies are labour-intensive and very much a 'craft activity', they are currently considered the best method of evaluation available.

In general, case studies are used to gather narrow, in-depth information compared to broader data gathered through survey instruments. Therefore, case studies tend not to be used for comparisons across many projects, programmes or centres. Rather, they are used to be illustrative is some particular way. Bornmann (2013, p.26) states "case studies do not permit generalizations to be made, but they do provide in-depth insight into processes which resulted in societal impact and therefore lead to a better understanding of these processes". Furthermore, case studies may be used to generate a number of examples of best practices and success stories that may inform future research projects and programmes (Guthrie et al. 2013).

A key strength of case studies as an RIA tool is related to their flexibility. The complexities of the research impact process make it difficult to ascertain ex-ante the full range of potential impacts from a research project. Case studies are used provide in-depth analysis of impact generation across multiple dimensions, including unexpected impacts. Bell, Shaw, and Boaz (2011, p.228) state case studies offer engagement "with complexity… and the detailed, in-depth understandings gained about events or initiatives over which the researcher has little or no control". Therefore, this approach is well suited for conducting formative or process-oriented evaluations of research impact. The approach provides detailed information on the research impact process, highlighting contextual and environmental factors that influence the generation of research impacts. The depth and richness of information provided by case studies are useful for demonstrating diverse impact channels and allows for the inclusion of multiple impact categories.

The primary limitation of case studies for evaluating the impact of publicly funded research is the lack of generalisability of findings. Case studies are often context-specific, thus drawing comparisons across researchers, projects or organisations is a difficult task. Therefore, the usefulness of case studies for informing or justifying public investment decisions is subjective. Usually, "case studies do not permit generalizations to be made, but they do provide in-depth insight into processes which resulted in societal impact and therefore lead to a better understanding of these processes" (Rymer, 2011 as cited in Bornmann 2013, p.226).

However, Guthrie et al. (2013, p.130) state "groups of case studies together can say more about the broader population if they are carefully selected". For example, Joly et al. (2015) developed the ASIRPA RIA framework. ASIRPA is an ex-post RIA approach that draws on standardised case studies which combine quantitative and qualitative methodologies. An advantage of case studies is they may be applied across a wide variety of organisations and contexts. However, this wide applicability makes defining a strict methodology for producing case studies difficult.

Furthermore, case studies are resource-intensive, requiring a high level of initial investment that can be a challenge for evaluating large amounts of research, for example the Research Excellence Framework adopted in the UK. The approach is generally expensive to administer, and the depth of the information may take a long time to analyse. As such, smaller subsets of the total population are usually selected, followed by 'overview' techniques (Guthrie et al. 2013).

According to Donovan (2008), case studies represent the last of the stages currently employed in the methodical approach to measure research impacts. Furthermore, Joly et al. (2015, p.5) state "However, so far, the approaches available generally remain very qualitative and context related. The main challenge for impact evaluation then is to retain the advantages of case studies while reducing their limitations."

### 3.3.3 Econometric Studies

Generally, econometric studies focus on large scale patterns and are useful for providing an aggregate picture of statistical regularities among countries and regions. Generally, these studies are conducted under New Growth models (Romer 1986, Lucas 1988) which incorporates human capital, knowledge and innovation into the growth model and relies on the existence of externalities, increasing returns and the lack of inputs that cannot be accumulated. Usually, studies of this nature attempt to measure the impact of public R&D on productivity and growth and virtually all studies have found a positive relationship between public investment in R&D and economic growth.

Hughes and Martin (2012, p.21) state

> “the production function approach may be useful in identifying broad statistical relationships but it generally requires a host of simplifying assumptions about the precise underlying nature of the production technologies linking inputs to outputs, the weights to be attached to each ‘factor’ of production in estimating their impact on output and productivity, and the time-lags between the application of a particular input (e.g. publicly funded research) and its associated output”.

Moreover, there is a lack of reliable indicators developed in these models on the impacts of publicly funded research on economic growth. Tekes (2011, as cited in Mostert et al. 2014, p.8) state that “there are very few indicator-activities that genuinely link socio-economic impact factors to research and innovation, and there are even fewer activities linking socio-economic impacts in specific areas to RDI activity”. As such, results can be misleading with studies often too simplistic with unreasonable assumptions about the nature of innovation (Salter and Martin 2001).

Furthermore, econometrics studies linking publicly funded research to productivity essentially occur within a ‘black box’, shedding little light on the process through which impact occurs (Hughes and Martin 2012). Moreover, this approach cannot be used to assess the effect of a single research centre on indicators such as growth, employment and productivity.

### 3.3.4 Economic Analysis

Guthrie et al. (2013, p.147) describe economic analysis as "a comparative analysis that examines the costs (inputs) and consequences (outputs) of two or more policies, actions or interventions. The economic evaluation takes a number of different forms, depending on the extent of monetisation of costs and benefits to be analysed and/or compared". Two of the most popular economic approaches in evaluation exercises are i) cost-benefit analysis and ii) input-output approaches. These approaches are discussed further below.

#### 3.3.4.1 Cost-Benefit analysis

Cost-benefit analysis (CBA) is conceptually the simplest of all forms of economic impact analysis (OECD 2019). CBA is an analytical tool commonly used to appraise public investment decisions including for example, policy proposals, programs, and projects, in the areas of transport, water conservation, recreational travel, public infrastructure projects etc. CBA of publicly funded research centres is a new and developing research area. Preliminary efforts to demonstrate the feasibility of the tool have been developed, yet there is still a lack of experience and consensus around best practices in applying the tool to research organisations. Recently, some attempts to develop a CBA theoretical framework for RDI infrastructures have been made.

Sartori et al. (2014) develop a framework for measuring the impact of research infrastructures through cost-benefit analysis. The rationale for CBA is to facilitate a more efficient allocation of resources, demonstrate the societal benefits of a particular intervention rather than possible alternatives (Sartori et al. 2014, p.15). Furthermore, Florio, Forte, and Sirtori (2016) develop an ex-ante CBA model for major research infrastructures. The authors apply the model to two cases in physics involving particle accelerators (the Large Hadron Collider at CERN and the National Centre for Oncological Treatment in Italy). The findings suggest that benefits exceed costs, with an expected net present value of about €2.9 billion.

Section 3.2 presents the key challenges facing government, funding bodies and evaluators when conducting RIA exercises. These challenges present issues for effective implementation of CBA as a research evaluation tool. Firstly, measuring impacts through CBA requires all benefits and costs associated with a proposal, policy or project to be transformed into monetary terms, including items for which the market does not provide a satisfactory measure of economic value.

Secondly, research impact is a complex, nonlinear process characterised by a high degree of uncertainty. Florio, Forte, and Sirtori (2016) note that the use of CBA to evaluate RDI infrastructures has often been hindered by the intangible nature and the uncertainty associated with the achievement of research results. The uncertainty of outcomes associated with an investment in research centres is much higher than other public infrastructure investments such as roads, bridges, hospitals etc. Bornmann (2017) highlights the high degree of inequality in outcomes of research investments. Typically, a large portion of overall research impacts is generated from a small sample of investments. However, difficulties associated with determining ex-ante which projects will lead to the largest impacts is a significant issue faced by policymakers and evaluators.

#### 3.3.4.2 Input-Output Approaches

Input-output approaches are based on identifying direct, indirect and induced impacts of an activity or investment. These studies are important, due partly to the perceived need to justify the investment of publicly funded research centres. Input-Output studies have been the most common method of demonstrating the magnitude of impacts generated by publicly funded research centres in Ireland. For example, Lucey (2015) calculated that an investment of €108 million in SFI-funded research centre AMBER generated €505 million in output over a ten-year period between 2007 and 2016. Therefore, every €1 of public funding invested in the research centre generated €3.67 in the economy.

Similarly, Lenihan, Mulligan, and Perez-Alaniz (2018) conducted an input-output exercise to measure the economic impact of SFI funded research centre Lero. The study estimates that for every €1 invested in Lero between 2005 and 2008, the research centre contributed €5.25 to the Irish economy. A third study by SFI-funded research centre APC finds that every €1 invested in the research centre contributes to €5.60 to the economy. Taking 2017 as a representative year, APC produced €65.4m in output from an input of €11.7m State investment. Furthermore, for every €1 invested by SFI, APC has added another €1.84 of inward investment, with 50% coming from non-exchequer sources.

The ‘attribution problem’ is a key issue with economic analyses, with many commentators highlighting potential issues with their claims of ‘exceptional returns’. The complexities of the research impact process make it difficult to directly attribute the portion of overall impacts resulting from a specific piece of research or research centre. Hughes and Martin (2012, x-xi) note “identifying exactly what proportion of the ultimate economic benefit should be attributed to the earlier biomedical research involves making a number of truly heroic assumptions that are open to challenge”. Economic approaches such as production function and input-output approaches are useful for providing estimates for the magnitude of research impacts. However, these approaches are limited as they do not shed light on the processes involved in generating these impacts.

Also, there is the additionality problem. The money invested in these centres could have been invested in another research centre or activity. The research centre only adds value if its return is greater than the next best alternative for funding and the contribution to the economy is actually the difference between the research centre and the next best possible return. This is a counterfactual analysis that is very difficult to conduct, though it should be possible to compare the claimed returns to a standard return on investment benchmark.

### 3.3.5 Bibliometrics

Metrics are a well-established tool for capturing the economic and societal impacts of publicly funded research. The field of metrics-based evaluations has developed rapidly with many subfields emerging. Firstly, bibliometrics refers to the use of statistical techniques to measure the quality of scientific research. This method involves multiple techniques for assessing the quantity, and quality of scientific publications and patents.

Secondly, scientometrics is a field of study concerned with measuring and analysing the science of science. Scientometrics can be defined as the “quantitative study of science, communication in science, and science policy” (Hess 1997, p.75). Scientometrics is a subfield of bibliometrics. However, it is much broader in scope, including research funding, demography, geography etc. Thirdly, altmetrics are based mainly around social media applications such as research blogs, social media e.g. Twitter, and reference management software e.g. Mendeley. Several different forms of measurable signals are available on social media (e.g. likes, shares, downloads, number of followers, comments etc.). As such, several categorisation of altmetrics have emerged (Lin and Fenner 2013, Haustein 2016).

There are several advantages associated with using metrics-based approaches to measure and evaluate the economic and societal impacts of publicly funded research. Firstly, metrics are a well-established method of measuring scientific quality. Therefore, they are widely applicable to the evaluation of grants, projects and programmes that emphasise publishing or patenting. Secondly, metrics are a useful tool for addressing a wide range of research topics such as research outputs and activities, knowledge transfer and commercialisation channels and collaborative relationships and networks. Future advancements in the sophistication of these tools may contribute to the development of indicators of 'quality' or even 'research excellence' (Guthrie et al. 2013). Thirdly, metrics generate a wide range of indicators for research impact assessments, which can be very useful for addressing large amounts of complex data. Fourthly, metrics are useful as they allow for consistency and comparability across researchers, research centres and research systems.

Finally, metrics may be used to support qualitative evaluation methods such as peer review and expert opinion. The Leiden Manifesto sets out ten guiding principles for evaluators when conducting research impact assessment exercises. The first principle of the Manifesto states that quantitative evaluation should support qualitative, expert assessment. Bibliometric analysis is often combined with qualitative tools, such as peer review or case studies, to provide a more in-depth, contextual approach to evaluation. Moed (2009) suggests that the future of research evaluation rests on the intelligent combination of bibliometric analysis with peer review, which may reduce limitations inherent in the peer review system.

However, metrics-based approaches are not without limitations. Grant (2006) notes that "although metrics can provide evidence of quantifiable changes or impacts from our research, they are unable to adequately provide evidence of the qualitative impacts that take place and hence are not suitable for all of the impacts we encounter". Additionally, Donovan (2011, p.75) finds "metrics-only approaches employing economic data and science, technology and innovation indicators were found to be behind the times: best practice combines narratives with relevant qualitative and quantitative indicators to gauge broader social, environmental, cultural and economic public value”.

However, Tang and Hu (2018, p.331) acknowledge that the “misuse of metrics such as journal impact factors and citation counts can discredit creative research, encourage citation gaming and provoke research misconduct”. The significance of indicators of scientific quality and research impact guiding both investment and employment decisions has naturally led researchers and research organisations adapting their behaviour in order to perform well in assessment exercises. This is an issue identified by Goodheart’s Law which states that “when a measure becomes a target, it ceases to be a good measure” (Muller 2018). These developments have limited the ability for policymakers and practitioners to conduct robust RIAs.

The shift in focus of research policy in many countries from demonstrating scientific excellence towards funding research with the potential to generate wider economic and societal impacts has led to many commentators questioning the usefulness of traditional metrics. Hicks et al. (2015, p.429) caution against the reliance solely on metrics-based approaches for conducting research impact assessments noting “metrics have proliferated: usually well-intentioned, not always well informed, often ill-applied”.

The Research Excellence Framework (REF) is the current national assessment exercise in the UK to measure scientific excellence and impact of UK HEIs. The rationale for the development of the REF was to shift away from research evaluations based on qualitative, expert opinion towards a metrics-based approach focused on wider research impacts. However, the proposal experienced a backlash from the academic community, citing the lack of suitable measures of research impact and research quality available. Donovan (2019) warned that this shift in policy focus might contribute to a rise ‘metricide’ by abandoning time-consuming impact narratives in favour of simple metrics.

From a theoretical perspective, some researchers doubt whether metrics-based approaches can capture multidimensional concepts, such as scientific quality and research impact. Furthermore, metrics-based approaches present methodological challenges for evaluation exercises, including issues related to journal coverage in bibliometric databases, identifying author affiliation, and choosing the right timeframe

(Guthrie et al. 2013). Furthermore, it is often difficult to assess the contribution of each individual to multi-author research projects (Sheikh 2000).

Another challenge facing evaluators using metrics-based approaches is capturing discipline-specific differences, particularly for transdisciplinary and multidisciplinary research. Bibliometric indicators of scientific quality, such as publication counts and citation counts, and commercialisation indicators, such as patent counts vary significantly across disciplines.

It is argued that while metrics-based approaches are suitable for measuring research 'outputs', they tend to be less suitable for capturing wider economic and societal impacts of research activities. Section 2.3 presented the evolutionary model of research impact proposed by Hughes and Kitson (2012). The authors illustrate that the degree of attribution is reduced as research outputs are transformed into outcomes and impacts. Similarly, Ofir et al. (2016) identify research outputs with a research institutions 'sphere of control' while research impacts are categorised as 'sphere of interest'.

The time lag associated with research impacts also presents challenges for metrics-based approaches to evaluation. Research outputs and impacts are often associated with considerable time lags from initial investment to final impact (Morris, Wooding, and Grant 2011). Given publication and citations build up over time, it has been argued that this approach biases against early career researchers as typically they do not have sufficient time to build up a large publication profile.

### 3.3.6 Peer Review

Peer review is a widely accepted method within academia for evaluating the scientific merit and quality of research outputs. Peer review is defined as "a process of subjecting an author's scholarly work, research or ideas to the scrutiny of others who are experts in the same field" (Kelly, Sadeghieh, and Adeli 2014). The underlying assumption is that experts within a given field are the best-placed individuals to understand the subject, identify the strengths and weaknesses of the work, and assess the scientific quality of the research. Furthermore, peer review is often used to inform decisions relating to funding, hiring, and promotion within academia, and the broader scientific community.

One of the key strengths of peer review as a research methodology is its credibility and acceptability amongst the academic community (Guthrie et al. 2013). The practice of peer review emerged in the early 19th Century with many learned societies seeking referee reports to ensure the expertise involved in decision-making. The widespread acceptability across the academic community is critical for establishing the credibility of the decisions resulting from peer review evaluations.

However, despite the strengths of peer review for RIAs, the approach has some limitations. Firstly, there is a significant degree of burden and costs associated with the peer review process. Peer review tends to be a slow process with reviews often taking up to a year, which can delay the progress of the research process. Peer review is almost always conducted free of charge, and often reviewers work outside regular working hours. As such, journal editors often have difficulties recruiting experts to review scientific outputs.

As Riley and Jones (2016, p.629) note

> "Most journals provide no training, there are almost no tangible rewards, and little, if any, acknowledgement. It is a time-consuming task, with several sources quoting the average time spent on each review as being as much as 6 hours or more".

Secondly, some commentators have questioned the effectiveness of the peer review process for evaluating the quality of science. Numerous scholars have expressed concern that peer review is primarily devoted to maintaining the status quo, placing less of an emphasis on radical, paradigm-shifting research (Mahoney 1977, Horrobin 1990). There are many examples of academic journals initially rejecting ground-breaking research through the peer-review process.

For example, George Akerlof's seminal contribution to the field of economics of information, *'The Market for 'Lemons': Quality, Uncertainty and the Market Mechanism",* analysed whether products would exist in markets with asymmetric information and unobservable product quality. The article contributed to a new sub-discipline within economics and Akerlof was awarded the Nobel Prize. However, three leading economics journals initially rejected the paper before it was published in the *Quarterly Journal of Economics*. Akerlof identified two reasons for the article's initial rejection from academic journals. Firstly, the publication of the article introduced the economics of information into the mainstream conversation and secondly, Akerlof believed the editors did not like the article's readable style.

As Akerlof (1994, as cited in Gans and Shepherd 1994, p.171) stated

> "The editors probably objected most to two things. They were afraid that if 'information' was brought into economics, it would lose all rigour since in that case, almost anything could be said-there being so many ways that information can affect an equilibrium. They also almost surely objected to the style of the article which did not reflect the usual solemnity of economic journals"

A recent study by Siler, Lee, and Bero (2015) analysed 1,008 manuscripts submitted to three leading medical journals to determine the effectiveness of peer review for assess the quality of research, proxied through citation outcomes. The findings suggest that desk rejected articles received fewer citations than articles that went for review while lower manuscript peer review scores were associated with lower citations when articles were eventually published. However, there were many instances of highly cited articles being rejected, including the fourteen most popular. Despite this finding, results show that, on the whole, there was value added in peer review

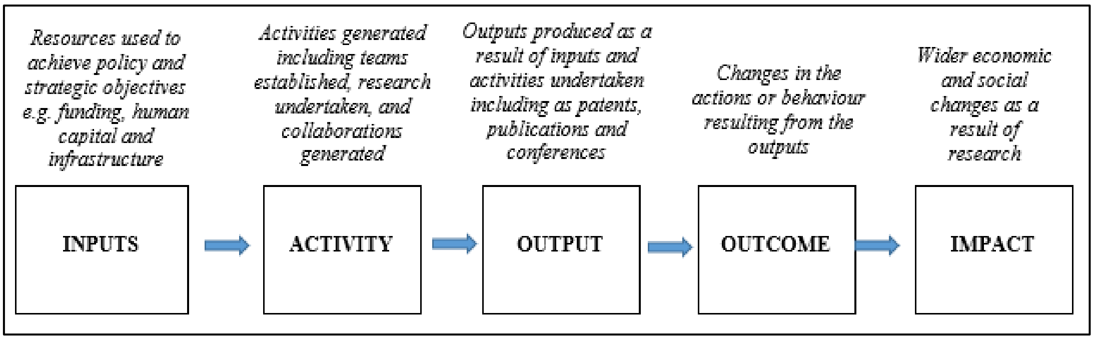
Thirdly, a common criticism of peer review is that it is an anonymous process that presents potential biases against early career researchers. As Pendlebury (2009, p.6) states, "bias in peer review, whether intentional or inadvertent is widely recognized as a confounding factor in efforts to judge the quality of research". Merton and Merton (1968) insisted that science tends to reward high-status academics based on their previous reputation, labelling this bias 'Matthew Effect'. Furthermore, early career researchers may be at a disadvantage when making funding proposals as they do not have sufficient publication history to support their grant application. Publications and citations build up over time. Therefore, reviewers may express bias when evaluating funding applications based on seniority of academics.

Fourthly, peer review may be less useful for evaluation multi, and transdisciplinary research as reviewers are often experts in specific fields and may not have sufficient expertise to review across fields. Previous research highlights difficulties associated with peer review panels resolving 'interdisciplinary research' in light of different interpretations of the concept within a panel (McLeish and Strang 2016, Lamont 2009). Finally, while peer review is a useful methodological tool for evaluating the quality of scientific research, many authors question its usefulness for measuring broader economic and societal impacts of research.

### 3.3.7 Logic Modelling

The logic model is widely used across the research impact assessment literature to distinguish between the different 'stages' of the research impact process. The logic model is a graphical representation of he shared relationships among the resources, activities, outputs, outcomes, and impact of a research project, programme or centre. Figure 3.1 presents each stage of the research impact process diagrammatically.

**Figure 3.1 Stages in Logic modelling**




Source: Compiled by Author

Throughout the literature, the terms 'outputs', 'outcomes' and' impacts' have been used almost interchangeably, but important differences exist between the terms in relation to timescales and their relevance. Penfield et al. (2013, p.21) argue that "although some might find the distinction somewhat marginal or even confusing, this differentiation between outputs, outcomes, and impact is important". Table 3.4 distinguishes between each 'stage' of the research impact process.

**Table 3.4 Stages of Logic Modelling**

| Stage | Description |
|---|---|
| Inputs | Resources used to achieve policy and strategic objectives and deliver economic and commercial impact, including capital (including human capital) and infrastructure required to achieve policy objectives. |
| Activities | Activities generated as a result of research funding, including teams, established, grants awarded, and research is undertaken. |
| Outputs | Outputs produced as a result of inputs and activities undertaken, e.g. patents, publications, conferences attendances. |
| Outcomes | Changes in the actions or behaviour resulting from the outputs (e.g. citations in policy documents, new products and technologies developed) |
| Impacts | Impact refers to the broader economic and social benefits of research |

Source: Compiled by Author

Research outputs refer to the short-term products of science resulting from the combination of research inputs and activities undertaken. However, evaluators and practitioners should be cautious when interpreting outputs as 'impacts' in and of themselves. Godin and Doré (2004, p.8) state "while output is the direct result or product of science – production or mere volume of output as economists call it – impact is the effects that this output has had on society and the economy". Therefore, outputs may be considered short-term, direct results of research that may lead to potential impacts in the future. However, this process of transforming outputs into impacts remains highly uncertain.

For example, while patents are considered an important output of publicly funded research, the value and impact of the patent itself are often uncertain. Nelson (2009) finds that direct patent citations dramatically understate the extent of technology diffusion compared to licenses and publications. As such, a patent represents only a potential measure of research impact, which must be transformed and exploited before generating wider economic impacts from research activities.

Research outcomes or 'intermediate' outcomes may be categorised intermediate effects, with 'impact' associated with longer-term, ultimate effects of research activities. Hughes and Martin (2012, p.21-22) note "long time-scales, uncertainty, and complementarities may make it helpful to assess changes in 'intermediate' level activities and outcomes rather than focussing solely on final output or impact effects".

Similarly, Jaffe (2015) suggests the usefulness in identifying intermediate outputs as their achievement would contribute towards achieving the ultimate desired impact.

Research impact is sometimes referred to as the ‘final’ outcome, however this conceptualisation is problematic as often it is impossible to know when an impact is final (European Science Foundation 2012). For example, George Boole (1847) introduced Boolean algebra in his first book ‘*The Mathematical Analysis of Logic’*. Boolean algebra is used in all modern-day computers and is utilised by companies, such as Google, to facilitate internet searches. Therefore, Boole’s research, which was conducted in the middle of the 19th Century is still generating economic and social impacts today. Furthermore, it is not yet known whether further applications of Boole’s work will be made in the future. Thus, one cannot say with certainty that the current impacts of Boole’s research are ‘final’.

Despite the limitations associated with this approach and its variants, logic modelling is still widely used to evaluate the impacts of research activities. RIA frameworks, such as the ‘Payback’ framework are based on an adapted logic model. The next section presents the established RIA frameworks developed to measure and evaluate the impacts of publicly funded research.

## 3.4 Established Approaches to Measuring Research Impact

It is generally accepted that investment in publicly funded research contributes to many economic and societal impacts. However, there is a lack of consensus amongst practitioners around suitable frameworks to describe the research impact process, methodologies and indicators to capture the full range of research impacts and the variety of channels through which research impact can be realised. This section outlines available frameworks for measuring the impact of publicly funded research evident in the literature.

The aim of the literature review is to update previous efforts by highlighting developments within the field of RIA studies, identifying key issues in RIA exercises and proposals to overcome these issues. Furthermore, this section provides recommendations towards future developments in the field of RIA towards the development of robust, flexible frameworks. Table 3.5 consolidates the main features of different types of research impact assessment frameworks across a set of selected comparative dimensions.

**Table 3.5 Research Impact Assessment Frameworks**

| Approach | Developed By | Implemented By | Impact Category | Level of Aggregation | Methodology |
|---|---|---|---|---|---|
| **Payback** | Buxton and Hanney (1994) | Hanney (2007),Nason et al. (2008), Scott et al. (2011) | Health | Grants, Individual Projects, Departments, Institutions | Case Study, surveys, bibliometrics, interviews, logic modelling, economic analysis |
| **Research Impact Framework (RIF)** | Kuruvilla et al. (2006) | Kuruvilla, Mays, and Walt (2007), Ovseiko, Oancea, and Buchan (2012) | Health | Individual Projects | Case Study, interviews, surveys, economic analysis |
| **Research Excellence Framework (REF)** | HEFCE (2007) | Hinrichs and Grant (2015), Greenhalgh and Fahy (2015), Kellard and Śliwa (2016) | Societal | Individual Researchers, Individual Projects, Departments, Institutions | Case study, bibliometrics, peer review, expert panel |
| **SIAMPI** | Spaapen and Van Drooge (2011) | Molas-Gallart and Tang (2011), De Jong et al. (2014) | Societal | Individual Projects, Departments, Institutions | In-depth interviews, document mining, site visits |
| **ASIRPA** | Joly et al. (2015) | Yet to be Implemented | Agricultural Research | Individual Projects | Case Study, Interview, bibliometrics, expert panel |
| **Contributions Framework** | Morton (2015) | Morton and Fleming (2013) | Policy | Grants, Individual Projects, | Case study, contribution analysis, interviews |
| **STAR Metrics** | NSF (2010) | Lane and Schwarz (2012) | Societal | Individual Researchers | Bibliometrics, data mining, economic analysis |
| **Research Quality Plus (RQ+)** | Ofir et al. (2016) | McLean and Sen (2018) | Scientific and Societal | project, program, grant portfolio | Case study, expert panel, bibliometrics |

Source: Compiled by Author

RIA frameworks are categorised into five categories: National assessment exercises, Health impact frameworks, Interaction based frameworks, Big data frameworks and Alternative frameworks.

### 3.4.1 National Assessment Exercises

#### 3.4.1.1 Research Excellence Framework (REF)

The Research Excellence Framework (REF) is the current framework for evaluating the quality of scientific research and impact of UK HEIs. In 2006, the UK government announced its decision to replace the previous evaluation framework, Research Assessment Evaluation (RAE) with the REF. This proposal represented a shift away from research evaluations focused on scientific quality towards a metrics-based approach focused on wider economic and societal impacts of research. The original aims of the REF were:

- to produce robust UK-wide indicators of research excellence for all disciplines which can be used to benchmark quality against international standards and to drive the Council's funding for research
- to provide a basis for distributing funding primarily by reference to research excellence, and to fund excellent research in all its forms wherever it is found
- to reduce significantly the administrative burden on institutions in comparison to the RAE
- to avoid creating any undesirable behavioural incentives
- to promote equality and diversity
- to provide a stable framework for our continuing support of a world-leading research base within HEIs" (HEFCE 2007).

Between 2008 and 2010, the Higher Education Funding Council of England (HEFCE) conducted several pilot studies to test the feasibility of bibliometric based evaluations of research quality and develop an approach to measure impact in REF. Early proposals by the UK Higher Education funding bodies suggested that citation analysis may be included in the new evaluation framework, in addition to previous quantitative measures, as citations could be considered a measure of research quality. 'Impact' was later added as an important separate and explicit element. 'Impact' was considered broader than academic sphere and focused specifically on wider economic and social impacts.

However, these early proposals were met with considerable resistance from the academic community with several critiques put forward against the proposed changes. Firstly, one of the issues identified was that suitable metrics and indicators of research quality and impact were not widely available. The RAE was a qualitative evaluation based on peer review and expert opinion. Secondly, Martin (2011) warned that research evaluation is becoming increasingly ‘complicated, burdensome and intrusive’ and questioned whether the costs of assessment are becoming greater than the benefits associated with them. Thirdly, the threats to academic autonomy were identified as key issues that must be overcome when designing effective evaluation frameworks (Smith, Ward, and House 2011). These criticisms led to considerable backtracking on the initial proposals, particularly related to the intended use of bibliometrics of evaluation. As Guthrie et al. (2013, p.78) state

> “As a result, the current REF framework proposals are in essence an extended RAE, with an additional significant assessment component accounting for 20 per cent of the overall evaluation covering the wider impacts of research outside academia, such as those on society and the economy. Whether the REF reduces burden or even aims to do so, is questionable, although this was one of the key rationales for making changes to its predecessor, the RAE”.

The first REF exercise took place in 2014 with 154 higher education institutes in the UK making submissions across thirty-six subject-based units of assessment. These submissions were then reviewed by a panel of experts and ‘impact profiles’ were produced for each submission. The impact profile for each submission was generated through an assessment of REF case studies and accompanying impact statements. These submissions were made at the level of subject-specific sub-panels, which typically corresponded to academic disciplines. The initial criteria for scoring each case study provided to the assessment panels were related to ‘reach’ and ‘significance’, which provided ratings across three components: assessments of the quality of outputs, the impact of the research, and the research environment of the unit that is submitted for assessment. Table 3.6 outlines the Research Excellence Framework scoring criteria.

**Table 3.6 Research Excellent Framework Scoring**

| Star | Score | Details |
|---|---|---|
| **Four Star** | **Exceptional** | Ground-breaking or transformative impacts of major value or significance with wide-ranging relevance have been demonstrated |
| **Three Star** | **Excellent** | Highly significant or innovative (but not quite ground-breaking) impacts relevant to several situations have been demonstrated |
| **Two Star** | **Very good** | Substantial impacts of more than incremental significance or incremental improvements that are wide-ranging have been demonstrated |
| **One Star** | **Good** | Impacts in the form of incremental improvements or process innovation of modest range have been demonstrated |
| **n/a** | **Unclassified** | The impacts are of little or no significance or reach, or the underpinning research was not of high quality, or research-based activity within the submitted unit did not make a significant contribution to the impact |

Source: Higher Education Funding Council United Kingdom (2010)

The overall quality profile awarded to each submission is based on three elements of assessment, weighted as follows: the quality of research outputs (65 per cent), impact of research beyond academia (20 per cent), the research environment (15 per cent). Each overall impact profile shows the proportion of research activity judged by the panels to have met each of the four starred quality levels. Despite criticism aimed at incorporating impact into national evaluation strategies, it appears impact is gaining increasing relevance for future evaluation exercises. In REF2021 the weighting of 'impact of research beyond academia' has increased to from 20 to 25 per cent.

### 3.4.1.2 Excellence in Research for Australia (ERA)

ERA is the framework for measuring and evaluating research quality in Australia's Excellence in Research in Australia (ERA) higher education institutes. The framework was allocated in the 2009-2010 budget and is being managed by the Australian Research Council. The objectives of the ERA include:

- establish a framework which can be used by firms, businesses and policymakers to measure and evaluate the quality of research produced in Australia's research institution
- identify discipline areas of research strength and areas where opportunities exist for further improvements in research areas
- identify emerging research area and opportunities for development in these areas
- allow for comparisons of Australia's research nationally and internationally for all discipline areas.

The unit of analysis of the ERA is the research discipline for each institution as defined by Fields of Research (FoR) codes. The ERA 2015 evaluation collected data and undertook evaluations across eight discipline clusters[2]. The ERA 2015 evaluations were informed by four broad categories of indicators including: indicators of research quality, indicators of research activity, indicators of research application and indicators of recognition. Similar to the Research Excellence Framework, the ERA developed a five-point rating scale to evaluate research quality. The similarities in the measurement scale allow for comparisons across countries. Table 3.7 presents the five-point scale developed by the ERA.

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[2] Biological and Biotechnological Sciences; Humanities and Creative Arts; Economics and Commerce, Education and Human Society, Engineering and Environmental Sciences, Mathematical, Information and Computing Science, Medical and Health Sciences, Physical, Chemical and Earth Sciences.

**Table 3.7 ERA Five Point Scale**

| Star | Details |
|---|---|
| **Five Star** | The unit of evaluation profile is characterised by evidence of outstanding performance well above world standard presented by the suite of indicators used for evaluation. |
| **Four Star** | The unit of evaluation profile is characterised by evidence of performance above world standard presented by the suite of indicators used for evaluation. |
| **Three Star** | The unit of evaluation profile is characterised by evidence of average performance at world standard presented by the suite of indicators used for evaluation. |
| **Two Star** | The unit of evaluation profile is characterised by evidence of performance below world standard presented by the suite of indicators used for evaluation |
| **One Star** | The unit of evaluation profile is characterised by evidence of performance well below world standard presented by the suite of indicators used for evaluation. |
| **n/a** | Not assessed due to low volume. The number of research outputs does not meet the volume threshold standard for evaluation in ERA |

Source: ERA (2015, p.26)

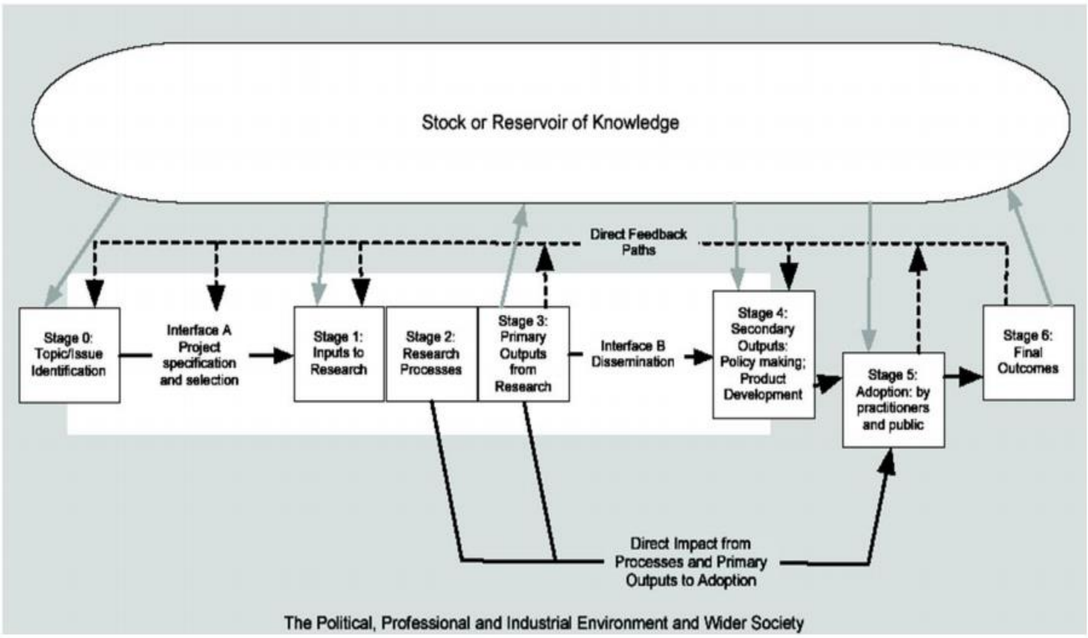
### 3.4.2 Health Impact Approaches

Measuring and evaluating the impacts of health research is the most widely studied areas of research impact assessment. Health research generates high levels of both private and public funding for research activities; thus, accountability and justification for funding is high on the research agenda.

#### 3.4.2.1 Payback Framework

The Payback Framework was developed by Martin Buxton and Stephen Hanney to assess the impacts of health research. The framework provides a common structure which facilitates the collection of comparable data across multiple projects, and programmes. It is currently the most widely used and comprehensive method available for measuring research impacts in a systematic way. The Payback Framework is outlined diagrammatically in

**Figure 3.2 Payback Framework**




Source: Hanney et al. (2004, p.7)

The Payback Framework consists of two elements: a logic model representation of the research processes and multidimensional categorisation of research impacts. The model consists of seven stages and two interfaces. The framework traces health research impacts from initial inception (stage 0) and research inputs (stage 1) through the research process (stage 2) and dissemination (interface B) towards wider health and societal impacts (stage 6). Furthermore, the framework contains a series of feedback loops highlighting the non-linearity of the research process. The Payback framework classifies impacts or ‘Paybacks’ across five categories: two traditional academic categories and three wider impact categories. These categories are highlighted in Table 3.8.

**Table 3.8 Payback Categories**

| | Impact Categories |
|---|---|
| **Traditional Academic** | Knowledge Production (e.g. peer-review articles etc.) |
| | Capacity building and targeting future research |
| **Wider** | Informing policies |
| | Health and health sector benefits |
| | Broader economic benefits |

Source: Based on Buxton and Hanney (1996)

The Payback Framework facilitates comparability across space and place by providing data collection structures for each case study, allowing data and information to be recorded in the same place. While attributing research impacts at different stages of the research process is difficult, it is possible to identify broad correlations that identify where categories of impact are most likely found in the logic model (Donovan and Hanney 2011).

For example, knowledge production and capacity building are generally considered research outputs, requiring dissemination, absorption and translation before being transformed into wider impacts. These wider impacts include informing policies, health and health sector impacts and broader economic impacts benefits. Although the framework was initially developed to measure and evaluate health research, the design is flexible enough so that it can be applied across a wide range of research typologies. Donovan and Hanney (2011, p.181) note

> "it could be undertaken by researchers internally within the scientific community and be aimed at addressing particular scientific imperatives or unanswered questions. Alternatively, the topic identification could involve, at least partially, the wider environment and include policy-makers, healthcare professionals, patient representatives, etc."

The Payback framework is the most widely applied RIA framework. Kwan et al. (2007) applied an adapted version of the Payback framework to evaluate the outcomes and impacts of Health and Health Services Research Fund in Hong Kong. The study collected data though a survey instrument rather than applying the commonly used case study approach. In Ireland, Nason et al. (2008) applied the Payback Framework to eight case studies of research grants funded by the Health Research Board (HRB) to illustrate the diversity and extent of impacts stemming from that research. The report recommends that the HRB could extend this work by carrying out additional case studies to build a bank of cases that would provide general insights into the development of HRB-funded research. Over time, such a bank would start to allow comparisons between different types or areas of funding.

Scott et al. (2011) applied an adapted Payback framework of the Mind-Body Interactions and Health Program in the United States. The evaluation called for the completion of case studies for 15 National Institute of Health (NIH) research centres, while the research projects were evaluated based on semi-structured interviews with principal investigators. The authors identified two key issues which present challenges to the future application of the framework – the timing of the evaluation and the attribution problem.

#### 3.4.2.2 Becker Medical Library Model for Assessment of Research Impact

The ‘Becker Medical Library Model for Assessment of Research Impact’ aims to assess the impacts of research beyond traditional measures of impact, such as publications and citations. The framework is intended to be used as a complement, not a substitute, for these traditional measures of research impact to provide a more robust measure of research impact. The aim of the framework is to trace outputs of research to identify tangible impact indicators that demonstrate evidence of research impact.

The Becker Medical Library Model for Assessment of Research Impact framework was initially launched in 2009 and subsequently revised in 2011. The development of the framework resulted from a review of a large clinical trial study on glaucoma, the Ocular Hypertension Treatment Study. The authors aimed to develop a framework for research evaluation which goes beyond the standard citation analysis towards the identification of outcome and impact indicators that can be documented and quantified for assessment of research impact (Sarli, Dubinsky, and Holmes 2010).

Similar to the Payback framework, the Becker Medical Library Model for Assessment of Research Impact adopts a logic model approach to research impact assessment focused on identifying specific indicators for each stage of the research process.

Table 3.8 presents the impact categories included in the Becker Medical Library Model for Assessment of Research Impact.

**Table 3.9 Categories of Impact in the Becker Model**

| Impact Category | Potential Indicators |
|---|---|
| **Advancement of Knowledge** | Publications, citations, conferences, collaborations, licensing, outreach activities, methodologies and instruments, altmetrics, training |
| **Clinical Implementation** | Biological materials, clinical decision aids, clinical outcome trials, clinical guidelines, coding, diagnostic testing, medical devices, mobile applications, quality of life measures |
| **Community Benefit** | Awareness, consumer health information, health promotion, lifestyle interventions, partnerships, standard of care |
| **Legislation and Policy** | Committee Participation, guidelines, legislation, policy, regulations, standards |
| **Economic Benefit** | Cost-saving, cost-effectiveness, disease prevention, quality of life, licensing, life expectancy, spin-offs, start-ups |

Source: Compiled by Author based on Sarli, Dubinsky, and Holmes (2010)

The advantages and disadvantages of metrics-based approaches to research impact assessment are presented in Section 3.4.4, thus will only be discussed here briefly. Firstly, not all indicators of research impact are easily quantifiable. Secondly, there is a lack of consensus or guidance on the selection of suitable indicators to provide a robust measure of research impacts. Thirdly, similar to Payback framework, it is difficult to attribute a specific impact to a particular stage in the research process. Sarli, Dubinsky, and Holmes (2010) noted that an in-depth review was required in some instances to identify the correlation between research findings and a specific indicator, and often multiple research studies were cited as supporting documentation. Despite these limitations, the framework is useful in guiding evaluators and raising awareness of the importance of tracing and documenting indicators from initial inputs to outcomes and impacts.

#### 3.4.2.3 Research Impact Framework

The Research Impact Framework was developed by Kuruvilla et al. (2006) to measure and evaluate health research impacts in the UK. The objective of the framework is to facilitate a ‘DIY’ approach to research impact assessment, which encourages researchers to systematically analyse and evaluate the impact stemming from their research activities. The framework aims to develop a standardised approach for measuring research impacts to facilitate benchmarking across time and cases and promote accountability in relation to the use of resources. However, “the framework is not aligned with any particular philosophy, is not in itself evaluative and does not prioritise impacts or propose causal pathways” (Kuruvilla et al. 2006, p.3).

The initial steps undertaken in developing the framework involved a review of the research impact assessment literature. The aim of the literature review was to identify potential impact areas from health research. Following the initial mapping exercise, the authors developed a semi-structured interview guide designed to allow researchers to provide narratives of their impacts. However, the authors note “it is important to recognise that these narratives are generated and assessed in the context of historically rich and complex, often contending, views on the role of science and its relationship with society” (Kuruvilla et al. 2006, p.2).

The next stage involved conducting semi-structured interviews with principal investigators from a sample of research projects. The design of the interview was guided by narrative areas identified during the mapping project.

Table 3.10 outlines the impact categories identified by Kuruvilla et al. (2006). These categories were designed to guide impact narrative and are not considered exhaustive and may not be suitable in all contexts. However, these categories point to potential research impact areas that may facilitate researchers thinking more strategically about their impact.

**Table 3.10 Research Impact Framework Impact Categories**

| **Description of research project/programme** | Topics/research area:<br>Geopolitical contexts:<br>Funders and budget:<br>Research management, influencing events and challenges: |
|---|---|
| **1. Research related Impacts** | 1.1 Type of problem/knowledge<br>1.2 Research methods used<br>1.3 Publications and papers<br>1.4 Products, patents and translatability potential<br>1.5 Research networks<br>1.6 Leadership and awards<br>1.7 Research management<br>1.8 Communication |
| **2. Policy impact** | 2.1 Level of policy-making<br>2.2 Type of policy<br>2.3 Nature of policy impact<br>2.4. Policy networks<br>2.5 Political capita |
| **3. Service impact** | 3.1 Type of services: health/intersectoral<br>3.2 Evidence-based practice<br>3.3 Quality of care<br>3.4 Information systems<br>3.5 Services management<br>3.6 Cost-containment and cost-effectiveness |
| **4. Societal impact** | 4.1 Knowledge, attitudes and behaviour<br>4.2 Health literacy<br>4.3 Health status<br>4.4 Equity and human rights<br>4.5 Macroeconomic/related to the economy<br>4.6 Social capital and empowerment<br>4.7 Culture and art<br>4.8 Sustainable development outcomes |

Source: Kuruvilla et al. (2006, p.4)

Kuruvilla, Mays, and Walt (2007) tested the validity and feasibility of the Research Impact Framework on projects in the Department of Public Health and Policy at the London School of Hygiene and Tropical Medicine. These projects were selected in order to maximise variation with regards to project topics and with regard to the familiarity of the principal investigators with research impact assessment concepts. The study involved primary analysis of seven projects and secondary analysis of a further four projects. The analysis involved using the framework categories as a guide to help researchers identify and describe the impacts of specific research projects. Kuruvilla, Mays, and Walt (2007, p.30) found that recurrent themes identified across the case studies which positively influence research impact include “researchers’ continued involvement in research and policy networks, established track records in a field, and the ability to identify and respond to key influencing events, such as policy window".

### 3.4.3 Interaction-based Approaches

#### 3.4.3.1 Social Impact Assessment Methods for research and funding instruments through the study of Productive Interactions (SIAMPI)

'Social Impact Assessment Methods for research and funding instruments through the study of Productive Interactions between science and society', better known as SIAMPI, is a project funded by the European Commission which uses a unique approach to evaluating research impact. SIAMPI aims to measure societal impacts through productive interactions, i.e. mechanisms through which research activities are translated into societal impacts. 'Interaction' refers to contact between a researcher and a stakeholder.

The rationale for the development of the SIAMPI approach is twofold: firstly, to develop a robust tool to capture the mechanisms of translating scientific outputs to address grand societal challenges. These mechanisms include both codified (publications, policy documents, prototype, shared facilities) and tacit (staff mobility, workshops) transfer mechanisms. Secondly, the approach focuses on *productive interactions,* i.e. the relationship between researchers and society contributes to societal impacts. The focus on productive interactions is an attempt to reduce the 'attribution problem' inherent in RIA studies. Rather than attempting to attribute a monetary value of impact generated through collaboration, instead the productive interaction approach focuses on the mechanisms or 'pathways' to research impact.

The objectives of the approach are based on institutional learning rather than attempting to provide comparative analysis across space, place or time. The application of the approach can be either formative or summative and can be conducted at a variety to levels, e.g. project, programme or group. SIAMPI approach is based on the fundamental premise that research evaluation should be used for organisational and personal learning rather than competitive ranking and judgement. As such, SIAMPI has not been used for funding allocation purposes.

The underlying assumption of this approach is that the creation and development of knowledge and research impact are facilitated through interactions between researchers and society. This process is multi-directional with three types of Productive interactions identified including:

- Direct personal contacts: any direct communication and might be as simple as a conversation but also covers more complex interactions such as research collaborations.
- Indirect interaction: any type of interaction that is mediated by a carrier. This could be interaction via a publication of any type, from journal article to clinical guideline, or through the media, an exhibition, film or production, or through artefacts, such as websites, prototypes, demonstrations and designs.
- Financial interaction: where there is some kind of economic exchange between stakeholders and researchers. This could take the form of direct research funding, but could also include IP rights, interaction in relation to contracts, or consulting, for example, or interactions through financial contributions in kind, such as facility sharing.

The SIAMPI approach is focused on analysing the process of research impact, as opposed to impacts themselves. The rationale for this is that researchers and research centres have direct influence over the process of impact, and thus can control and develop strategically. As such, the SIAMPI approach is less constrained by the issue of time lags, which are evident in a wide variety of research evaluation approaches. The reason being that while impact generally takes several years before it is realised, interactions take place as research is being conducted.

A key idea of this approach is that research impact assessment should be context-specific, considering the goals and strategic objectives of researchers and research centres. As Guthrie et al. (2013, p.92) state “different research will be conducted with different goals and purposes in mind, and one-size fits- all approach does not produce the best results in learning and development, as it does not consider the context in which research is conducted”.

The flexibility of the approach has been identified as one of its key strengths. However, this flexibility acts as a 'double-edged sword' in the sense that open-ended approaches to RIA are often difficult to manage. These approaches present challenges in the development of standardised metrics and indicators to measure research impact. As such, comparability and generalisability of results are limited.

Another strength of the approach is that it reduces perverse incentives presented by metrics-based approaches. Section 3.3.5. discusses these limitations in more detail. The emphasis on the research impact process, as opposed to impacts themselves, means the SIAMPI approach is less vulnerable to gaming compared with metrics-based approaches. However, due to the detailed data requirements to carry out analysis, which tends to be time-consuming, the approach has not been widely applied.

#### 3.4.3.2 Research Contribution Framework

Morton (2015) developed the Research Contribution Framework to measure and evaluate the policy impacts of research activities. The approach adopts a case study approach to explore the pathways to research impact. The framework incorporates and analyses both process and outcomes of research activities, thus moving beyond other frameworks which tend to focus on one approach over the other.

This approach suggests research 'contributes' to research outcomes and impacts, rather than implying causation. The aim is to address the 'attribution problem' raised in impact assessment studies (Spaapen and Van Drooge 2011). The Research Contribution Framework provides "a method of linking research and knowledge exchange to wider outcomes whilst acknowledging and including contextual factors that help or hinder research impact" (Morton 2015, p.405).

Morton (2015) identifies research impact as a complex, interactive process with research impact viewed as a process of engagement. The framework proposes a model of research impact generation involving interaction and communication between several stakeholders over time. Morton (2015, p.414) argues that the idea of a counterfactual is unnecessary when viewing research impact from a systems perspective as counterfactuals are "irrelevant in a complex system".

Morton (2015, p.211) highlighted the five-stage process of applying the Contributions framework: i) to conduct contextual analysis, ii) to develop a logic model for the unit of assessment identified by the participants (project, programme, or centre); iii) assess assumptions and risks; iv) identify possible evidence and evidence gaps; and v) assemble a research contribution story or report based on the work.

Since the development of the framework, it has been used to assess the impact of several Economic and Social Research Council (ESRC) investments, the impact of participatory research (Morton and Fleming 2013), and the Knowledge to Action work of National Health Service (NHS) Education for Scotland.

#### 3.4.3.3 RQ+ Assessment Framework

Research Quality Plus (RQ+) framework was developed by the Canadian International Development Research Centre (IDRC) to evaluate the quality of research for development. The aim of this approach is to support the planning, management, and learning processes of a research project, programme, or grant portfolio (Ofir et al. 2016). The RQ+ Assessment Framework provides a flexible, systems-based, holistic approach to measuring and evaluating the scientific quality and impact of research. RQ+ is a flexible framework that allows evaluators to tailor the assessment to goals and objectives, context and values.

In 2011, the IDRC launched a study to fill this gap by identifying ways to improve evaluation and strengthen research quality. The aims of the study were to define and conceptualise ‘research excellence’ in international development research, develop frameworks and tools to evaluate research excellence, analyse the performance of the IDRC in relation to achieving their goals and identify factors that influence IDRC performance in supporting research excellence. These early studies contributed to the development of the RQ+ Framework (Ofir et al. 2016). RQ+ aims to address the systemic weaknesses in research evaluation highlighted in the Leiden Manifesto (Hicks et al. 2015) and offers a potential method of operationalising the principles set out in the Manifesto (McLean and Sen 2018).

The RQ+ framework is an adopted logic model which incorporates non-linear processes. The research impact process is composed into three spheres representing the short, medium- and long-term outcomes of the research process. Furthermore, the model incorporates the ease of attribution of results resulting from a research grant, project or organisation.

The RQ+ categorises three stages along the process of generating research excellence:

- Sphere of Control: The sphere of control is largely under the control of the researcher or research team and partners. The sphere of control typically relates to shorter-term outputs generated directly through research activities (e.g. publications, patents etc.) Therefore, research outputs within the sphere of control have a high degree of attribution, thus may be linked back to a specific piece of research.
- Sphere of Influence: Outputs within this sphere are influenced by the work of the researcher or research team but are not directly under their control. The outputs included in this sphere are typically generated through the dissemination, translation and exploitation of research findings by other stakeholders within the innovation system, most often private businesses. The 'attribution problem' is often present in this sphere, as it is often difficult to estimate attribution in outcomes produced involving multiple stakeholders.
- Sphere of Interest: Sphere of interest refers to wider economic and societal impacts of research activities. Under the logic model, these are traditionally referred to as impacts. These impacts are traditionally nonlinear, produced over a longer time period and involve multiple stakeholders. Thus, attributing these impacts to a specific piece of research or research group is a very difficult task. Many authors argue that a contributions-based approach to wider research impacts is more appropriate (Morton 2015, Joly et al. 2015). This approach allows researchers and research teams to identify how their research influenced impacts without requiring them to provide robust estimates.

The RQ+ Assessment Framework is composed of the three main elements. They include: i) key influences; ii) research quality dimensions and sub-dimensions; and, iii) evaluative rubrics**.**

- *Key Influences:* This component refers to those influences, both internally within the organisation and externally in the wider environment, that influence the quality of research produced by a research organisation.
- *Research Quality Dimensions and Sub-Dimensions:* Research quality is categorised into four dimensions: research integrity (scientific quality), research legitimacy (relevancy to stakeholders), research importance (originality of research) and positioning for use (impact enhancement).
- *Evaluative Rubrics:* Each key influence and research quality dimensions are based on customisable assessment rubrics that make use of both qualitative and quantitative measures. Assessments must be systematic, comparable and based on qualitative and quantitative empirical evidence, not just on the opinion of the evaluator — no matter how expert they are.

McLean and Sen (2018) applied the RQ+ framework to assess 170 studies conducted by the IDRC between 2010 and 2015. The authors conducted a meta-analysis of the evaluations to assess the feasibility of the RQ+ framework to measure research excellence. The research included in the sample is multidisciplinary and was conducted globally, with the majority in developing regions of Africa, Asia, Latin America, the Caribbean, and the Middle East. The findings suggest scientifically excellent research is useful research, a deeper understanding of the research environment in which research is conducted helps in understanding the research quality, and capacity strengthening is positively correlated with both the quality and originality of research.

#### 3.4.3.4 Socio-Economic Analysis of the Impacts of Public Agricultural Research (ASIRPA)

Joly et al. (2015) developed an approach to measure and evaluate the socio-economic impact of public research organisations through case studies. The Socio-Economic Analysis of the Impacts of Public Agricultural Research (ASIRPA) was established by the French National Agricultural Research Institute in 2011. ASIRPA is an ex-post

RIA framework based on standardised case studies with the aim to provide opportunities for internal learning and accountability.

The approach attempts to move beyond simply identifying input, outputs and outcomes in the research impact process towards an understanding of the process of transformation of knowledge into tangible outputs, outcomes and impacts. As such, the framework has similarities with the SIAMPI framework with its emphasis on interaction, communication, networking and engagement as drivers of research impact. Joly et al. (2015 p.2) note

> "ASIRPA belongs to the family of approaches that investigate impact-generating mechanisms, disentangle the roles of networks of actors in the innovation process, bypass project fallacy pitfalls (Georghiou et al. 2002), and account for long-term impacts".

This approach presents a methodology for evaluating research impacts at the institutional level by scaling up individual case studies to the level of the institution. Furthermore, the study describes the process of standardisation of case studies, which allows for comparison and aggregation of data through the creation of a database. The next sub-section presents the big data approaches to measuring and evaluating impacts from research.

### 3.4.4 Big Data Approaches

#### 3.4.4.1 STAR Metrics

'Science and Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competitiveness and Science' (STAR) Metrics is a collaborative effort between government and research centres in the United States to develop a data infrastructure and tools that can be used to measure and evaluate the impact of publicly funded research projects. The project was led by the National Institute for Health (NIH) and National Science Foundation (NSF), under the auspices of Office of Science and Technology Policy (OSTP). The objectives of the project are to provide accountability for investment decisions, improve decision making and reduce the burden on scientists performing research by creating comparable and reproducible data sets.

In 2009, a pilot was conducted which covered two phases:

- Phase I: Develop quantifiable and standardised measures for the impact of research investment on job creation, using data from research institutes existing database records.
- Phase II: Develop measures of the impact of federal science investment on knowledge advancement, societal outcomes, employment outcomes, and economic outcomes.

The unit of analysis under the STAR Metrics framework is the scientist or cluster of scientists. Phase I of the pilot identified ways of collecting information on how many scientists, including graduate students, undergraduate students and research staff, are receiving public funding to support research activities. Furthermore, it calculates the impact of public funding on employment. The approach traces funding awards made to scientists through the administrative systems of each institution.

This data is used to estimate the number of jobs supported by public investment in research activities. The number of jobs created was classified across four categories: jobs supported for employees directly employed by research institute, indirect jobs created by research institution spending for the purchase of goods and services, jobs supported by research institution spending on sub-awards, and jobs supported by indirect costs such as spending on facilities and administrations (NIH 2010).

Phase I of the STAR Metrics project was discontinued on 1st January 2016 with the project no longer accepting new applicants and participating applicants allowed submit data only until that time. Phase II of the project will attempt to connect a particular investment with the outcomes that it produces. While the choice of metrics is currently under development, it has been suggested that impact categories will include economic, social and health impacts as well as knowledge creation (Guthrie et al. 2013).

#### 3.4.4.2 ResearchFish

While not an RIA framework *per se*, ResearchFish provides a useful mechanism to gather data for impact assessment. ResearchFish is an online system used by funders, research institutions and researchers to track over £45 billion of research funding, over 100,000 awards and over two million research outputs, outcomes and impacts.

ResearchFish provides an online platform that aims to reduce the burden of data gathering on research performers, organisations and funders. The platform allows for standardised data collection across multiple funding bodies.

Research performers are required to provide data on common indicators and metrics of impact across all funding bodies throughout the duration of their funding, and for a period after that has ended. Therefore, this approach moves away from reporting-based evaluations produced following the completion of the research project. Furthermore, research performers are required to provide additional information for specific awards or specific funding body awards.

### 3.4.5 Comparative Analysis: Towards a Research Impact Assessment Framework for Irish Research Centres

The objective of this sub-section is to provide a detailed analysis of established RIA frameworks in order to identify similarities and differences across the approaches within a range of related conceptual contexts in which research impact is situated. This analysis provides key insights into the strengths and limitations of available frameworks to measure impacts from research. These considerations provide key insights into for the development of a novel framework to measure and evaluate the economic impacts of publicly funded research centres. The IMPACTS framework, presented in Chapter 5, provides a holistic approach to research impact assessment (RIA) which aims to maintain key strengths of previous RIA frameworks while overcoming key limitations.

RIA is a research discipline in its relative infancy yet has developed an extensive and growing literature. The previous section highlighted the most commonly used RIA frameworks (e.g. Payback, REF, SIAMPI) which have been applied across a wide range of studies as well as recent contributions that have yet been implemented across a wide range of studies (e.g. ASPIRA, Research Contribution Framework, RQ+).

Table 3.11 consolidates the main features of different types of research impact frameworks across a set of selected comparative dimensions. Different frameworks are appropriate in different circumstances as a single, all-embracing universalistic framework suitable for capturing both dynamics and magnitude of research impact.

**Table 3.11 Frameworks to Measure Research Impact**

| Approach | Developed By | Implemented By | Impact Category | Level of Aggregation | Methodology |
|---|---|---|---|---|---|
| **Payback** | Buxton and Hanney (1994) | Hanney (2007),Nason et al. (2008), Scott et al. (2011) | Health | Grants, Individual Projects, Departments, Institutions | Case Study, surveys, bibliometrics, interviews, logic modelling, economic analysis |
| **RIF** | Kuruvilla et al. (2006) | Kuruvilla, Mays, and Walt (2007), Ovseiko, Oancea, and Buchan (2012) | Health | Individual Projects | Case Study, interviews, surveys, economic analysis |
| **REF** | (HEFCE 2007) | Hinrichs and Grant (2015), Greenhalgh and Fahy (2015), Kellard and Śliwa (2016) | Societal | Individual Researchers, Individual Projects, Departments, Institutions | Case study, bibliometrics, peer review, expert panel |
| **SIAMPI** | Spaapen and Van Drooge (2011) | Molas-Gallart and Tang (2011), De Jong et al. (2014) | Societal | Individual Projects, Departments, Institutions | In-depth interviews, document mining, site visits |
| **ASIRPA** | Joly et al. (2015) | Yet to be Implemented | Agricultural Research | Individual Projects | Case Study, Interview, bibliometrics, expert panel |
| **Contributions Framework** | Morton (2015) | Morton and Fleming (2013) | Policy | Grants, Individual Projects, | Case study, contribution analysis, interviews |
| **STAR Metrics** | NSF (2010) | Lane and Schwarz (2012) | Societal | Individual Researchers | Bibliometrics, data mining, economic analysis |
| **RQ+** | Ofir et al. (2016) | McLean and Sen (2018) | Scientific and Societal | project, program, grant portfolio | Case study, expert panel, bibliometrics |

Source: Compiled by Author

### L*evel of Analysis*

An important consideration when choosing, developing or implementing RIA frameworks is the level of analysis the framework is concerned with. Greenhalgh et al. (2016) provide a comparative analysis of six RIA frameworks asserting “one size does not fit all”. The characteristics of the RIA framework is an important determinant of its suitability for conducting analysis at various levels of aggregation. The level of aggregation can range from analysis of an individual grant, researcher or project to departments, institutions or the research system.

The level of analysis is dependent on the objectives of the researchers and the funding bodies. It should be noted that the levels of analysis utilised in each framework are not mutually exclusive with many frameworks implemented simultaneously at many levels of analysis. For example, the Payback Framework has been conducted primarily at an individual project level yet is flexible enough that it can be applied across departments or research centres. Greenhalgh et al. (2016) identify potential limitations of frameworks which measure research impact at the project level. RIA at the project level may not be sufficient when exploring the impact of the total sum of research activities. It may be possible to simply aggregate the impacts from individual projects into an overall research impact as synergy effects, multiple funding sources and difficulties in attributing research impact to a project may prove extremely problematic.

### *Methodological Approaches*

Research evaluation can be used for multiple purposes, including “to provide accountability; for analysis and learning; to facilitate funding allocation; and for advocacy” Guthrie et al. (2013, p.1). However, researchers face trade-offs when conducting research impact evaluations. RIA frameworks may inform decision-making in relation to the type of data to collect and where to find it, but they cannot identify how to collect it. There are numerous data collection methods, but most fall into two broad categories, quantitative methods and qualitative methods. The methodology chosen is dependent on the aims and purpose of the evaluation exercise.

Quantitative approaches tend to provide top-down, longitudinal data comparable across time, sectors, and countries. A key strength of quantitative data is that it tends to be objective and transparent, removing the requirement of decisions made through opinion or interpretation. Notwithstanding this, subjective judgement may be required in deciding on which indicator data is required. However, this type of analysis requires a high level of initial burden as significant work may be required at the outset to develop and implement the approach (Guthrie et al. 2013). Alternatively, qualitative approaches consist of gathering and interpreting primary data through case studies, face-to-face interviews and focus groups. These approaches provide a much narrower scope than the top-down approach and recommendations based on these studies are usually made with reference to centres or industries regions rather than multiple centres/industries at a regional, national or international level.

Quantitative economic approaches for estimating the rate of return on investment in research tend to be convenient, practical and easy to use. However, these approaches suffer from many limitations which should be considered when estimating the rates of return on investment in research. Firstly, while these approaches may provide estimates on the magnitudes and elasticities of both private and social returns to investment in research, they provide very little explanatory value on the underlying dynamics of the research impact process. This failure to provide value in opening the 'black box' of research impact has been identified as a major drawback of these approaches.

Secondly, quantitative approaches often operate under the assumption that impacts are generated in a linear process. The limitations of this approach are outlined in 3.3.6. Under this approach, public and/or private entities invest funding for research activities. This funding is then used to convert knowledge in research organisations into impacts across multiple categories including economic, social, technological, health, human capital etc. However, these approaches fail to provide an explanation as to how this process occurs and underappreciates the complexities inherent in the research impact process such as multidirectional flows of knowledge, synergies in relationships between actors in the research system and absorptive capacities of the industry to exploit knowledge. These 'soft' processes, such as networking, interaction and collective learning which are considered an important driver of growth in contemporary economies.

Thirdly, quantitative approaches often fail to address common issues in RIA studies such as attribution and additionality. These issues have been highlighted as key challenges in research impact assessment (Salter and Martin 2001, Martin and Tang 2007, Hughes and Kitson 2012, Penfield et al. 2013, Harland and O' Connor 2015, Morton 2015).

The challenges presented by additionality and attribution issues have led to many authors to develop qualitative approaches which attempt to explore the underlying dynamics of the research impact process. These approaches provide an explanation of the pathways through which research inputs are transformed into outputs, outcomes and wider economic and societal impacts. These approaches focus on the interactions and relationships that exist between researchers, departments and/or institutions and other entities within the innovation system such as individual, firms and universities. As such, the focus shifts from an emphasis on the magnitude of research impact towards an emphasis on the underlying dynamics (or ‘pathways’) of research impact.

These approaches (SIAMPI, ASPIRA, and Contributions framework) identify the relationships between the research sphere and other actors within innovation system. This facilitates enhanced learning and accountability by tracing research impact through different stages of the impact process. By doing so, these approaches attempt to identify which factors have had the greatest influence on the overall impact achieved by a researcher, department or research institute. However, these approaches are not without limitations.

Firstly, qualitative approaches tend to focus on the underlying dynamics of the research impact process which may be more time consuming than approaches focused on solely measuring the magnitude of research impact. Secondly, these approaches can be constrained by the data availability when conducting analysis. As such, these approaches may be limited to measuring impact by measures which are easily quantifiable, as opposed to measures which are of most significance.

Thirdly, approaches focused on the dynamics of research impact may be more susceptible to conflicting narratives. An important consideration when conducting analysis using these frameworks is the individual that is providing qualitative information. Gathering data through interviews may provide conflicting results depending on whether one is interviewing individual researchers, managers or directors. These individuals may have contrasting opinions regarding goal setting objectives, important indicators of impact, and whether objectives have been achieved by the research institute.

Finally, accountability tends to be favoured over learning by research funding bodies when making investment decisions. Research funding bodies are increasingly emphasising value for money and justification for investment researchers, projects and institutions. As such, approaches which measure the magnitude of research impact may be favoured over approaches which measure the underlying dynamics of the research impact process. A potential consequence of this focus is that researchers knowing the evaluation criteria of funding bodies may respond to these incentives by overemphasising the outputs and impacts of their research to match funding bodies' research impact criteria.

This section considered the strengths and limitations associated with quantitative and qualitative approaches to research impact assessment (RIA). While each approach is illuminating, neither is complete. As such, future RIA studies must make efforts to overcome the weaknesses of each approach and move towards more integrated, robust and flexible measures of research impact. These measures should provide a comprehensive framework which considers the underlying dynamics of the research impact process, as well as estimating the magnitude of research impact. While initial steps have been made towards this type of research assessment framework (Morton 2015), the results are neither comprehensive nor complete.

It is clear from the analysis that no standalone method is sufficient to provide a comprehensive assessment of the economic impacts of publicly funded research. The suitability of the methodology varies by the types of questions which the research wishes to answer. Additionally, the type of impact and data requirements to answer research questions will influence the choice of methodology. As such, a mixed-method approach is likely to provide the greatest opportunity to capture the full extent of research impact. However, as Grant (2006) notes "the method is not without drawbacks such as being time intensive and needing to be adapted to different stakeholder's wants and needs".

## 3.5 Conclusion and Next Steps

The aim of the literature review in this chapter was to identify key conceptual and methodological challenges facing evaluators when designing and implementing frameworks and tools to measure and evaluate the economic impact of publicly funded research centres. Firstly, research impact is complicated as impact is often context-specific, meaning different things to different people. Research centres are differentiated by their aims and objectives, nature of research activities, organisational structure, funding sources and research discipline.

As such, the development of an all-encompassing, universal definition of impact is challenging, if not impossible. Furthermore, definitions of research impact are further complicated by the multiple dimensions of impact, attribution and contribution-based approaches to evaluation, and subjectivity related to whether impacts are positive or negative, or both depending on an individual's perspective.

The IMPACTS framework presented in Chapter 5 adopts an evolutionary perspective to research impact. This approach views research impact is a complex, dynamic, multidimensional process involving multiple stakeholders. Therefore, the definition of research impact developed must be both flexible and robust to the "indirect, opaque, partial nature of impact" (Martin, 2011). The definition of research centre impact developed in this thesis is

> "the contribution of research centres, either direct or indirect, short or long term, intentional or unintentional to society and the economy".

This definition of research impact is grounded in a contributions-based approach which reduces some of the assumptions and limitations associated with attribution-based approaches. This definition identifies the multidimensional nature of research impact and provides the foundation for the construction of the Research Impact Index (RII), presented in Chapter 7.

The IMPACTS framework was developed to address the limitations evident in previous research impact assessment frameworks. Section 3.2 highlighted the key challenges facing evaluators when conducting RIA exercises including data availability, attribution, additionalities, time lags, nonlinearities and absorptive capacity. The development of the IMPACTS framework includes key strategies designed to address these methodological issues to provide a robust approach for measuring and evaluating the economic and commercial impacts of publicly funded research centres. These strategies are presented in Section 5.1 and 5.2.

Section 3.4.1 outlines the strengths and limitations of quantitative and qualitative approaches to RIA. While each approach is illuminating, neither is complete. As such, the IMPACTS framework adopts a mixed-method approach to measuring and evaluating the economic impact of publicly funded research centres. Quantitative methods, such as surveys and metrics, are used to develop the Research Impact Index (RII), a multidimensional index to measure research centre impacts across several dimensions. Chapter 6 presents the process of developing, piloting and implementing the two survey instruments developed in this thesis to gather impact data, Research Centre Impact Questionnaire and Industry Partner Impact Questionnaire. The data gathered through these instruments was used to construct the RII in Chapter 7.

Surveys provide a broad overview of the current status of a programme, project or body of research (Guthrie et al., 2013). Therefore, research evaluators often favour mixed-method approaches to RIA by combining survey methods with more in-depth qualitative tools, such as narratives and case studies. As such, the RII is combined with qualitative approaches to RIA such as impact narrative/statements and expert opinion. The combination of quantitative and qualitative approaches, guided by the IMPACTS framework, provides a more robust measurement tool to measure and evaluate the economic impact of publicly funded research centres.

The development and testing of the IMPACTS framework in Chapters 5, 6 and 7 led to the identification of key conceptual challenges facing evaluators in conducting RIA exercises, namely measurement difficulties resulting from the diverse meanings and conceptualisations of research impact. As such, conceptual clarity on what constitutes an impact is required before effective research policies to promote research impact and robust RIA tools to measure and evaluate the impacts may be developed.

The next chapter explores the meanings and conceptualisations of research impact across the research sector in Ireland. The aim is to assess the diverse meanings and conceptualisations of research impact across different stakeholders, opinions on the research impact agenda and its impact on the future directions of the Irish research sector.

# Chapter 4: Meanings and Conceptualisations of Research Impact across the Research Landscape in Ireland

## 4.1 Introduction

This Chapter presents a qualitative analysis of the meanings and conceptualisations of research impact among key stakeholders across the research sector in Ireland. The aim is to assess the different perceptions of the impact agenda and its effect on the direction of the research sector in Ireland. Thirteen semi-structured interviews with key stakeholders across the Irish research sector, including funding bodies, research centres, and universities, were conducted.

The impact agenda has gained considerable traction amongst policymakers and academics, both in Ireland and internationally. The impact agenda has resulted in a shift in policy focus from primarily demonstrating scientific excellence towards an emphasis on the generation of wider economic and social impacts which address societal challenges. However, research impact is often context-specific, based on scientific discipline, research objectives, and technological intensity of the research centre. As such, impact can mean different things to different people. Therefore, a shared understanding of what impact is, how it can be produced, and what types of impacts are valued is required before effective evidence-based policy may be implemented.

The rest of the chapter is set out as follows. Section 4.2 discusses the research methodology adopted to explore meanings and conceptualisations of research impact. The method comprised primary analysis of qualitative data collected via semi-structured interviews with representatives from thirteen stakeholders across the research sector in Ireland. This section provides an overview of the advantages and disadvantages of qualitative interviews as a research method. Following this, the steps involved in conducting thematic analysis are set out.

Section 4.3 describes the fieldwork undertaken in conducting a qualitative analysis of the meanings and conceptualisations of research impact across the research sector in Ireland. The section sets out the process of designing the interview guide. The interview guide includes a list of questions or issues to be explored during the interviews. The interview guide was informed by a priori knowledge of key issues facing research impact assessment (RIA) exercises, while also providing opportunities for new research directions.

Section 4.4 presents the findings from thirteen semi-structured interviews with key stakeholders across the research landscape in Ireland. Following a detailed thematic analysis of the interview transcripts, two overarching themes were identified. The themes highlight significant opportunities and challenges facing funding bodies and research centres in the drive towards the research impact agenda. Section 4.5 concludes and discusses the findings from this Chapter.

## 4.2 Methodology

From a review of the literature on research impact assessment (RIA) and a series of preliminary and exploratory interviews with key stakeholders across the research sector in Ireland, a research gap emerges regarding in-depth studies analysing diverse meanings and conceptualisations of research impact among key stakeholders across the research sector. Given the increased interest in both academic and policymaking circles to demonstrate and evaluate research impacts, few academic studies have taken place in this regard (Jones, Manville, and Chataway 2017, Deeming et al. 2017).

Jones et al. (2017) conducted a qualitative study analysing the key challenges facing policymakers and researchers in the design, development and implementation of robust RIA exercises. The study conducted 126 semi-structured interviews and small focus groups with key stakeholders across the research sector in the UK. The study identified key challenges when evaluating the impacts of publicly funded research including difficulties in attribution and contribution, time lags associated with generating impacts, nonlinearities of the research process, and issues in providing evidence of impacts.

Deeming et al. (2017) conduct a qualitative study of attitudes and opinions of medical research institutes in Australia towards RIA frameworks. The authors carried out 15 semi-structured interviews with senior representatives of health research institutes in Australia. The findings suggest that current RIA “does not have an explicit purpose, nor are they systematically designed to realise specific objectives, despite the relevance of purpose to their form, method and content” (Deeming et al. 2017, p.10).

The next sub-section discusses the rationale for adopting qualitative interviews as a research method.

### 4.2.1 Qualitative interviews

This thesis adopts a qualitative approach to explore diverse meanings and conceptualisations of research impact across the research sector in Ireland. Qualitative research can be broadly defined as “any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification” (Strauss and Corbin 1990, p.17). Although qualitative methods have often been underappreciated by economists, they offer a unique approach to understanding phenomenon that is not often captured by traditional quantitative methods (Starr 2014).

Bryman (2008) identifies two main forms of interviews in qualitative research - ‘unstructured’ and ‘semi-structured’. Unstructured interviews typically begin with the interviewer having a general topic in mind, but many of the specific questions are formulated throughout the interview process, in response to the information provided by the interviewee. Unstructured interviews are particularly useful for conducting in-depth narrative interviews and life stories.

Semi-structured interviews typically involve the researcher having a specific set of questions or topics that they wish to cover in the interview but “there is freedom and flexibility in how and when questions are asked and how the interviewee can respond”. (Edwards and Holland 2013, p.29). The ability of semi-structured interviews to draw on “rich and illuminating data” (Robson 1993a, p.229) is particularly useful when analysing new ideas and concepts.

Semi-structured interviews were selected as the mode of data collection. Semi-structured interviews offer several advantages compared to unstructured interviews for the purposes of this study. Firstly, unstructured interviews are typically in-depth discussions on a limited number of topics, usually one or two. The purpose of the qualitative analysis in this thesis is to explore several topics related to the meanings and conceptualisations of research impact including definitions of impact, measurement tools, indicators and metrics and future directions of the research sector in Ireland. Furthermore, participants typically have very busy schedule with limited time available to conduct interviews. Therefore, semi-structured interviews are the most suitable approach to data collection as they maximise the likelihood of covering all research topics.

The next sub-section discusses the potential issues faced by researchers when conducting qualitative studies. These challenges must be considered in light of the design, implementation and analysis of qualitative interviews.

#### 4.2.1.1 Issues of Quality in Qualitative Research

Quality in qualitative research remains a complex and emerging area. Noble and Smith (2015, p.34) assert qualitative research

> "is frequently criticised for lacking scientific rigour with poor justification of the methods adopted, lack of transparency in the analytical procedures and the findings being merely a collection of personal opinions subject to researcher bias"

There is a lack of consensus of widely accepted methodologies for assessing the quality and robustness of qualitative research (Leung 2015). There is considerable debate as to whether the principles of validity, reliability and generalisability typically associated with quantitative research can be applied effectively to studies adopting a qualitative interpretative approach. As Winter (2000, p.11) states "qualitative research sets itself up for failure when it attempts to follow established procedures of quantitative research".

Several authors have proposed alternative criteria for assessing the quality and robustness of qualitative research. Lincoln and Guba (1985) identify alternative measures for demonstrating robustness within qualitative research, i.e. truth value, consistency and neutrality, and applicability. Furthermore, Kitto, Chesters, and Grbich (2008) suggest six criteria for assessing overall quality of qualitative research, including clarification and justification, procedural rigour, sample representativeness, interpretative rigour, reflexive and evaluative rigour and generalisability. Despite ongoing debates regarding the applicability of terms such as validity, reliability and generalisability to assess the quality and robustness of qualitative research, these remain the most widely used terms to evaluate the scientific rigour of qualitative research.

***Validity***

In quantitative research, 'validity' refers to "the result and culmination of other empirical conceptions: universal laws, evidence, objectivity, truth, actuality, deduction, reason, fact and mathematical data to name just a few" (Winter 2000, p.7-8). Joppe (2000, p.1) provides the following explanation of validity in quantitative research:

> "Validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are. In other words, does the research instrument allow you to hit "the bull's eye" of your research object? Researchers generally determine validity by asking a series of questions and will often look for the answers in the research of others".

***Reliability***

In qualitative research, reliability refers to the extent to which results are consistent, representative and reproducible over time. Joppe (2000) refers to reliability as

> "the extent to which results are consistent over time, and an accurate representation of the total population under study is referred to as reliability, and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable".

However, some authors have questioned the suitability of 'reliability' as a criterion of qualitative research. For example, Stenbacka (2001, p.522) notes "the concept of reliability is even misleading in qualitative research. If a qualitative study is discussed with reliability as a criterion, the consequence is rather that the study is no good". While others identify validity as a sufficient condition to demonstrate the reliability of findings in qualitative research. For example, Lincoln and Guba (1985) states that "since there can be no validity without reliability, a demonstration of the former [validity] is sufficient to establish the latter [reliability]".

***Generalisability***

Polit and Beck (2010, p.1451) define generalisation as “the act of reasoning that involves drawing broad conclusions from particular instances—that is, making an inference about the unobserved based on the observed”. In quantitative studies, generalisability is considered a key condition for analysing the quality and robustness of research results. However, in qualitative studies, researchers are less concerned with the generalisability of results. Leung (2015, p.326) argues “most qualitative research studies, if not all, are meant to study a specific issue or phenomenon in a certain population or ethnic group, of a focused locality in a particular context”. Therefore, generalisability is not an expected characteristic of qualitative research findings.

***The Researcher***

The role of the researcher has been identified as a key issue in analysing the quality and robustness of qualitative research studies. In quantitative research, the researcher’s role is assumed to be non-existent. Research findings are based on statistical techniques independent of the views, feelings and opinions of the researcher. However, in qualitative researchers, the role of the researcher is substantially different.

Interviews have been described as “a form of conversation that are initiated by the interviewer for the specific purpose of obtaining research-relevant information and focused on content specified research objectives of systematic description, prediction or explanation” (Cohen, Manion, and Morrison 2007, p.351). However, while research interviewing involves the cultivation of conversational skills that most people already possess, the cultivation of these skills can be challenging (Brinkmann and Kvale 2015).

The next sub-section discusses the adoption of thematic analysis as a research method to explore the meanings and conceptualisations of research impact across the research sector in Ireland.

### 4.2.2 Adopting Thematic Analysis as a Research Approach

Thematic analysis is the process of identifying patterns or themes within qualitative data. Braun and Clarke (2006 p.78) suggest that it is the first qualitative method that should be learned as “it provides core skills that will be useful for conducting many other kinds of analysis”. The reasons for choosing thematic analysis (TA) as opposed to other qualitative approaches, such as grounded theory, discourse analysis and/or interpretative phenomenological analysis (IPA) are threefold.

Firstly, while grounded theory and IPA aim to identify patterns in qualitative data, they are theoretically bounded. TA offers a flexible approach for analysing qualitative interviews, not tied a specific theoretical framework. Therefore, TA can be used within different theoretical frameworks (Braun and Clarke 2006). Secondly, the aim of grounded theory is to develop a grounded theory of a specific phenomenon. Contrastingly, TA is used to explore meanings within a dataset. Thirdly, the flexibility of TA does not require detailed theoretical and technical knowledge of qualitative approaches such as grounded theory and DA. (Braun and Clarke 2006).

King, Cassell, and Symon (2004) identify four stages in conducting thematic analysis, including creating a coding scheme, coding the data via hand or computer, grouping sections with similar text, and finally analysing the sections. Ritchie, Spencer, and O'Connor (2003) describe a similar process for analysing data using a TA. The authors identify four key stages in the analysis process, beginning with identifying initial themes or concepts, labelling or tagging the data sorting the data by theme or concept and finally summarising or synthesising the data.

This thesis adopts the six-step framework proposed by Braun and Clarke (2006). This framework provides the most popular approach to thematic analysis as it offers a clear and straightforward framework for conducting thematic analysis. Table 4.1 highlights the stages of thematic analysis outlined by Braun and Clarke.

**Table 4.1 Phases of Thematic Analysis**

| Phase | Description of Process |
|---|---|
| **1.** Familiarizing yourself with your data | Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas |
| **2.** Generating initial codes | Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code. |
| **3.** Searching for themes | Collating codes into potential themes, gathering all data relevant to each potential theme |
| **4.** Reviewing Themes | Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis. |
| **5.** Defining and naming themes: | Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme. |
| **6.** Producing the report | The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis. |

Source: Braun and Clarke (2006, p.87)

**Step 1. Familiarising yourself with your data**

The first step in conducting TA is familiarising yourself with the data. Braun and Clarke (2006, p.87) note "during this phase, it is a good idea to start taking notes or marking ideas for coding that you will then go back to in subsequent phases". It should be noted that this approach to managing and analysing data is not necessarily a linear, rigid process, it is possible to revisit earlier stages in the analysis should immersing oneself in the data reveal further key themes or issues.

The qualitative researcher is often described as "the research instrument insofar as his or her ability to understand, describe and interpret experiences and perceptions is key to uncovering meaning in particular circumstances and contexts" (Maguire and Delahunt 2017, p.3352). However, interviewers must be cautious not to influence the participant's own views and feelings. As Britten (1995, p.251) states

> "in a qualitative interview the aim is to discover the interviewee's own framework of meanings and the research task is to avoid imposing the

> researcher's structures and assumptions as far as possible. The researcher needs to remain very open to the possibility that the concepts and variables that emerge may be very different from those that might have been predicted at the outset".

Transcription of data is one of the most common ways to prepare it for analysis (Bazeley 2007). Transcription allows researchers to become familiar with the raw data by immersing oneself in it (Pope, Ziebland, and Mays 2000). In this study the transcription was undertaken by a third party. However, the researcher conducted the qualitative interviews himself and thus had already been exposed to the data. Furthermore, once the transcriptions were received, they were read over and checked for consistency, which familiarised the researcher with the data.

**Step 2. Generating initial codes**

In total, three rounds of coding were conducted to iteratively make sense of themes identified through analysing the interview data. During the first round of coding, a coding frame of the transcriptions was developed using computer assisted qualitative data analysis (CAQDAS) software package, NVivo-12. Several CAQDAS software packages have been developed to assist researchers analysing large quantities of data in a systematic way. These packages have been viewed as a means of enhancing the rigour of qualitative studies (Bazeley 2007). However, they should always be considered a complement, not a substitute for researchers' time, effort and skills.

The researcher participated in a two-day training course aimed at understanding key elements of qualitative analysis and its interrelation to CAQDAS. The workshop offered guidance into managing, coding, organising and analysing qualitative data in the CAQDAS system. During the initial coding the interview data was coded into "meaningful and manageable chunks of text, such as passages, quotations, single words…" (Attride-Stirling 2001, p.391). The initial coding is included in Appendix A1.

**Step 3. Searching for themes**

Following initial coding, potential themes and sub-themes within the interview transcripts were identified

**Step 4. Reviewing Themes**

In the second round of coding, the themes were refined and merged into common categories and subcategories to consolidate the findings. During this phase of TA, some initial themes are collapsed into a smaller number of themes, whether because they are too diverse or there is a lack of evidence supporting the theme. The axial coding is included in Appendix A2.

**Step 5. Defining and naming themes**

The third and final round of coding involved the coder reviewing the themes identified from the second round of coding. The aim of this phase was to be able to "…clearly define what your themes are and what they are not" (Braun and Clarke 2006, p.92).

**Step 6. Producing the report**

The final phase of the analysis focused on the production of the report based on the previous five stages of TA. This phase focused on analysing the data and providing a narrative account of the data that "…goes beyond description of the data, and make an argument in relation to your research questions"; while it also "…provides a concise, coherent, logical, non-repetitive and interesting account of the story the data tell-within and across themes" (Braun and Clarke 2006, p.93).

The next section discusses the fieldwork undertaken in conducting qualitative interviews exploring meanings and conceptualisations of research impact across the research sector in Ireland.

## 4.3 Fieldwork Undertaken in Conducting Qualitative Interviews

This section describes the fieldwork undertaken in conducting a qualitative analysis of the meanings and conceptualisations of research impact across the research sector in Ireland. Firstly, the process of developing the interview guide to facilitate semi-structured interviews is discussed. The interview guide includes key questions and topics to be explored during the qualitative interviews. Secondly, the mode of data collection is presented.

### 4.3.1 Designing the Interview Guide

Several authors have performed literature reviews and surveys within the domain of research impact. Most prominent among these include work from Guthrie et al. (2013), Greenhalgh et al. (2016) and Milat, Bauman, and Redman (2015). From these studies, major methodological trends emerge. Key themes that come from reviews of literature include a diversity of frameworks and methodologies to measure research impacts, multidimensional nature of impacts from research activities, the definition of impact and key challenges facing evaluators when assessing research impacts. These studies guided thinking and considerations when developing the interview guide.

Stakeholder interview questions focused on the following issues:

i) their conceptualisations of research impact
ii) their experiences of impact measurement
iii) their experiences of research evaluation
iv) their perceptions of the research landscape in Ireland.

The purpose of the interview guide was to frame the interview process and to ensure that the key issues identified were discussed. At the outset of each interview, interviewees were asked to provide some general information about their background, including their role within the company, employment and educational history. This gave interviewees the opportunity to 'tell their story', to ease them into the interview process and to assist with the understanding of the context of their experiences. Following the completion of the first few interviews, transcriptions were evaluated to determine whether any revisions were required.

Figure 4.1 presents the interview guide developed in this thesis to explore the meanings and conceptualisations of research impact among stakeholders across the research sector in Ireland.

**Figure 4.1 Interview Guide**

**Getting to know the interviewee**

- Describe the role of the centre and what you do.

**Background**

- What is the rationale/objectives for setting up the research centre?
- Key strengths of the research centre?
- What are the main types of research activities provided by your centre?
- At your organisation, what are the expected uses of research results?

**Research Impact**

- What does research impact mean to you?
- What are the most important types of impacts generated by your centre?
- Could you provide examples of research impacts generated by your centre?
- Do you feel the research sector needs to think more strategically about impact?

**Measuring Research Impact**

- How is research impact measured within your research centre?
- How useful is the concept of 'impact' to guide evaluation?
- Key challenges when measuring research impact?
- What are the most important impact indicators and metrics for your centre/funding body?
- How does your research centre measure the contribution of impact generated by their industry partners?

**Looking ahead**

- What are the future directions of impact?
- What are future challenges in the research sector in Ireland – How do you plan on tackling them?
- What are the future opportunities in the research sector in Ireland – How do you plan on exploiting them?

Source: Compiled by Author

### 4.3.2 Mode of Data Collection

Semi-structured interviews were conducted with thirteen stakeholders across the research system in Ireland. The sample includes a diverse range of actors from the research sector, including research funding bodies, directors and principal investigators. The sample includes representatives from the two largest research centre programmes in Ireland, the Science Foundation Ireland research centre programme and Enterprise Ireland technology centre programme. Potential participants were selected based on advice from experts across the Irish research sector and supervisors. Initially, ten potential interviewees were contacted through email requesting a face-to-face interview. The interview request is included in Appendix A4. The process of contacting interview participants is included in Appendix A5.

These interviews were planned and conducted between December 2018 and February 2019. Each interview consisted of a face-to-face meeting apart from one interview, which was conducted by phone. Each interview was recorded and transcribed apart from the phone interview, where field notes were taken by the interviewer. The interviews lasted between 45 and 75 minutes. Interviewees were selected based on their senior position and experience of working within the Irish research sector. Exploratory interviews were transcribed, and textual analysis was conducted to identify themes.

#### 4.3.2.1 Recruitment

Participants were selected based on their level of expertise within the research sector in Ireland. As such, these participants are more likely to be familiar with the research impact agenda and how it has influenced developments within the research sector in Ireland. The recruitment strategy was to identify participants from diverse institutions and backgrounds. The inclusion of participants from diverse organisation reduces potential bias of results.

The recruitment process is presented in Appendix 7. Positive responses from thirteen out of the thirty-one participants (42%) contacted to participate in the study. Research centre personnel were the most common participants (85%), with participants working in a variety of roles including research centre directors (38%), research centre managers and department heads (31%), principal investigators (15%). Furthermore, participants recruited from funding bodies represented 15% of the total sample. Table 4.2 provides a more detailed description of the interview participants.

**Table 4.2 Contact List for Interviews**

| No. | Position | Description |
|---|---|---|
| **R1** | Director | Male, director of research centre. Background in industry. |
| **R2** | Head of Research | Female, background in machine learning and artificial intelligence. |
| **R3** | Programme Manager | Male, programme manager, organises centre related activities, including industry projects and industry liaison. |
| **R4** | Programme Manager | Male, programme manager since 2006. |
| **R5** | PI | Female, in charge of the research team, co-leader on a research team and a funded investigator. |
| **R6** | PI | Male, PI, project leader, and pillar lead. |
| **R7** | Deputy Director | Male, head of school, PI, the national deputy director. |
| **R8** | Head of Research Policy | Female, in charge of several different areas ranging from research integrity, open access, open data. |
| **R9** | Commercialisation Manager | Male, the role is fundamentally to capture, record, and exploit intellectual property. |
| **R10** | General Manager | Male, the general manager, works alongside the director to lead, manage, oversee the centre and its work. |
| **R11** | Director | Male, director, lead of research pillar |
| **R12** | Director | Male, director of the centre. |
| **R13** | Head of Business Strategy | Male, worked for 16 years in government, mainly in R&D. |

Source: Compiled by Author

#### 4.3.2.2 Consent

Prior to contacting potential participants in the study, the researcher obtained ethical approval from the Social Research Ethics Committee (SREC) in University College Cork (UCC). At the beginning of each interview, the researcher outlined the aims and scope of the study and provided an opportunity for each participant to ask any questions they may have regarding the interview process and the study generally. Each participant was then provided with an information sheet and consent form, included in Appendix 3. The information sheet outlined the purpose of the study, the objectives of the interviews, data collection and data storage methods and contact information for the author.

For all interviews, whether face-to-face or by telephone, participants were asked to provide their consent to allow interviews to be audio-recorded. All participants, except for one interview conducted by telephone, indicated that they were happy for the researcher to audio record the interview. For face-to-face interviews, a small digital recorder was placed between the researcher and participant, and in the telephone interview data was recorded by the researcher taking field notes. Participants were informed that the recording could be stopped at any time throughout the interview.

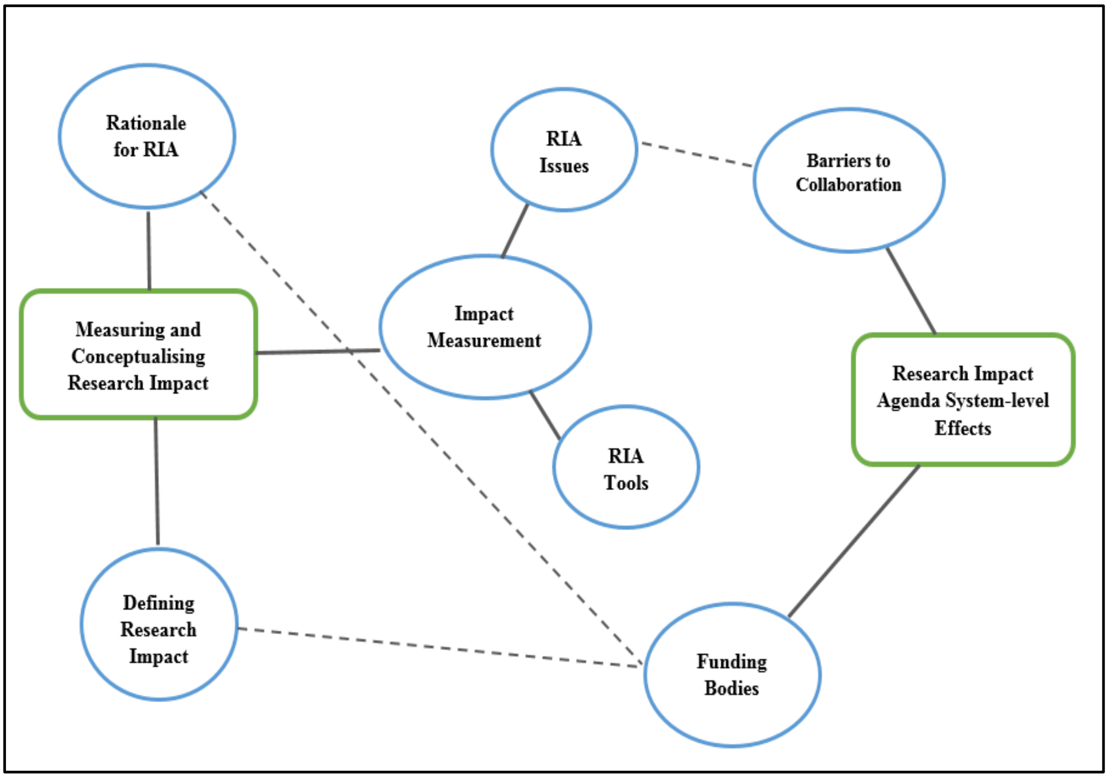
## 4.4 Exploration of stakeholders understanding of Research Impact

This section presents the findings from thirteen semi-structured interviews with key stakeholders across the research landscape in Ireland. The narrative of experiences of stakeholders across the Irish research sector highlights several contextual factors that influence the understanding of research impact. These contextual factors provide a vivid and practice-based illustration of why defining and evaluating research impact is so difficult to perform in a way that is robust, systematic and generalisable within research organisations and across the research system.

The purpose of this section is to identify the most significant themes and sub-themes that emerged from interviews with research practitioners. The themes are described using the words of the interviewees. By identifying and classifying individual themes, this section assists in categorising key practical, managerial and strategic issues which are likely to increase or decrease the magnitude of research impact in the future.

Figure 4.2 shows the two overarching themes that identified through interviews with key stakeholders across the Irish research system. The two themes relate to (i) meanings and conceptualisations of impact (ii) system-level effects of research impact agenda. The sub-themes include the rationale for RIA, conceptualisations of research impact, measurement tools, measurement issues, collaboration with industry partners, perceptions of funding bodies, future directions of the research sector in Ireland. The themes and sub-themes identified are presented graphically in Figure 4.2

**Figure 4.2 Thematic Map of Meanings and Conceptualisations of Research Impact**




Source: Designed by Author

In the diagram, the unbroken lines suggest a direct effect between the theme and sub-theme while the unbroken lines indicate an influence. For example, the rational for RIA falls under the theme ‘measuring and conceptualising research’ represented by an unbroken line in Figure 4.2. The sub-theme ‘funding bodies’ falls under the theme ‘research impact agenda system-level effects’, however funding bodies also significantly influence the rationale for RIA, therefore this relationship is represented by broken line in Figure 4.2.

The next sub-section discusses the themes and sub-themes identified through interviews with key stakeholders across the Irish research system.

### 4.4.1 Measuring and Conceptualising Research Impact

#### 4.4.1.1 Rationale for Research Impact Assessment

The first sub-theme identified by respondents was the rationale for research impact assessment (RIA). The main rationales for conducting RIA in the literature are presented in Section 3.2. Guthrie et al. (2013) identify the 4 A's of impact assessment, namely: accountability, allocation, analysis, and advocacy. Each of these rationales were identified throughout the interviews, but accountability and allocation were the two most prominent reasons given by respondents for conducting RIA exercises

Section 1.2 discusses the impact of the 2007 global financial crisis on Irish research policy. The crisis led to significant cutbacks in Irish government expenditure, leading to a shift in focus from funding scientific excellence towards funding research with 'impact'. This shift in policy focus emphasises the principles of accountability and justification for the allocation of public funding for research activities.

> "*The other thing, I think, is that I have no problem with economic and societal impact. That's part of… One of the reasons for that is to justify to the taxpayer*" (R12, Director)

However, there is a worry that this shift in policy may have a negative impact on producing scientifically excellent research at the expense of short term, commercially driven research.

> "*I'm sure there is a case to be made that you have to defend the use of the taxpayers' money, and all the rest of it, but at the same time, I think it does detract from the focus on getting on and doing the science, and applying for proposals, and delivering the impact bit as well"* (R10, General Manager)

RIA requires a significant amount of effort on the part of the research centre staff from collecting data and submitting funding applications to writing narratives and impact statements. As such, research centres are required to provide justification for the use of public funding, and this was identified as a key rationale for conducting research impact assessment exercises.

> *"The funders like SFI need that help, they rely on centres and academics to do that, and I don't think there's enough recognition on behalf of academics that they really do need to take some responsibility to have the funders to provide them with the data and the information to make the case to industry*

*that it is worth putting more exchequer funds into R&D at the expense of housing, hospitals"* (R9, Commercialisation Manager)

This implies that research centres see themselves as part of a system and must contribute to the case for the system as a whole. Advocacy has been identified as a key rationale for measuring and evaluating the impacts generated through investment in research activities (Guthrie et al. 2013, Jones, Manville, and Chataway 2017). Science Foundation Ireland (2018) identifies the creation of a "favourable environment for the entire population to have an informed debate on many scientific issues that impact on society" as a key benefit of investment in research.

> *"I think in SFI's case, certainly the way it was spoken about, we need to have an informed citizenry so that citizens appreciate science, so that there's a respect for science, but also that there will be an acceptance to increased funding for science. So, there's a bit of a self-interest thing as well as a societal benefit"* (R11, Director).

As well as advocating for greater public investments in research activities, interviewees pointed to the importance of demonstrating impacts in order to help secure private investment in research activities. Given that research centres are required to generate an increasingly significant portion of total investment from industry partners, advocacy on behalf of industry partners is increasingly important.

> *"We need to show value for the industry to engage in what we're doing for their financial contribution. And we also need to show value to the Exchequer of what we're doing with their public money. So, there are lots of different paymasters" (*R13, Head of Business Strategy).

Another participant reiterates this point stating research centres must assist businesses, particularly multinationals, in communicating the benefits of collaboration with the research centre internally within the business.

> *"What we need to help our companies with is actually articulating that internally for them. So, when they've got to argue for budget, internally, they're companies, and they've got to compete with peers wanting to do other stuff with that budget"* (R1, Research Centre Director)

The next sub-section highlights the second sub-theme identified through qualitative interviewing: conceptualising research impacts.

#### 4.4.1.2 Conceptualisations of Research Impact

The diverse meanings and conceptualisations of research impact across the academic literature were presented in Chapter 3. The findings suggest research impact may be characterised as a 'chaotic' concept in the sense of conflating and relating quite different types, processes and objectives into an all-encompassing, universalistic notion. This section highlights the diverse range of conceptualisations of research impact identified through the semi-structured interviews.

***Economic Impacts***

When discussing the meanings and conceptualisations of research impact, the interviewees tended to discuss impacts primarily from an economics perspective. This focus seems logical, given the policy shift towards accountability and justification for investment in research activities. For example, when asked what research impact means to them, one participant noted "*I think it is reasonably clear. It is mainly about economic impacts but also societal impact"* (R9, Commercialisation Manager).

Despite the acknowledgement that economic impacts were the primary focus when demonstrating research impacts, clear differences could be observed across the research participants regarding the types of economic impacts that were most desirable. Some interviewees discussed economic impacts in a very narrow sense:

> *"Ultimately, for us, it comes down to jobs. Jobs and revenue but really it's jobs… it all fundamentally comes down to the same thing"* (R1, Research Centre Director)

While others defined economic impacts in the broadest sense:

> *"looking at spinouts, how those spinouts are doing, have they gone on to operate successfully in the marketplace? It's looking at things like transferring technologies to the Irish industry base and multinationals, industry engagement, bringing in foreign direct investment and industry funding into*

*Ireland, R&D funding, so creating R&D jobs in Ireland, whether it be in the centre or in spinouts"* (R9, Commercialisation Manager)

The focus on job creation makes sense considering the Irish government's Science, Technology and Innovation (ST&I) policy, which emphasises full employment as a key policy target. Furthermore, research centre policies in Ireland are highly centralised within the Department of Job, Enterprise and Innovation (DJEI). As such, the structure of the research funding system in Ireland gives a clear preference towards demonstrating economic impacts.

Some participants from research centres were critical of the apparent 'bias' towards demonstrating economic impacts as the main determinant of funding bodies awarding research funding. For example, one respondent noted

> *"Take the example of SFI. Yes, they're the biggest science funding agency in the state, but they sit under the Department of Enterprise, Jobs and Innovation. That does set a particular tone, I suppose, in terms of what is expected in return. It clearly has to set a bias, a prejudice, a shift, an emphasis, whatever pejorative or non-pejorative word you want to use"* (R10, General Manager)

Interview participants identified advocacy as a key rationale for the focus on economic impacts as these impacts are more easily demonstrable to taxpayers or "*Joe average on the street*" (R8, Head of Research Policy). Although some interviewees argue that impact assessment exercises should not be reduced to PR events, for others, it is apparent that RIA exercises are best suited to telling (or selling) a story.

> *"The easiest things to give good impact numbers or quite crystal impact numbers for the business side. So, to impact on the business in Ireland, they would look at two things. One is increased turnover or increased employment, and they are the nice sexy numbers to give because a minister or the man on the street would understand that as being good".* (R4, Programme Manager)

***Industry Cash***

The Impact Measurement and Performance Assessment of Centres for Technology and Science (IMPACTS) framework developed as a major contribution of this thesis is presented in Chapter 5. The framework provides a holistic, evolutionary approach to RIA. The framework identifies industry cash as an important input into the research process. However, when discussing the meanings and conceptualisations of research impact with key stakeholders across the research sector in Ireland, generating industry cash was perceived as one of the most important impacts generated by a research centre.

> *"When we are discussing the metrics, I get a sense that things like the amount of cash you have got in the bank from companies is paramount and dominates almost everything else"* (R7, Deputy Director)

The rationale for including industry cash as an impact as opposed to an input is threefold. Firstly, funding bodies are very influential in the Irish research system, and industry cash has been identified as an important key performance indicator (KPI) that research centres must achieve to sustain investment. Secondly, industry cash may be leveraged by research centres to generated funding from other sources, e.g. the EU 7$^{th}$ Framework Programme (FP7), Horizon 2020 etc. Thirdly, industry cash is considered a key signal of industry engagement, which increases potential future impacts.

Many participants discussed research impact in terms of hitting their KPI targets set by funding bodies, particularly their industry cash contribution. However, a clear distinction needs to be made between KPIs and research impacts. Research impacts are external facing and generally broader than performance measurement based on KPIs. Some KPIs do not directly measure the wider impact of a research centre, at least in the terms set out by SFI's definition of research impact, "demonstrable contribution that excellent research makes to society and the economy".

Many respondents are critical of the approach that values attracting industry investment over other measures of research impact e.g. scientific excellence. These frustrations are summarised by one participant highlighting the messages received by research centres from funding bodies

> *"Screw your Nature papers, Science papers, Nobel prizes, to hell with that. The number one thing, or else we aren't going to get funded, or we're in*

*trouble, is going to be this ability to bring in industry money. That is the tone that is set"* (R10, General Manager).

However, others emphasised the usefulness of industry cash as a metric to demonstrate economic impacts and as a signal of industry partners interest in collaboration with their research centre.

> *"So, you can wax lyrical all you want, or follow along all you want, but the real measure of how interested you in it are is, are you taking money out of your pocket and putting it into the centre?"* (R1, Research Centre Director)

As well as proxying for the degree of industry engagement, industry cash may be considered as a potential signal of research centre quality as research centres with better reputations should be able to attract higher levels of non-exchequer funding.

> *"If you are bringing in non-exchequer funding, is that economic impact? It probably is. Now, it's not strictly within the definition of an input/output, if you're looking at it strictly from that definition, as it is more an input, but from the SFI's point of view, they would consider it more an impact because it's funding that is leveraged off the exchequer investment of the centre, you are bringing in FDI essentially"* (R9, Commercialisation Manager)

> "*I would say within a centre it would be seen as, 'If we are getting lots of money in then that indirectly shows that we must be having impact because the word is out there amongst companies that we are doing good stuff.' If the money is coming in, it is a way of demonstrating that we must be having impact"* (R7, Deputy Director).

***Scientific Impact***

Scientific excellence is the traditional measure of research impact. However, scientific impact can mean different things to different people. The conceptual and methodological debates within the scientific community around measuring the scientific impact of publicly funded research are presented in Section 3.4. Currently, there is a lack of clear and generally accepted indicators and metrics to capture the full scale of scientific impacts generated through research activities.

The most common indicators of scientific impact include different variants of peer-reviewed publications and citations. However, the shift in policy focus from scientific excellence towards wider societal and economic impacts means that these traditional measures of scientific impact are no longer considered the most appropriate measures of impact.

> *"So traditionally I suppose research impact can be measured in the number of publications, patents maybe, but that's internal facing"* (R2, Head of Research)

Similar to the previous discussion on industry cash as a measure of research impact, publications and citations can at best be considered measures of potential research impact. In order to generate economic and societal impacts, scientific outputs must first be translated and exploited by industry partners into wider economic and societal impacts. Publications and citations demonstrate evidence of scientific excellence however if these scientific outputs are not used to improve productivity, reduce costs or contribute to the development of new products, services or technologies then their wider economic and societal impacts are limited. Respondents identified the importance of these next steps in the research process before impact is achieved

> *"Has the research been cited by its peers? Is it being used? Is the research being utilised, picked up? Is it influencing companies' decisions to either come and collaborate with the centre or product development outside of the collaboration with the centre?"* (R9, Commercialisation Manager).

Respondents also questioned whether research funding bodies even consider scientific outputs as measures of research impact

> *"Sometimes when you are filling in proposals and applying to SFI, it is not clear whether SFI would consider things like that as impact or not because when you publish a paper, there is no immediate impact. It takes a while for it to be cited"* (R7, Deputy Director).

The limitations of scientific impact measures for demonstrating wider research impacts have contributed to shifting towards more collaborative measures of research impact. Research centres do not generate impacts in isolation; as such, it is important to consider 'mode 2' collaborative measures in RIA exercises.

> *"When it comes to impact, the traditional academic metrics may not be the most reliable. You are probably relying much more on things like interactions with industry, number of students graduated, and number of researchers trained. I think that is a very important point"* (R7, Deputy Director).

The interviews identified the time lag between producing scientific outputs, such as publications and citations and translating them into economic and societal impacts as key issue in RIA exercises.

> *"The academic impact is a harder one because, as I say, things like citations in publications and stuff are a bit longer term"* (R7, Deputy Director).

Some research projects will have an immediate impact, whereas other projects may take much longer to achieve impact – sometimes many decades, with results varying across sectors. One respondent noted that one of the greatest inventions to have come out of the interviewer's university was not even valued during the inventor's lifetime

> *"you could be very controversial and say what life-changing invention has come out of UCC since Boole? And even in his lifespan, nobody saw the value of what he did"* (R5, Principal Investigator)

The interviewees pointed to a conflict between producing scientific impacts and wider economic and societal benefits. The incentives underlying the two objectives are often competing rather than complementing one another and getting the balance right is a difficult task.

> *"There is a conflict there because for academic progression you need the academic citations and the centres want that because if they don't get that they are not going to be world-class and they won't be... But then the other side is they need the support from the companies, and they need the commercial impact or the other types of impact"* (R5, Principal Investigator).

***Capacity Building***

One of the key impacts identified throughout the interviews was the effect on capacity building within the research sector in Ireland. The Irish research sector developed much later than the systems of their European neighbours, yet the development has been rapid. A key rationale for the development of the research centre programme was to develop critical mass across key strategic research areas.

> *"the other significant impact in my view is in terms of building capacity and infrastructure and the foundation for this research. You can look at that as an impact or you can look at that as the building blocks, but effectively it wasn't there six years ago in the way that it is now"* (R11, Director).

Some respondents noted that the goal for private businesses collaborating with research centres may not be accessing new knowledge and technologies, but rather, gaining access to networks and potential future employees

> *"it might not be the research. And the other side is they want to network and see what other people... They love meeting people at meetings, that's a big impact there as well"* (R5, Principal Investigator)

while others feel industry objectives may be less genuine. Given the late emergence of the Irish research system and small size of the sector relative to other European countries, many of the industry partners that collaborate with research centres are direct competitors.

> *"You're not really collaborating with me. You're just watching what I'm doing and making sure that you are still ahead of where I am"* (R1, Research Centre Director)

Respondents identified the strength of networking and linkages across the Irish research system as a key competitive advantage when attracting multinational companies (MNCs) to locate in Ireland. Research centres play a key role in bringing companies together, overcoming trust issues and secrecy to enhance the generation of economic and societal impacts.

> *"What's strong about it, even compared to its comparatives in Europe, is that the level of cooperation you can get in Ireland from businesses, particularly businesses that would appear to be, on the face of it, direct competitors"* (R4, Programme Manager,)

> *"what these companies often say to us is they are surprised at the fact that the academic community in Ireland appears to be very small and close-knit… I think that is certainly a very clear benefit from the companies' point of view, no doubt about it"* (R7, Deputy Director)

In Ireland, many research centres perform the function of Institutes for Collaboration (IFC) or knowledge intermediaries. Porter and Emmons (2003) identify examples of IFCs including "chambers of commerce, industry associations, professional associations, trade unions, technology transfer organisations, think tanks and university alumni association" amongst others. Publicly funded research centres can most certainly be added to this list.

> *"The other important impact – and this is something that is genuinely due to the research centres – is I have had situations where companies will come to me and say, Can you help us? Do you know anything about X?' I will say, 'I know nothing about X, but I know exactly the guy who does."* (R7, Deputy Director).

***Policy Impacts***

Policy impacts have been identified as important impacts delivered by publicly funded research centres. Informing decision making is an important step in delivering wider economic and societal impacts. However, one participant indicated that policy impacts are not a common impact identified through evaluation exercises, probably because of time lags associated with research and policy change.

> *"But occasionally you do get investments or awards that we make where something emerges from them that perhaps changes a policy or a practice. But it's more the exception than the norm. It's a much longer-term game"* (R8, Head of Research Policy).

Policy impacts were identified as a key form of research impact in the energy sector. The reasons for this focus are numerous, including Ireland's adoption of the United Nations Sustainable Development Goals in 2015 and the adoption and of the 2015 Paris Agreement on Climate Change. Ireland's failure to meet climate change goals was identified as a key reason for the focus on policy impacts in the sector.

> *"It's becoming more recognised now as an area of interest because we're so far behind on our targets of climate reduction and renewable energy. So, part of our work will be engaging with government departments and presenting our results to them and discussing them with them, and then also it is having an impact in our case on the policy side of things, informing policy"* (R11, Director)

An interesting finding from the semi-structured interviews is that it may be industry driving this shift in policy rather than research centres themselves. One participant pointed out:

> *"When industry talk to us, they want to develop a project that can aid policy-making. So, the outcome can help shape a new policy in government. So that's why industry think that while we're independent and at arm's length from government, they think that the outcome from research can inform government. And I think that's an important"* (R13, Head of Business Strategy).

***Human Capital Impacts***

Training skilled graduates has been identified as a key mechanism for transferring knowledge from the public to the private sector (Salter and Martin 2001, Hughes and Martin 2012). Publicly funded research centres play an important role in enhancing economic impacts through the movement of researchers to the commercial sector of the innovation system. The importance of researchers for driving impact within the innovation system was identified throughout the interviews. R5 asserts *"the people who transition from the centres into the companies, I think they can have a big impact"*.

The transfer of PhDs to industry as a first destination has been identified by funding bodies as a key metric to measure research centre impact. Many participants identified researcher mobility as an important mechanism for transferring knowledge and technology from publicly funded research centres into the private sector. For example, one respondent notes

> *"the human capital to me is pivotal: the development and the training and the further education of the researchers, the research assistants, the postdocs, the students, that are involved in delivering these projects. That to me is hugely important and I always put the human capital at the centre of it because that's the knowledge and the expertise that walks out the door and carries that knowledge and expertise with them into the next role, mostly in industry, in our case"* (R6, Principal Investigator,).

However, the generation of human capital impacts, particularly the mobility of researchers to industry, has been identified as a *"catch-22 situation"* for research centre and is *"cannibalistic"* in nature (R2, Head of Research). A key challenge facing the research sector in Ireland is recruiting and maintaining high-quality people within the sector.

> *"That's the number one challenge that we are facing at the moment; we have got more projects than we have people to work on them"* (R3, Programme Manager).

Publicly funded research centres are competing with private enterprises for high-quality staff but cannot afford to offer competitive salaries, which leaves them at a distinct disadvantage in recruiting and maintaining high-quality researchers.

> "*One of the challenges we have had in a way is retaining good people. As a result, because the postdoc salaries are clearly not on a par with the equivalent industry salaries, and good people that are ambitious and are convinced that they want to work in the industry long-term typically don't want to hang around"* (R6, Principal Investigator).

> *"It is difficult to get excellent people because industry takes all those people. Not all of those people but many of those people because they can pay four or five times more than you are going to earn at [research centre]"* (R3, Programme Manager)

The next sub-section highlights the third sub-theme identified through the semi-structured interviews, namely measurement issues facing evaluators conducting research impact assessment exercises.

#### 4.4.1.3 Measurement Issues

The third sub-theme identified through the semi-structured interviews was related to challenges measuring and demonstrating research impacts. Section 3.2 outlined the key challenges facing researchers, evaluators and policymakers when attempting to measure and evaluate research impacts. These issues were reaffirmed through the semi-structured interviews with key stakeholders across the Irish research sector and are presented below.

***Attribution***

The process of generating research impact is multidimensional, complex and nonlinear involving multiple stakeholders often across long time frames and as such, directly attributing research impacts back to any single investment, project, researcher or institution is very difficult and should be approached cautiously. Many participants acknowledged the difficulties associated with attribution, but solutions to the issue were scarce.

> *"Exactly and that is one of our biggest challenges, is how do we track this. I don't have an answer"* (R2, Head of Research)

Long time-lags associated with generating wider economic and societal impacts coupled with limited resources available within research centres to trace these impacts means estimating attribution rates is difficult. One respondent noted "*It is a broad spectrum in that regard. Once something leaves the centre, it is very hard to find out what it is being used for"* (R7, Deputy Director). Furthermore, another participant asserts

> *"the problem is trying to capture that impact, unless you get a letter of support from a company to say it's saved them so much money. So yes, it's harder to measure and sometimes the companies won't say... They'll get the knowledge, but they won't feedback in how that knowledge benefitted them"* (R5, Principal Investigator).

Measuring the impact of publicly funded research centres requires data collection across multiple stakeholders including but not limited to research centres, funding bodies, universities, collaborative partners and technology transfer offices. However, research centres are often limited by the willingness of stakeholders to provide data required to estimate attribution accurately. For example, industry partners often require confidentiality when providing potentially sensitive information. As one participant states

> *"Once the project is finished, it can disappear off their horizon and the centre might not necessarily then know really what the longer-term impact of that engagement with the company was because the company is, by their nature, they operate confidentially, they can be very guarded"* (R9, Commercialisation Manager)

If research centres can collect data and demonstrate that an impact has occurred, it is still difficult, if not impossible, to disentangle and accurately estimate the degree to which the impact may be attributed to different stakeholders.

> "*That wouldn't have happened, I don't think, without us. Now, of course, it wouldn't have happened without them either, so this question of attribution is tricky."* (R11, Director).

The interviewees identified multiple methods used to measure the portion of total impacts attributable to research centre collaboration. Both quantitative and qualitative methods of measurement were identified by respondents, yet most of these evaluations were done on an ad-hoc basis, and a clear lack of a systematic approach to RIA was evident.

> *"We collect metrics and narratives, so we have a series of prompt questions where we actually ask the impact arising from my award is most relevant to whatever, X, Y in our area"* (R8, Head of Research Policy).

> "*We did a survey. We're producing another one now actually for over the next 6 months but leading up to the last funding cycle there was a survey done"* (R1, Research Centre Director).

> *"Attribution? Yeah, so basically, they work through a bunch of cleverly nested questions to try and get at that and put an estimate around it".* (R4, Programme Manager)

One participant identified testimonials and quotations from their industry partners as a means of establishing attribution.

> *"We would also ask them for quotes. Many of them, invested, they bought the [company] to [Irish city]. They've got about 250 people there now. We have some collaborative research projects with them. That's easy to get a quote from them saying, 'we came here because of [research centre].' And most companies are happy to say that."* (R12, Director).

While the above quotation does provide some evidence of the contribution of the research centre to economic impacts such as job creation and foreign direct investment (FDI), it is not clear whether the centre attributes all these jobs to collaboration with the centre, and it is debatable whether the quote from a company would provide sufficient evidence for calculating attribution rates. This issue was raised by some interview participants.

> *"I think it's sometimes a bit weird when a research centre that's basically grounded in scientific research starts making these wild claims that aren't necessarily scientifically based, that their research or a particular finding led to or caused a particular outcome. It's more a leap of faith rather than an evidence-based piece of analysis"* (R9, Commercialisation Manager).

These issues have contributed to debates concerning attribution-based approaches and whether they are reliable, or even desirable. Difficulties associated with providing robust estimates for attribution rates have led to calls for alternative approaches to RIA. The attribution versus contribution debate in presented in Section 3.2, with the latter approach generating increased interest and favour amongst researchers, funding bodies and evaluators in recent years.

In Ireland, there has been a gradual shift in the definition of the research impact concept from attribution-based definitions towards definitions grounded in a contributions approach. This view was also reflected in the interviews with key stakeholders from research sector in Ireland.

> *"But there's also an opportunity for them to talk about – and I think this is probably more realistic – how they might have contributed to something more broadly as part of maybe a number of initiatives, even beyond the research centre"* (R8, Head of Research Policy)

Economic and societal impacts usually involve multiple stakeholders and take much longer to generate, which makes attribution much more difficult. These findings were confirmed during the semi-structured interviews.

> *"I think at that stage it's probably preferable to use the word 'contribution' rather than 'attribution'. I would look at that the same with the output in outcome-impact sort of continuum, that, okay, it's much easier to attribute a particular funding source or a centre to a particular output, like a publication or a patent, but once you get to outcomes and certainly to longer-term impacts, really I think it's probably not right to talk about direct attribution, it's more a contribution"* (R9, Commercialisation Manager).

One suggestion provided by participants to potentially address the challenges presented by estimating attribution rates was to create positions within centres to trace longer-term economic and societal impacts.

> *"If we had more of a systematic methodology for doing it, and it takes time of course, you do need somebody with the time to do that and to coordinate it, which really, we don't have"* (R9, Commercialisation Manager)

> *"there is a role for somebody to trace these impacts, to trace these post-project results, beyond academic publications"* (R2, Head of Research).

These roles have already been discussed and developed in other regions. For example, the development of the Research Excellence Framework (REF) in the United Kingdom has led to the creation of new roles within research centres and universities. Research impact officers are responsible for implementing systems to record, monitor and evaluate impact activities in addition to supporting the development of impact case studies for REF. The development of these roles in Ireland are at a much earlier stage. However, University College Dublin (UCD) began advertising for the role of research impact officers in 2019, so these roles may start to emerge more broadly across the research system which should contribute to improvements in impact measurement in the future.

***Burden of Evaluation***

Many participants pointed to the burden that impact evaluations place on researchers and research centres. While acknowledging the importance of research evaluation for accountability and providing justification for the allocation of public funding, respondents suggested that the methods of evaluation were inefficient and the development of a systematic approach to evaluation was required to improve efficiency and reduce the burden of evaluation.

Respondents pointed to funding bodies becoming increasingly bureaucratic with the drive towards the impact agenda.

> *"You have to report on what you do, and it's reasonable to have metrics, but I think if you over-engineer your system, and as it becomes overly bureaucratic, anecdotally, I would say, surely, in the centre's context, there is a hell of a lot of reporting."* (R10, General Manager)

Jones, Manville, and Chataway (2017) identify the benefits and burdens associated with RIA in the UK. The authors find that in several universities and research centres, the burden of producing REF case studies was concentrated in relatively few staff, primarily those designated as impact case study authors. This resulted in researchers having to take time away from research activities in order to prepare evaluations. Similar trends have been identified across Irish research centres.

> *"The EU projects were much more onerous and bureaucratic in their reviews. SFI was great. Now that has very much flipped over. SFI is extremely bureaucratic with annual reports and KPIs and governor's committees and executive committee meetings and advisory boards. So, there's far more mandated activity that I think gets in the way of research"* (R12, Director).

This burden of evaluation is increased by the perceived absence of a systematic approach to evaluation across the Irish research system. As such, inefficiencies in the form of double reporting have been identified as key problems with evaluation practices. Research centres receive funding from multiple sources, each with their own reporting standards and data collection methods.

> *"There is certainly a more efficient way of doing it, let's say, such that you'd have databases that could be populated and pulled down for reporting purposes. What has happened is that we have had different templates and different versions of templates from different coordinators at different time points, a lot of repetition, and a lot of email chasing, and a lot of frustration for researchers because they find themselves busy filling in forms, as opposed to getting the job done"* (R6, Principal Investigator).

Furthermore, this contributes to a greater burden being placed on the research centre's collaborative partners as the same data and information is being requested by each research centre, they collaborate with. This contributes to industry partners refusing to provide key data which may lead to key evidence of impacts being lost.

> *"Last year, I put through two innovation partnerships, and I'd say they nearly killed me, with trying to get them up and running through the university. And one company said, 'I'm just not signing any more agreements. They basically signed so many agreements they said, I'm not signing any more agreements. I'm refusing to"* (R5, Principal Investigator).

Respondents identified some potential steps to reduce the burden of evaluation across the research sector. Firstly, research centre representatives identified improved data collection methods as an important step to reduce the burden on research centres. While respondents acknowledged that longer-term impacts and case studies would need to be provided by centres, they questioned whether shorter term, publicly available output data such as bibliometrics and patents could be sourced from alternative sources.

> *"Fundamentally, it looks on principle all the same, smart, simple and that, but you end up having to populate things individually, for each funding partner.*

*Particularly things like publications, it should be straightforward to be able to link to a Google Scholar or some kind of profile, rather than the tedium that's involved. Certain things can be done simply and then others are trickier"* (R11, Director).

Many respondents identified the potential for a more systematic approach to be developed across the entire research system in data collection and evaluation exercises. Given that many funding bodies require similar type of data, there is a desire to move towards a more systematic approach to data collection.

> *"It would be nice if it was streamlined a bit more, and particularly across the funders I think because generally, they all look for the same data. They may place a different emphasis on different elements of the data, but they all want to know what publications and outputs came out. They are all increasingly looking at more long-term impacts on health or policy or practice or whatever. So, I think that would be really valuable"* (R9, Commercialisation Manager).

***Time Lags***

Time lags are widely acknowledged as a key issue in RIA exercises. Time lags refer to the time it takes for research activities to be translated into impacts. However, the length of the time lag varies across sectors, disciplines and research activities.

> *"TRLs are different on each market and will run at different speeds. Life science is quite slow, software is very quick, most of the rest are somewhere in between. So, if you tried to look like for like for like, it is comparing apples with oranges essentially"* (R4, Programme Manager)

As such, when conducting RIA exercises and benchmarking research centre performance, the timing of the evaluation is extremely important. Furthermore, context-specific factors that affect the length of the time lag associated with research activities should be incorporated into RIA tools to improve comparability across research centres.

> *"If you're ramping out some code in digital media or something, you're probably talking weeks and months. Whereas, I'm thinking, a seizure detection*

*system, you are talking ten years. So, how can you get some kind of meaningful way of comparing and contrasting those two in a fair and transparent manner?"* (R10, General Manager)

However, solutions to this issue were not identified by interview participants and are far from straightforward.

***Data Collection***

One of the key challenges identified by interview participants was the need for a more systematic approach to track, measure and evaluate research impacts. There is currently a lack of consensus on best practices and standardised approaches to RIA, but participants agreed that a more systematic approach to data collection was required to increase efficiency and reduce burden. Interviewees suggested improvements are required in data collection systems and processes.

> *"So sometimes a challenge is tracking the stuff because we know the stuff is happening, but in terms of, on the metric side, gathering and getting that data populated… And systems are a nightmare, the idea that you have to individually put in journal papers is just ridiculous. So, the systems for gathering this stuff don't help"* (R11, Director)

Moreover, many interviewees questioned whether a nationally coordinated research impact assessment exercise involving multiple funding bodies could be developed. The aim of this approach is to reduce the amount of double reporting and burden associated with data collection. Although funding bodies have different aims and objectives which requires specialised data, there is much data that is required by almost all funding bodies, e.g. bibliometric data.

> *"It would be a lot more efficient if there was one agreed national funder impact survey or something like that, akin to what they are doing in the UK"* (R9, Commercialisation Manager)

> *"I do think it probably will move to a more nationally coordinated... at least I hope it does because it would make sense for the funders to come together and somehow coordinate around us"* (R9, Commercialisation Manager).

The next sub-section explores the fourth sub-theme identified through thematic analysis - measurement tools for evaluating research impacts.

#### 4.4.1.4 Measurement Tools

This sub-section highlights the most commonly use impact measurement tools identified by participants. Research centres utilise both quantitative and qualitative approaches, or a combination of the two, when conducting research impact assessments.

***Metrics-based Approaches***

The most common approach for measuring research impact identified through the qualitative interviews was metrics-based approaches. The potential limitations of metrics-based approaches for measuring the economic impact of investment in publicly funded research centres are presented in Section 3.3. Firstly, the issue of one-size-fits-all approaches to RIA was identified by many participants as a significant challenge.

It is well established that research centre outputs, outcomes and impacts vary significantly across disciplinary and sub-disciplinary fields. Therefore, designing impact measurement tools with universally accepted metrics and indicators is a difficult, if not impossible, task. As such, the development of standardised impact metrics was identified by multiple participants as a key challenge facing researcher centres and funding bodies in Ireland.

> *"10 or 15 technology centres in their programme, all doing different things, they all have a different client base, some mature companies, some immature companies, some centres that have been around 15 years and some that have been around 10 years, and they're trying to develop KPIs that can be standardised across those. That's very difficult."* (R13, Head of Business Strategy)

> *"I think it's a particular issue that SFI are probably struggling with, in terms of having one-size-fits-all, in terms of how they evaluate, monitor, track impact through various metrics. It's a one-size-fits-all framework, but actually, it*

*doesn't take any cognisance of the different product life-cycles, even if you look at it on that level, and the different journey"* (R10, General Manager).

Secondly, there is a danger associated with metrics-based approaches to RIA of "counting what is easily counted rather than measuring what counts". Current impact metrics often focus on shorter-term measures of research input and output indicators rather than longer-term outcomes and impacts.

*"I think what we would say is just because you can count something, it doesn't necessarily mean it counts, and just because you can't count something it doesn't mean it doesn't count"* (R9, Commercialisation Manager).

Thirdly, research impact is a complex, nonlinear process involving multiple stakeholders, and the relationships among them, which are often intangible. Celeste, Griswold, and Straf (2014, p.66) note "the challenge, which has yet to be met, is to capture and articulate how these intangible factors enable the success of the research enterprise". The challenge of developing metrics that capture and value research impacts through evaluations was identified in the semi-structured interviews.

*"Then there's other measures of esteem that are really hard to quantify. Is somebody is invited to be on a particular scientific board, or someone is asked to give an invited talk, these are quite important in terms of the reputation of the centre and the person, and they do play a role when they companies are considering engaging with a centre. They do have an impact, but it would be quite a difficult one to quantify"* (R7, Deputy Director)

Furthermore, many impact metrics focus on the quantity rather than the quality of outputs. While Irish research policy aims to focus on measures of research impact, the actual targets are more specifically focused on research outputs and outcomes. This issue was identified as problematic by respondents during interviews.

*"I suppose, if you look at the KPI specifiers, they are based more on crude numbers of publications rather than citation impact. Its number of spinouts rather than the quality of spinout companies*" (R9, Commercialisation Manager)

Finally, the importance of achieving metric-based targets for securing future research funding creates perverse incentives for researchers and research centres to 'game' the system. For example, one respondent highlights the issue of using licenses as a metric to measure impact.

> *"Licensing is not the best measure of impact, because I can do licences to meet a KPI. We all understand why they are a measure and what they are trying to measure, and that's fine, but as a KPI, it can be easily manipulated"* (R1, Research Centre Director).

Despite some well-known limitations of this approach, metric-based approaches remain the most commonly used measurement tools for assessing research impacts, "*that's the game in town. Whatever metric you use it alienates some people"* (R12, Director). However, the limitations of metric-based approaches have contributed to the search for alternative approaches to measure and demonstrate research centre impacts.

> *"From our perspective, that's the discussion we are having at the moment; how can we get away from these quantitative measures? Not entirely though, because numbers are helpful, but I think to balance that with other ways of measuring and describing what we do. That's a live debate"* (R10, General Manager)

***Narratives***

Metrics are useful for measuring shorter-term inputs and outputs rather than research outcomes and impacts, which may take many years to achieve and involve multiple stakeholders. The limitations associated with metrics-based approaches to RIA has contributed to calls for qualitative and mixed-method approaches to assess the impact of publicly funded research. Donovan (2019) warns against committing 'metricide' by abandoning time-consuming impact narratives in favour of simple metrics.

> *"Narratives are very important… we could put a number on the amount of policy documents that reference our stuff, but when you actually show an example it has a higher impact, it makes it more real"* (R11, Director)

Section 3.2 discusses the advantages and disadvantages associated with narrative-based approaches to RIA. Narratives allow researchers and research centres to provide in-depth, detailed descriptions of the process and outcomes of public investments in research activities. Furthermore, narratives allow research centres to demonstrate evidence on intangible impacts generated through research activities, usually associated with longer-term economic and societal impacts. Thus, the combination of metrics-based approaches with in-depth narratives was identified as a useful approach to capture and measure research centre impacts.

> *"I think the use of case studies and narrative impact is very important to accompany the numbers because really to illuminate the numbers and to really show these types of more intangible type of impacts, the only way you can really do it is through narration and through case studies"* (R9, Commercialisation Manager)

One participant noted that metrics are the preferred measurement tool for research outputs, while narratives are more suitable for wider economic and commercial impacts. Research outputs are more easily attributable to the research centre and fall within a research centres sphere of control while wider economic and societal impacts are trickier to attribute to any piece of research, programme or research centre. Therefore, it may make more sense to identify how research 'contributes' to wider impacts through narrative approaches.

> *"KPIs are quite good on the outputs, but not on the outcomes, and impact is really about outcome. It's not even output, it's beyond that, and narratives seem to work well there, certainly in what we do"* (R11, Director)

The next sub-section presents the second theme identified though the semi-structured qualitative interviews – Research Impact Agenda System-level Effects.

### 4.4.2 Research Impact Agenda System-level Effects

#### 4.4.2.1 Barriers to Successful Collaboration

The fifth sub-theme identified through thematic analysis was the barriers to successful collaboration. The IMPACTS framework, presented in Chapter 5, adopts an evolutionary approach to measuring and evaluating the economic impacts of publicly funded research centres. As such, research centres do not generate impacts in isolation, but rather involve multiple stakeholders across the innovation system. The national strategy for science and innovation in Ireland, *Innovate 2020*, highlights the strengths and weaknesses of Ireland's innovative performance. In 2016, Ireland scored strongly in terms of talent and impact of innovation but lags behind innovation leaders in terms of the level of R&D investment (both public and private), the creation of patented intellectual assets, and the linkages of research to the private sector. This sub-section focuses on the final point, the linkages between publicly funded research centres and private enterprises.

***Culture***

Participants identified differences in culture as a key barrier to successful collaboration between public-private partnerships in Ireland. Confidentiality, secrecy, and lack of trust are common characteristics of business R&D operations, which obstruct successful collaborations with public research centres.

> *"You can talk until you're blue in the face, though, but there's a culture there of secrecy or a culture of fear"* (R1, Research Centre Director).

> *"It has been and continues to be a huge culture shift and change that needs to happen with the companies in our sector. Some are better than others, some have come a long way, and some have an awful long way to go"* (R1, Research Centre Director).

Some participants believe perceived differences in culture and incentives rather than expertise may act as a barrier to a successful collaboration with research centres.

> *"I think industry mistakenly can sometimes associate academic excellence with industrial irrelevance, which is a dangerous link to make"* (R6, Principal Investigator).

***Competition or Co-operation***

In Ireland, research centres play the role of knowledge intermediary bringing together diverse actors from across the research system. Given the Irish research system is small relative to other European countries, many of the research centre's industry partners are in competition with each other.

> *"Every company we deal with is competing, and all our members are effectively competitors with each other, both their products in the marketplace and, more relevantly, they are competing with each other for staff, to get staff at the moment"* (R1, Research Centre Director).

Therefore, research centres play a crucial role in increasing engagement between these organisations. However, openness to engagement amongst industry partners is difficult to achieve in practice.

> *"What's really happening is everybody is playing their cards very close to their chest. They are engaged but it's very much hands-off at a distance"* (R1, Research Centre Director).

> *"So, they are all competing with each other, yet we've got some people who are more than happy to engage and do engage and contribute and collaborate around a table, even though they know there are competitors there. Then we've got other people who just zip it and won't engage, will certainly sit at the table and listen, are happy to listen and take in everything, but won't give much"* (R1, Research Centre Director).

However, participants noted a reduction in potential barriers to collaboration as research centres have been able to identify shared problems and solutions which benefits each industry partner and encourages engagement.

> *"I think it's been a learning process for them as well because they have been able to identify more easily what's confidential and what's not, and what's company-specific and what's not. I think it's also broken-down misconceptions amongst industry that what they do at an individual level is very, very unique. I think they have begun to realise more and more that they have a lot of shared challenges and priorities and things that need to be worked on, and that can be done at a pretty competitive level"* (R6, Principal Investigator).

***Contact Point***

Many participants highlighted the importance of the contact point for businesses' absorptive capacity.

> *"One of the terms that comes up quite a lot is absorptive capacity. I think it's critical to the success of these centres, is that industry have continuity of representatives but also have representatives with the appropriate level of absorptive capacity, or some structure to absorb and disseminate what's coming through from a centre"* (R6, Principal Investigator).

Respondents identified the importance of the contact point for successful collaboration between research centres and firms in Ireland. The contact point possesses valuable tacit knowledge, skills and experience that are significant factors in reducing barriers to successful collaborations. However, respondents noted that should the contact person leave the company then they take their tacit skills with them.

> *"Yes, but sometimes the relationship with the company is very down to an individual and if that individual moves you can be..."* (R5, Principal Investigator,)

> *"One of the big challenges, actually, and it's probably not unique to [our centre] but has been continuity of industry partner representatives. There has been a lot of flux and change and chopping and changing of the representatives from several of the industry partners, but not all"* (R6, Principal Investigator).

The next sub-section explores the role of the funding body in shaping the research sector in Ireland. Research funding in Ireland is highly centralised with two government departments, Department of Job, Enterprise and Innovation (DJEI) and Department of Education and Skills (DES). In implementing this policy agenda, these Departments work with and fund, in whole or in part, several agencies and programmes, including SFI, IDA Ireland, EI, Higher Education Authority (HEA), Irish Research Council (IRC) and Health Research Board (HRB).

#### 4.4.4.2 Role of Funding Body in Irish Research Sector

The sixth sub-theme identified through semi-structured interviews was the role of funding bodies in shaping the research sector in Ireland. The key discussion under this sub-theme is the opinion of stakeholders that funding bodies have shifted focus from funding fundamental research towards more commercially-driven applied research. Several concerns were raised regarding this drive towards short term, commercially driven research.

***Autonomy***

Many participants questioned the autonomy of the leading scientific funding body in Ireland and the potential impact this may have on the future direction of the research sector in Ireland.

> *"Take the example of SFI. Yes, they're the biggest science funding agency in the state, but they sit under the Department of Enterprise, Jobs and Innovation. That does set a particular tone, I suppose, in terms of what is expected in return. It clearly has to set a bias, a prejudice, a shift, an emphasis, whatever pejorative or non-pejorative word you want to use"* (R10, General Manager).

> *"That does open up a philosophical question over, should a science funding agency that, by its nature, should be driven by a number of different agendas, some of which are not overlapping, be under the governance of one specific part of government policy, or government drive?"* (R10, General Manager).

***Narrow Conception of Research Impact***

Participants questioned whether SFI's remit under the Department of Enterprise, Jobs and Innovation leads to an overemphasis on economic impacts. The view of successive Irish governments over the last twenty years is the assumption that research funding should be justified based on generation of economic impacts. Respondents pointed out the shift in priorities from scientific excellence towards economic impact.

> *"Certainly, when I joined, there is no doubt, one of the very first messages you absorb was, this industry cost share was the number one thing. Screw your Nature papers, Science papers, Nobel prizes, to hell with that. The number one*

*thing, or else we aren't going to get funded, or we're in trouble, is going to be this ability to bring in industry money. That is the tone that is set"* (R10, General Manager)

Many interviewees highlighted the dangers associated with this narrow policy focus, particularly for a small open economy like Ireland. The Irish research sector is small relative to European comparators and as such an overemphasis by funding bodies on a particular policy may skew the behaviour of actors within the system.

> *"The other thing is, ultimately, Ireland is a small country. It is a limited pool. Therefore, if you are drawing on the same pool for the same things all the time, then it's a double risk. So, incentivising one kind of behaviour in a small system like this means, effectively, the whole system, even if they don't think it, are moving in the direction of the herd, just because there is a pull effect"* (R10, General Manager)

Furthermore, participants expressed concern whether this focus on delivering economic and commercial impacts would lead to funding bodies targeting short term, applied research projects at the expense of longer term, blue-skies research.

> *"If SFI want to fund fundamental research – and I think SFI have lost the plot a bit, they've kind of come more like EI – but they've all gone to applied research"* (R5, Principal Investigator)

Furthermore, many participants highlighted the challenges associated with the shift in funding models towards industry-led research funding. For example, one respondent asserts

> *"As I say, one risk in terms of that flow or that story, that narrative around impact, is if it is appropriate for industry to be spending more and to be valuing it more. Obviously, their share in funding should be increasing, but jumping as I say from one to seven to one to one is quite a steep jump and it's risky"* (R11, Director)

> *"The other challenge that it faces – and this has come back from our review panels – is the challenge it has on the research, because there can be a narrow*

*boundary between high TRL research and consultancy. And it's great to be empowering business and supporting business and making sure there's a value added coming from the research, but if it's providing a service to business, the research element can suffer as a result. So, it might have short-term benefits, but not long-term. But that's a tricky balancing act. It's loosely and poorly, I think, discussed in this country around this basic and applied research thing"* (R11, Director).

***Role of Small and Medium sized Enterprises (SMEs)***

The emphasis by funding bodies on demonstrating economic impacts has contributed to SMEs being neglected at the expense of MNCs, according to some respondents. In general, MNCs have greater research budgets, higher turnover and employment numbers compared to SMEs. Furthermore, MNCs tend to be well known so collaborating with internationally recognised businesses improves research centres reputation.

> *"My main challenge is that we have small players that are in our space that we routinely ignore, we're going to ignore, I believe, we are in danger of ignoring, because of the limited resources. It's much better chasing a bigger project than chasing ten small projects"* (R12, Director)

Furthermore, the current funding model mitigates against disciplinary fields and sub-fields that are dominated by SMEs, which leaves research centres collaborating with these businesses at a distinct disadvantage in terms of research impact capacity.

> *"If you're dealing with a small indigenous company, no one knows them. So, the model mitigates against SME involvement. That's one thing I'm very worried about. And that's a bad service to the software industry in Ireland which is 80% small SMEs. They're going to lose out"* (R12, Director).

***Openness to Engagement***

Many participants questioned the receptiveness of funding bodies to research centres input into the decision-making process around metrics, impact measurement and future direction of the research sector in Ireland.

> *"Are the centres being listened to? I think sometimes we are and sometimes we aren't, in the sense that SFI make the decisions. Would it be better if there was more collegial decision-making or more opportunity for input into those decisions? That's an open question, I think. They would be the key challenges"* (R11, Director).

Others suggested that while communication lines are open between research centres and funding bodies, often this amounts to nothing more than 'lip service' as the key decisions have already been made.

> *"The sense I have always had is that they give plenty of opportunities for the directors to provide feedback, but they don't often act on that feedback"* (R7, Deputy Director).

> *"So, they're having this big long consultation, but it seems to me, already, major decisions have been made about how their investments are categorised, and how they are valued, and the mood music about what their impact is supposed to be. Are people joining up the dots on that? I'm not so sure, but that is the reality"* (R10, General Manager).

The next section presents a discussion of the key findings from the thematic analysis of thirteen semi-structured interviews with key stakeholders across the research sector in Ireland.

## 4.5 Discussion: What does this qualitative research tell us about the Impact Agenda?

The aim of the thematic analysis was to explore the meanings and conceptualisations of research impact across the research sector in Ireland. A thematic analysis of thirteen semi-structured qualitative interviews with key stakeholders across the research sector in Ireland identified two overarching themes: (i) measuring and conceptualising research impact (ii) research impact agenda system-level effects. Furthermore, six sub-themes were identified in relation to rationale for RIA, definitions, methodological approaches and challenges, barriers, attitudes towards funding bodies and future directions of the research sector.

The first sub-theme relates to the rationale for conducting research impact assessment (RIA) exercises. The rationale for RIA influences the selection of appropriate methodological tools to capture research impacts. Guthrie et al. (2013) identify the 4 A's of RIA, namely: accountability, allocation, analysis, and advocacy. All these rationales were identified by interviewees, however the majority identified funding bodies as the main drivers of RIA exercises in Ireland. As such, the main rationale identified by interviewees was accountability and allocation.

Some participants identified the shift in policy focus towards the research impact agenda as contributing to a shift in focus towards short-term, commercially-driven research at the expense of blue sky, basic research. These feelings were echoed in a letter in the Irish Times newspaper in 2015 (Ahlstrom 2015). In a letter signed by over 800 leading scientists in the country, they highlight their concerns around Irish research policy with greater funding emphasis placed on economically driven research and a reduction in support for fundamental research, research for knowledge. More recently, spokesperson on Science for the largest opposition party, Fianna Fáil, James Lawless, insisted Science Foundation Ireland needed to shift policy to support researchers interested in conducting more fundamental, basic research (O'Sullivan 2018).

The second sub-theme relates to the diverse definitions and conceptualisations of research impact. Several impact dimensions were identified including economic impacts, scientific impacts, human capital impacts, capacity building impacts, policy impacts and societal impacts. However, participants pointed to the narrow conceptualisation of research impacts by funding bodies based predominantly on economic impacts, particularly generating industry cash. Although funding bodies outline a diverse range of impacts that may be generated through research centre activities, the value of economic impacts is considered paramount.

This potential 'bias' towards economic impacts is understandable given the focus on accountability and allocation as key rationale for RIA exercises. Furthermore, research centre policies in Ireland are highly centralised within the Department of Job, Enterprise and Innovation (DJEI). As such, the structure of the research funding system in Ireland gives a clear preference towards demonstrating the economic impacts of research. However, the overemphasis on economic impacts poses a range of problems for the research sector in Ireland.

Firstly, benchmarking research centre impacts is complicated as research centres are diverse organisations that may be differentiated by strategic objectives, research activities from pure basic to pure applied, TRLs, disciplinary and sub-disciplinary fields. Furthermore, external factors such as the aims and objectives of collaborative partners, absorptive capacity of innovative partners and the strength of the innovation system which a research centre is embedded are important considerations.

Secondly, funding bodies must be cautious not to adopt narrow goals for the research centre landscape in Ireland as this may contribute to large distortions across the research sector. The research sector in Ireland is small relative to European counterparts. The lack of diversity means that decisions of funding bodies have the potential to lead to significant distortions to the system. Thirdly, there was a fear that the focus of industry cash may contribute to research centres acting as consultants *working for* businesses rather than collaborative partners *working with* businesses.

Research centre directors and management expressed concern that the increasing portion of overall funding derived from industry partners may contribute to narrowing of the boundary between applied research and consulting. Research centres offer 'big picture' thinking for businesses that are often facing short-term issues and challenges. The research centres allow businesses to focus on short term commercialisation needs while ensuring that longer-term, blue sky research into future disruptive technologies is also being considered.

The third sub-theme relates to challenges faced by research centres and funding bodies in efforts to measure and demonstrate research impacts. Research centre directors and managers highlighted the need to develop more systematic approaches to data collection. This burden of evaluation is increased by the perceived absence of a systematic approach to evaluation across the Irish research system. As such, inefficiencies in the form of double reporting have been outlined as key problems with evaluation practices. Seminal steps have already been put forward to develop systems-based approaches to RIA. Big data approaches such as ResearchFish in the UK and STAR Metrics in the US offer potential guidance on the development of such systems.

This provides a potentially useful way to reduce the burden of evaluation that complicates RIA exercises.

Data collection is currently done on an ad hoc basis, typically annually or semi-annually. Participants identified funding bodies as the main drivers of data collection efforts, to meet grant conditions and provide justification for investment of public funding. The participants identified the need for a more systematic approach to data collection to reduce the burden of evaluation.

The OECD (2019, p.31) identified data collection and data analysis as important

> "Data collection and data analysis are two important but distinct parts of an assessment exercise. The analysis of indicators can be routine and standardised or annual reporting - or on demand - for a specific purpose. The aim is to limit as much as possible *ad hoc* data collection and to include within routine annual reporting information about impact".

Research centre directors and managers indicated more systematic approaches to data collection need to be implemented. Firstly, much of the traditional indicators are available in existing databases. Furthermore, software packages such as SciVal have made collection and analysis of bibliometric data much more straightforward. Secondly, many participants questioned whether a nationally coordinated research impact assessment exercise involving multiple funding bodies could be developed. The aim of this approach is to reduce the amount of double reporting and burden associated with data collection. Although funding bodies have different aims and objectives which requires specialised data, there is much data that is required by almost all funding bodies, e.g. bibliometric data.

Thirdly, some participants highlighted the need for additional specialised personnel to assist in demonstrating research impacts including developing case studies and leading data collection efforts. This view is supported by recent studies (Jones, Manville, and Chataway 2017, Wilkinson 2019). Jones, Manville, and Chataway (2017) note that most impact case studies are produced by a small number of staff and two-thirds of the work is conducted by one person, and in many cases leads to this person having to take a break from research activities. Furthermore, Wilkinson (2019) finds overwhelming support for the allocation of additional supports for demonstrating research impacts including staff workload and funding for impact activities in one university in UK. There was also support for additional staff in the collection and verifying of evidence.

The participants highlighted the potential for technological advancements and availability of large databases to reduce the burden of evaluation on researchers and research centres. Research centres receive funding from multiple sources, both public and private. Each funding body requires research centres to provide data for a variety of metrics. These metrics are differentiated by the aims and objectives of the funding body, nature of the research and the life cycle of the research grant.

However, many commonly used metrics exist in relation to scientific excellence e.g. publications and citations, technical impacts e.g. patents and licenses, and human capital impacts e.g. number of doctoral graduates etc. The participants highlighted the potential for commonly used databases as a potential solution to these data collection issues. Furthermore, much of the scientific data e.g. publications and citations are readily available online, with numerous tools available to gather data from online sources.

The fourth sub-theme relates to measurement tools to overcome these challenges. The most common approach to RIA identified is metrics-based approaches. Research centre directors and managers discuss impact measurement in terms of hitting KPIs, intrinsically linked to meeting funding criteria and ensuring eligibility for next round of research funding. However, many KPIs measure research centre performance rather than research centre impact. Research impacts are external facing and generally broader than performance measurement based on KPIs. Some KPIs do not directly measure the wider impact of a research centre, at least in the terms set out by SFIs definition of research impact, "demonstrable contribution that excellent research makes to society and the economy".

The issue of one-size-fits-all approaches to RIA was identified by many interviewees as a significant challenge. It is well established that research centre outputs, outcomes and impacts vary significantly across disciplinary and sub-disciplinary fields. Therefore, designing research assessment tools with universally accepted metrics and indicators is a difficult, if not impossible, task. As such, the development of KPIs and impact metrics were identified as key challenges facing the two largest science funding bodies in Ireland, Science Foundation Ireland and Enterprise Ireland.

Many interviewees identified the use of RIA to ‘tell their story’ and provide a narrative for ‘joe average on the street’. Some participants were unable to identify the methodological approach their centre used to measure research impact but were all too familiar with the results, particularly large positive results. One participant noted their surprise that research centres grounded in scientific method and evidence-based approaches to research, lack similar scientific rigour when estimating the impact of their research. The pressure to produce and demonstrate research impacts sometimes creates perverse incentives for researchers and research centres to overestimate, or at least overstate, their research findings.

The lack of standardised approaches to RIA and a lack of consensus on best practises in developing robust tools and frameworks to measure impacts contribute to this issue. There is a danger that research impact is used predominantly for advertising purposes based on sound-bites from collaborative partners. While testimonials are useful in terms of demonstrating and communicating some potential impact has occurred, it is less useful for developing robust estimates of research impact or attribution rates.

The fifth sub-theme relates to barriers to successful collaboration. Research impact is a social process involving multiple stakeholders. Therefore, the strength of relationships between research centres and other actors within the innovation system influences their research impact capacity. However, confidentiality, secrecy and lack of trust are common characteristics of business R&D operations which impede successful collaborations with public research centres. Participants identified numerous barriers that may disrupt successful collaborations and reduce potential impacts from research including differences in culture, the boundary between competition and co-operation, and the importance of the contact point.

A key challenge facing the research sector in Ireland is recruiting and maintaining high-quality researchers within the sector. Respondents identified collaboration with industry partners as a “*catch-22 situation”* and *“cannibalistic”* as publicly funded research centres are competing with private enterprises for high-quality staff but cannot afford to offer competitive salaries, which leaves them at a distinct disadvantage in recruiting and maintaining high-quality researchers.

The sixth sub-theme relates to the role of the funding body in the research sector in Ireland. Participants identified several factors including the role of the funding body in shaping the Irish research landscape, the perceived narrow conceptualisation of research impact, their openness to engagement and impact on role of SMEs within the Irish research sector. The key discussion under this theme is the opinion of stakeholders that Science Foundation Ireland (SFI), the main science funding body in Ireland have shifted focus from funding fundamental research towards more commercially driven applied research. Several concerns were raised regarding this drive towards short term, commercially driven research.

Participants questioned whether SFI's remit under the Department of Enterprise, Jobs and Innovation leads to an overemphasis on economic impacts. Furthermore, participants expressed concern whether this focus on delivering economic and commercial impacts would lead to funding bodies targeting short term, applied research projects at the expense of longer term, blue skies research. Donovan (2011) asserts that the impact agenda should produce no disincentive for conducting basic research. However, the emphasis on accountability and providing justification for public funding contributes to a natural shift towards emphasising economic impacts.

Many participants questioned whether there was a link between the emphasis on commercialisation activities and lack of support for SMEs. Ruane and Siedschlag (2015) argue that innovation policy will have little impact on MNCs becoming RD&I intensive as many of the companies do not perform the R&D activities in Ireland. Despite this, many research centres target MNCs collaborations as typically their investment capacity is much greater than SMEs. Bornmann (2017) highlights inequalities in science where a small number of projects contribute to large portion of overall impact. The emphasis of funding bodies on generating industry funding, particularly industry cash, as a key impact metric may incentivise research centres towards collaborating with MNCs as this may facilitate research centres hitting their funding targets with fewer collaborators.

## 4.6 Conclusion: Where do we go from here? The future of Research Impact Agenda in Ireland

This chapter presents the findings of a thematic analysis of thirteen semi-structured qualitative interviews with key stakeholders across the research sector in Ireland. The aim of the chapter was to explore the meanings and conceptualisations of research impact across the research sector in Ireland. Following a detailed thematic analysis of the interview transcripts, two overarching themes were identified. The themes highlight significant opportunities and challenges facing funding bodies and research centres in the drive towards the research impact agenda. The emerging sub-themes include the rationale for research impact assessment, dimensions of impact, measurement issues, measurement tools, barriers to successful collaboration and the role of funding bodies in research centre landscape.

The interviewees identified several key methodological challenges facing policymakers, research centres and evaluators across the research sector in Ireland. These challenges include the lack of systematic data collection methods, the burden of data collection on research centre's collaborative partners, dealing with time lags associated with research impact and difficulties estimating attribution rates. The development of the IMPACTS framework, survey instruments and Research Impact Index (RII) presented in Chapter 5, 6 and 7 highlight strategies to minimise these methodological challenges.

The next chapter presents a multidimensional framework to measure and evaluate the economic impacts of publicly funded research centres. The framework and the toolkit for operationalising it is an important contribution to research impact agenda in Ireland. It draws on existing literature and addresses many of the issues raised in the qualitative analysis presented in this chapter, including standard approaches to RIA across the system with flexibility to weight results by TRL, enabling efficiency measures relating inputs to outputs, and incorporating several measures of research output ranging from bibliometrics to industry cash.

# Chapter 5: Development of IMPACTS Framework

This chapter presents the novel framework developed in this thesis to measure and evaluate the economic impacts of publicly funded research centres, called the IMPACTS framework (**I**mpact **M**easurement and **P**erformance **A**ssessment of **C**entres for **T**echnology and **S**cience) framework. The IMPACTS framework aims to address the conceptual and methodological challenges to research impact assessment identified in Chapter 3 and Chapter 4. This is a major contribution of this thesis. It builds on previous frameworks in the literature but addresses some of their key limitations and seeks to address some of the challenges highlighted in the qualitative research presented in the previous chapter.

The development of robust RIA frameworks and tools to measure research centre impacts is far from straightforward. The research centre landscape in Ireland is composed of diverse institutions, both in terms of diversity of objectives, such as delivering economic growth, improving health and wellbeing, enhancing scientific excellence and capacity building, and in terms of types of activities including fundamental research up to and including commercially-driven research activities. Therefore, RIA frameworks must be flexible enough to allow comparison across heterogeneous research centres, both nationally and internationally. Furthermore, commonly identified methodological issues in RIA studies, such as attribution, additionality, time-lags and nonlinearities in the research process present challenges.

This shift in research policy focus towards the impact agenda emphasises accountability and demonstrating value for money, as well as the production both scientifically excellent research that has real-world impact. The emphasis on demonstrating broader economic and societal impacts of research represents a shift away from research evaluations based predominantly on demonstrating scientific excellence. RIA is generally considered broader than evaluating the scientific quality of research. Traditional measures of scientific quality, such as bibliometrics do not typically include the evaluation of its use, uptake, and broader impacts (Ofir et al. 2016). Therefore, the production scientifically excellent research is necessary, but not sufficient, condition for delivering economic and societal impacts.

The rest of the Chapter is structured as follows. Section 5.1 highlights the theoretical and conceptual underpinnings of the IMPACTS framework. The theoretical foundation of the framework highlights important dimensions and indicators that must be included in the RIA exercises using the framework. The development of the IMPACTS framework was guided by the Leiden Manifesto (Hicks et al. 2015), Metrics Tide (Wilsdon et al. 2015) and RAND Review (Guthrie et al. 2013).

Section 5.2 presents the novel framework for measuring and evaluating the economic impacts of publicly funded research centres. The IMPACTS framework provides a holistic approach to RIA. This approach adopts a systems perspective to RIA, considering the impacts generated by research centres in relation to their interactions with external actors within the innovation system. Thus, the absorptive capacity of external partners, both *potential* and *realised*, is vital to successfully translate knowledge and technologies from research centres into economic impacts. This is the first framework to incorporate this distinction explicitly.

The IMPACTS framework is designed to be operational and underpin a toolkit for funding bodies to undertake robust, systematic assessment of research centre impacts. The remaining sections demonstrate how this toolkit is constructed. Subsequent chapters will show its operation and practical implementation. Section 5.3 identifies a selection of metrics that could potentially be incorporated into the framework to measure impacts at different stages of the research impact process.

Research impacts are often dependent on context specific factors such as discipline, nature of research and life process of evaluation.  As such, no standardised indicators to capture the diverse impacts generated from research activities have been formulated. Some authors question whether standardised indicators are possible or even desirable (Stevens, Dean, and Wykes 2013).

Section 5.4 discusses how the framework may be operationalised. Many RIA frameworks remain conceptual in nature. The IMPACTS framework is operationalised through a mixed-methods approach. The development of a quantitative benchmarking tool Research Impact Index (RII) complemented by a well-established qualitative measurement tool, Research Impact Statements.

Section 5.5 concludes the presentation of the IMPACTS frameworks and discusses future steps in implementation and operationalisation. The next section discusses the development of a novel framework for assessing the economic impact of publicly funded research centres. 5.1 Theoretical and Conceptual Underpinnings of IMPACTS framework

## 5.1 Theoretical Underpinnings of IMPACTS Framework

This section discusses the theoretical and conceptual underpinnings of the IMPACTS framework. The framework considers research centre impact from an evolutionary perspective as pioneered by Nelson, Nelson, and Winter (1982), Dosi et al. (1988), Hodgson (1993), Metcalfe (1995). Section 2.3 provides detailed analysis of the key features of this approach; thus, it will only be discussed here briefly.

Salter et al. (2000, 28) highlight the key features of this approach:

- Innovation as an evolutionary process
- Research as a capability
- The absorptive capacity of industry
- The new mode of knowledge production and
- Creating social and technological variety

From this perspective, research centres are viewed as a vital cogs within an innovation system, intrinsically linked to other entities within the system, including firms, universities, and government agencies. Salter et al. (2000, 29, p.29) assert “firms do not innovate in isolation” as institutions outside of the firm are critical for supplying knowledge and skills necessary to conduct innovative activities. Similarly, from our perspective, research centres do not provide impacts in isolation. Hughes and Martin (2012, p.12) state “the impact of publicly funded research centres will be substantially dependent on the capacity of other actors in the innovation system to access, understand, and use the research outputs produced with public sector support”. As such, innovation and the diffusion of knowledge should not be considered in isolation but rather in their interrelation to one another

The evolutionary perspective views research as a capability embedded in specific researchers and collaborative networks. The neoclassical perspective undervalues the ‘tacitness’ of knowledge and thus is limited in assessing the potential and realised impact of publicly funded research centres. From the evolutionary perspective, knowledge is a necessary though not sufficient condition to achieve competitive advantage. Rather, it is the capacity of an individual researcher, firm, or government to make the best use of available knowledge which provides unique opportunities to increase productivity and innovation capacity.

Furthermore, the IMPACTS framework places significant importance on the absorptive capacity of firms within the innovation system. The neoclassical perspective implies that knowledge is "on the shelf, costlessly available to all comers" (Rosenberg 1990, p.165), whereas, the evolutionary perspective asserts that while knowledge is plentiful, "it is the capacity to use it in meaningful ways that is in short supply" (Salter and Martin 2001, p.512). As such, transforming knowledge outputs produced by a research centre into economic and commercial impacts is dependent on a firms' absorptive capacity, i.e. their ability to absorb, assimilate, transform and exploit knowledge.

Finally, the influence of regional-specific factors, relating to the improvement of innovative capacity, are considered in the context of its effect on a research centres ability to generate economic and commercial impacts. These regional-specific factors are labelled structural absorptive capacity, which relates to national system elements ability to identify, assimilate, and exploit knowledge. An important new, and to date underappreciated, element in this framework is the explicit inclusion of a research centre's contribution to the overall innovation system, while simultaneously identifying the strength of the system is an important input and platform for a centre's success.

## 5.2 IMPACTS Framework

This section presents the novel framework developed in this thesis to measure and evaluate the economic impacts of publicly funded research centres. The development of an RIA framework is an important step in highlighting the process of generating research impacts, and identifying indicators to measure research outputs, outcomes and impacts. As Fealing (cited in Stevens, Dean, and Wykes 2013, p.20) states:

> "The practice of assessment should [..] be anchored in a theoretical framework that formally represents the system under investigation, and that offers clear direction on where the likely outputs, outcomes and longer-term impacts are that result from inputs and activities in the system. This framework should also

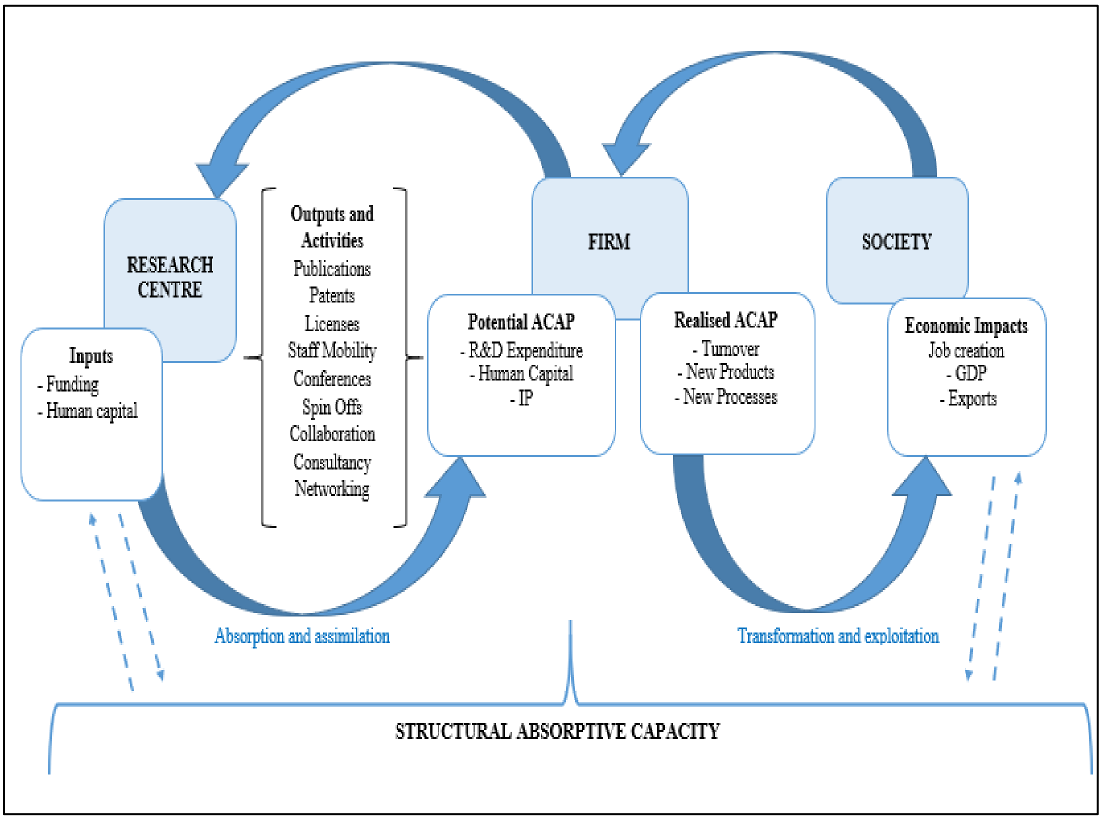
include elements from contextual environments that influence and/or interact with various aspects of the system."

The IMPACTS framework provides an overview of the process of transforming initial investments and research outputs into economic and commercial impacts. The framework provides a theoretical and conceptual foundation for the construction of the Research Impact Index (RII) outlined in Chapter 7.

### 5.2.1 Research Impact dimensions and sub-dimensions

Figure 5.1 illustrates the IMPACTS framework developed to measure and evaluate the economic impact of publicly funded research centres.

**Figure 5.1 IMPACTS Framework**

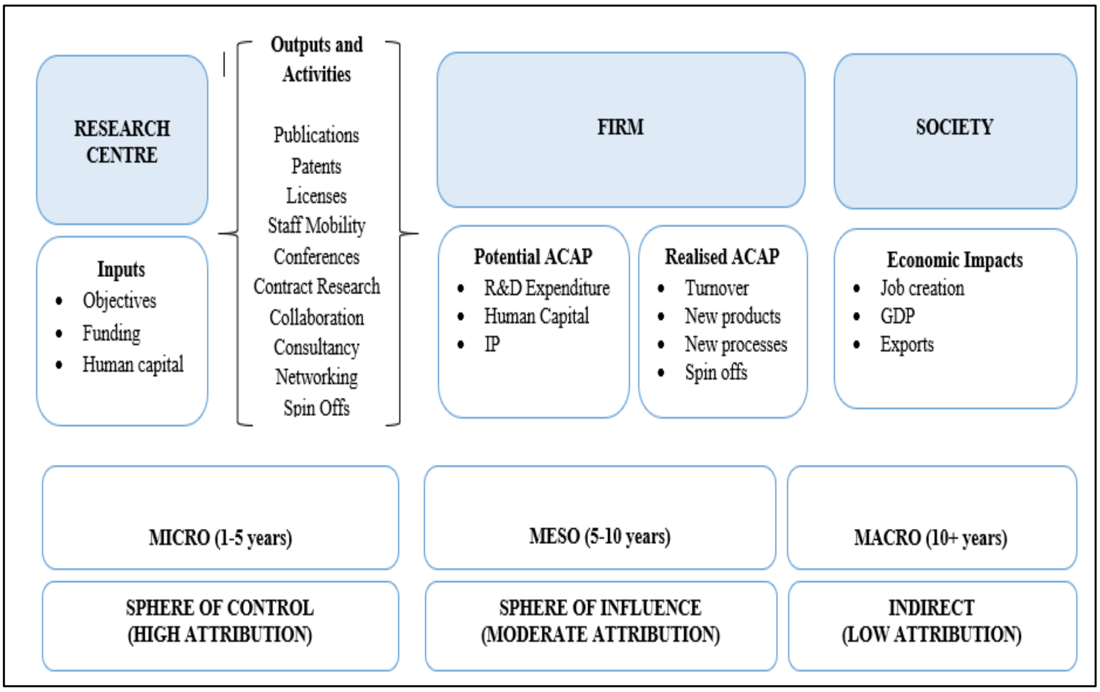



Source: Designed by Author

Barge-Gil and Modrego (2011, p.64) assert that "the influence of different contexts and multifaceted influences on impact is managed by the definition of a holistic model to explain impact". The IMPACTS framework presents a multifaceted and dynamic framework structure which views research centres as an essential element of a regional innovation system. The framework distinguishes between different stages and stakeholders involved in the process of generating research impacts.

The IMPACTS framework is composed of three key stakeholders: (i) research centres (ii) private enterprises and (iii) wider society. From this perspective, a research centre's ability to deliver economic impacts is directly influenced by both the *potential* and *realised* absorptive capacity of their industry partners and the strength of the innovation system which it is embedded within. These factors are discussed further in Section 5.2.2. The framework is designed to highlight the process of delivering economic impacts from investments in publicly funded research centres. However, the generation of research centre impacts is constrained by several conceptual and methodological challenges. Figure 5.2 illustrates the closely related issues of attribution, additionality and time lags which reduce the robustness of RIA exercises.

**Figure 5.2 Attribution, Timing and Research Impacts**




Source: Designed by Author

Figure 5.2 highlights the relationship between time lags and attribution rates along the research impact process. Research impact is a complex, nonlinear, dynamic process involving multiple stakeholders. Research inputs and outputs are typically achieved at an early stage of the research process, usually between 1 to 3 years. As such, research centres have a high degree of control over the production of research outputs which makes estimating attribution rates more straightforward. While research outputs may not themselves be considered impacts, they may act as a signal of potential impacts in the future.

The IMPACTS framework adopts a holistic approach to RIA which views the research centres as vital cogs in research impact process. However, a research centre's impact capacity is influenced by its external environment, both the absorptive capacity of collaborative partners and the strength of the innovation system which it is embedded. Therefore, the production of research outcomes, such as increased turnover, development of new products and processes, and creation of spin-offs requires inputs from both research centres and external partners. As such, estimating attribution rates for these outcomes tends to be more difficult.

Finally, wider economic and societal impacts, such as job creation, job retention, foreign direct investment and increased exports, are long-term in nature involving multiple stakeholders. As such, estimating attribution rates for these impacts is very difficult and has led to many studies adopting a contributions-based approach to RIA (Morton and Fleming 2013, Morton 2015, Ofir et al. 2016).

The challenges associated with attribution, additionalities and time lags provide rationale for measuring research impacts across multiple categorises. The IMPACTS framework categorises research impacts into four broad categories:

- Scientific Impacts (S): related to increases in publications and citations etc.
- Technical Impacts (T): related to increases in patents, licenses etc.
- Human Capital Impacts (H): related to increased investment in human resources etc.
- Economic Impacts (E): related to product development, job creation, FDI etc.

The classification of impact into these four dimensions allows evaluators to identify short, medium- and long-term impacts which reduce the issue of time lags, e.g. the time lag associated with basic research is much longer than commercially-driven research. As such, when evaluating research centres at lower technological readiness levels (TRLs), decision-makers will perhaps weight scientific and technical impacts more heavily as these may be achieved in the short term and may provide an indication of potential future economic impacts. Table 5.1 highlights the degree of attribution, time lags and levels of aggregation across each impact category included in the IMPACTS framework.

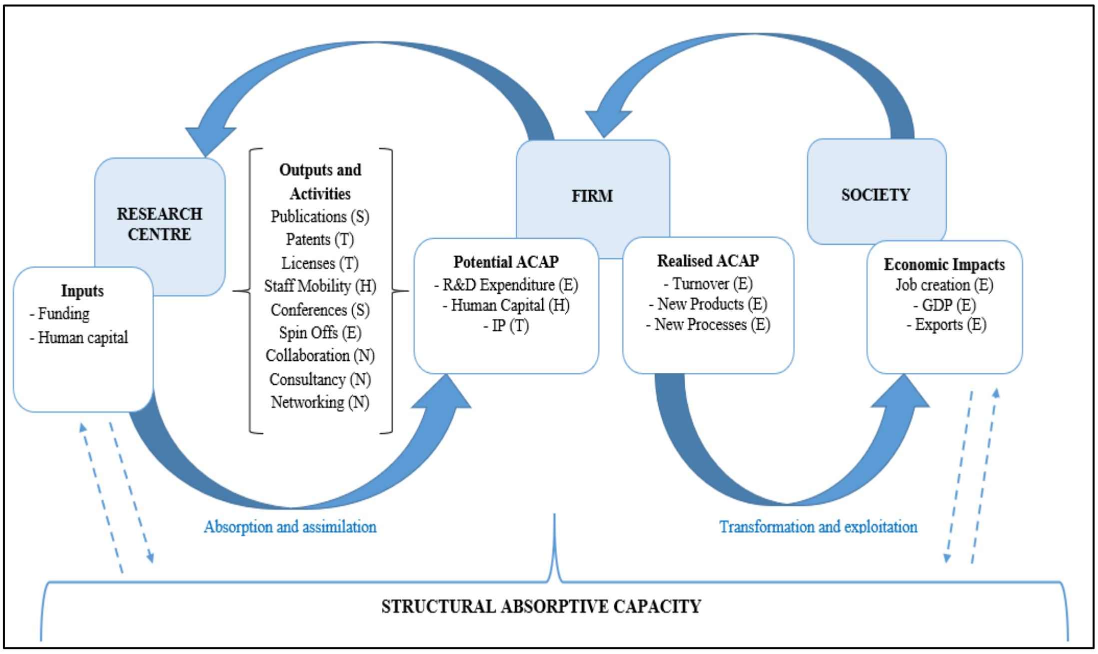
**Table 5.1 Attribution, Time Lags and Aggregate Level across Impact Categories**

| Impact Categories | Degree of Attribution | Time Lag | Aggregate Level |
|---|---|---|---|
| Scientific Impact (S) | High | Short | Micro |
| Human Capital Impact (H) | High | Short | Micro |
| Technical Impact (T) | Moderate | Medium | Meso |
| Economic Impact (E) | Low | Long | Macro |

Source: Compiled by Author

Figure 5.3 illustrates the IMPACTS framework with each indicator at each stage of the impact process designated by impact category (in brackets). It should be noted that networking activities, such as collaboration and consultation, are not categorised as impacts in the framework. However, these activities represent a research impact channels and are represented by (N) in Figure 5.3.

**Figure 5.3 IMPACTS Framework**




Source: Designed by Author

The next sub-section identifies the contextual factors underpinning the IMPACTS framework.

### 5.2.2 Contextual Factors

The IMPACTS framework adopts a systems-based approach to research impact assessment (RIA) that 'internalises' contextual factors into the assessment process. As such, this approach sets out an important, and to date underappreciated, element of the impact of research centres, which is its contribution to the system within which it operates. Such centres operate within an innovation system, and as such the strength of the system is an important input and platform for a centre's success. However, the system is not exogenous to the centre, as the strength of the system is influenced by the activities of the research centres within it. As such, when evaluating research centres across regions these regional specific factors play an important role in the determining the impact capacity of research centres.

#### *5.2.2.1 Absorptive capacity*

Under the IMPACTS framework, the process of converting new knowledge and technologies into economic impacts is dependent firstly, on the ability of research centres to create and disseminate new knowledge and outputs and secondly, on the ability of businesses to absorb, assimilate, transform and exploit this knowledge into economic and commercial impacts. Section 2.3.3 provides a detailed discussion of the theoretical underpinnings of the concept of absorptive capacity. As such, they will only be discussed here briefly in relation to their influence on the development of the IMPACTS framework.

Cohen and Levinthal (1989) introduced the concept of absorptive capacity which refers to a firm's ability to identify, understand and exploit the value of new information, both public and private, and to use it to achieve quantifiable economic and commercial impacts. Zahra and George (2002) provided a popular reconceptualisation of the term by suggesting that absorptive capacity may be reconceptualised into two subsets: potential and realised absorptive capacity. Potential absorptive capacity is related to a firm's ability to absorb and assimilate knowledge while realised absorptive capacity refers to the transformation and exploitation of knowledge.

The IMPACTS framework incorporates the concepts of potential and realised absorptive capacity into the research impact process. Potential absorptive capacity is measured using indicators of firm-level inputs into the innovation process. These indicators should measure a firm's ability to absorb and assimilate knowledge and outputs produced by the research centre. The inclusion of a firm's potential and realised absorptive capacity into the framework allows us to move beyond simply measuring research centre impacts but also allows us to assess whether research impacts are strengthened or limited institutionally within the centre or systematically, outside of the centre.

Realised absorptive capacity is defined as a firm's ability to transform and exploit knowledge into commercial ends. These outcomes could be considered midterm and intermediate economic effects, such as the introduction of new products and processes, and increased turnover. Jaffe (2015) highlights the usefulness of identifying intermediate outputs which are not impacts in themselves, yet their achievement would contribute towards achieving the ultimate desired impact. Wider impacts are considered longer-term and ultimate effects of research, such as increases in GDP, exports and job creation.

#### *5.2.2.2 Strength of the system*

Structural Absorptive Capacity refers to the country's ability to absorb, assimilate, transform and exploit knowledge. Investments in a country's structural absorptive capacity increase the probability of economic growth, competitiveness and innovation of the various actors in the National Systems of Innovation. Effelsberg (2011, p.2) notes "a high innovative capacity can increase the growth and employment of a national economy sustainably and thus determines the realization of political, economic and social objectives on a national scale".

It is important when benchmarking the economic and commercial impact of publicly funded research centres to consider differences in the structural capacity of each country. The level of the structural absorptive capacity in a system affects potential and realised economic and impacts. Therefore, government policy should focus on developing a country's structural absorptive capacity to strengthen the potential and realised impacts provided by various actors within the National Innovation System.

The next section identifies potential indicators and metrics to measure and evaluate the economic impact of publicly funded research centres. There is a lack of consensus regarding suitable indicators and metrics to measure research centre impacts, as impacts are often context-specific, depending on the nature of the research, objectives of the centre and stakeholders involved. As such, setting evaluation metrics requires much consideration and consultation between multiple stakeholders including research centres, funding bodies and policymakers.

## 5.3 Identifying Impact Indicators and Metrics

### 5.3.1 Research Centre Inputs

Research centre inputs refer to resources required to achieve policy objectives and deliver research impacts. Research centre inputs are categorised into three categories: financial resources, human resources and infrastructural resources. Under the IMPACTS framework, *financial resources* are comprised of various sources of funding including public funding (from national and international sources) which is leveraged with both industry and competitive funding to finance activities within the research centre. The composition of research funding varies from centre to centre.

Financial investment from industry has been identified as a key input into the research centre impact process. Here the firm makes a financial contribution on the basis that the economic value of the further developed knowledge/Intellectual Property (IP) will be enhanced through their inputs and that they have preferential access terms. Inputs include providing detailed final product specifications, production process and costing.

Firm Contribution/Investment consists of 4 levels:

i) No contribution to Research centre and no investment to absorb "free knowledge."
ii) No contribution to Research centre but an investment to absorb "free knowledge."
iii) No contribution to Research centre but an investment to acquire IP associated with knowledge from Research centre along with investment to absorb "free knowledge
iv) Contribution to Research centre to ensure that the knowledge is developed into knowledge that meets the specific needs of the firm, e.g. a specific product.

The level is critical to the ability of a firm to turn knowledge into economic impacts, such as increased turnover through to new product launches. The assumption is that firms investing at levels three and four that before making the investment decision it ensures that it has sufficient absorptive capacity in place to transform and exploit outputs generated in the Research centre. Thus, maximising the likelihood that the knowledge will be subsequently converted into economic impacts. Table 5.2 presents commonly used metrics in research impact assessment frameworks and studies to capture research funding.

**Table 5.2 Research centre Inputs: Funding**

| Input Indicators | Potential Metrics | Details | Studies Used |
|---|---|---|---|
| **Industry funding** | Total amount of industry funding | Total financial value of funding generated from industry sources | Finne et al. (2011), OECD (2013), Lähteenmäki-Smith et al. (2013), Mostert et al. (2014), De Jong et al. (2014), Fikkers and Ploeg (2015), Griniece, Reid, and Angelis (2015), European Commission (2015), Harland and O' Connor (2015) |
| | % of industry-funded HEIs and PROs budget | The percentage of overall funding generated from industry sources | |
| | Number of Projects funded by companies | Total number of projects funded by industry | |
| | Revenue to HEIs/PROs from R&D contracts with firms and other users | Total financial value of service provided from HEI/PRO to client(s) under the contract | |
| **International funding** | Total EU funding | Total financial value of funding generated through EU funding | |
| | % of total funding from the EU | Percentage of total funding generated from EU sources | |
| | % of total funding from international partners | The total share of overall funding generated through international partners | |
| | Leverage of funding from international sources | Total financial value of international funding leveraged from core funding | |
| **Government funding** | Level of Third-party funding | Total financial value of funding leveraged from third parties | |
| | Additional investment from public third parties | Total financial value of funding leveraged from public third parties | |

Source: Compiled by Author

*Human resources* have been identified as a key input into the process of research centre impact. Human resources refer to the stock of knowledge, skills and other intangible assets of individuals which may be used to create economic value for the individual, employer and society. The level of education is the most common indicator of human capital, and as such, human capital is proxied using measures of educational attainment such as the percentage of staff with PhDs and the percentage of staff working in R&D. Table 5.3 presents commonly used metrics to measure human resources.

**Table 5.3 Research Centre Input: Human Resources**

| Indicator | Potential Metrics | Details | Studies used |
|---|---|---|---|
| Employees | Number of employees | Total number of employees in research centre | (OECD 2013, Lähteenmäki-Smith et al. 2013, Griniece, Reid, and Angelis 2015) |
| Internationalisation | Number of international students as % of total students trained | The share of international students as a percentage of overall students | Spaapen and Van Drooge (2011) |
| Mobility | Job mobility of employees | The ability of employees to find work elsewhere in the field | (Mostert et al. 2014, Griniece, Reid, and Angelis 2015, American Evaluation Association 2015, European Commission 2015) |
| | Cross-sector mobility of employees | Cross-sector mobility as a percentage of researchers changing employer | |
| | Inter-sector mobility of employees | Inter-sector mobility as a percentage of researchers changing employer | |
| PhD | Number of PhDs | Total number of PhDs currently at the research centre | (American Evaluation Association 2015, European Commission 2015) |
| | Doctorate Graduates (% of the workforce) | The share of employees with PhD as highest level of education | |
| | Number of new PhDs | Total number of new PhDs in the research centre, year on year | |
| Postdocs | Number of Post-doctoral graduates | Total number of post-doctoral graduates employed in research centre | (Spaapen and Van Drooge 2011, American Evaluation Association 2015), |

/ Source: Compiled by Author

*Infrastructural resources* refer to "facilities, resources and related services used by the scientific community to conduct top-level research in their respective fields" (European Commission 2010, p.11) Research infrastructure provides a useful indicator of innovative capacity yet is underutilised in most studies on innovation and research impact. OECD (2015, p.22) assert "indicators of facilities available for R&D may be envisaged but are seldom collected and are not discussed in the Manual". However, they do point to potential indicators of research infrastructure including "standardised equipment, library facilities, laboratory space, journal subscriptions and standardised computer time would all be possible measures". Table 5.4 identifies potential indicators and metrics for measuring a research centre's infrastructural resources.

**Table 5.4 Research Centre Input Indicators: Infrastructure**

| Indicators | Metrics | Details | Authors |
|---|---|---|---|
| **Infrastructure** | Number of new pieces of research equipment purchased | Total value of new pieces of research equipment purchased | (Panel on Return on Investment in Health Research 2009, American Evaluation Association 2015, Griniece, Reid, and Angelis 2015) |
| | Use of research equipment by investigators who are not program participants | Total number of users, outside programme participants, using research equipment | |
| | Infrastructure Grants | Total value of grants awarded to purchase new infrastructure | |
| | % of activity grants with infrastructure support | Share of activity grants that have received additional infrastructure support to allow research to occur | |
| | Number of scientists, students, state-owned or private enterprises that benefitted from research infrastructure services | Total number of scientists, students, state-owned or private enterprises that benefitted from research infrastructure services | |

Source: Compiled by Author

### 5.3.2 Indicators of Research Outputs and Knowledge Transfer

This sub-section provides an overview of the research outputs and knowledge transfer channels which have been identified in the literature on science, technology, and innovation. Research outputs are the direct, immediate, short-term results of a research project or programme. Research outputs offer potentially useful information on the knowledge transfer mechanisms between public research centres and private business enterprises. Traditional output indicators such as patents, publications, and citations are used extensively in innovation and evaluation.

Knowledge transfer of publicly funded research into the commercial sphere has become an increasingly important part of the innovation ecosystem as it has been found to enhance the potential economic and societal impacts of publicly funded research. However, the relationship between knowledge, research, commercialisation, and economic development is a complex one, mediated by a complex set of overlapping interactions and institutions. There is an increasing need for consensus regarding defining, quantifying and qualifying the performance of knowledge transfer activities between the public and private sphere (Holi, Wickramasinghe, and van Leeuwen 2008).

As Finne et al. (2009, p.5) state

> "Knowledge can be produced, mediated, reproduced, acquired, and transformed in and between the different forms through these channels. Knowledge transfer takes place in channels of *interaction* between public research organisations and other actors. This understanding is in line with modern views of innovation as mostly interactive *learning* processes – where learning includes the generation of new knowledge as well as the integration of knowledge from external sources."

Recently, a growing body of literature has emerged which attempts to identify robust metrics to be used in the evaluation of knowledge transfer activities from the public to the private sphere (Holi, Wickramasinghe, and van Leeuwen 2008, European Commission 2007, OECD 2013). However, the state of knowledge remains relatively fragmented and tentative (Perkmann et al. 2013). Evaluation of knowledge transfer mechanisms is complicated by its dependence on the characteristics of knowledge, such as the degree of codification, the tacitness or expected breakthroughs.

Contrasting evidence has been presented in the literature with studies suggesting that codified outputs, such as patents and publications are the most important transfer mechanisms (Arundel and Geuna 2001, Cohen, Nelson, and Walsh 2002) while other studies highlight the importance of tacit outputs such as conferences, networking and informal contacts as to knowledge transfer activities (Meyer-Krahmer and Schmoch 1998, Bekkers and Freitas 2008, Perkmann et al. 2013).

Furthermore, another line of research suggests that the primary motivation for academics to engage with industrial partners is to further their research rather than to commercialise their knowledge. However, Hughes and Kitson (2012) caution against overreliance on commercialisation channels as a measure of knowledge transfer, as they are an incomplete representation of the wider process of knowledge transfer between public and private enterprises.

Knowledge transfer and commercialisation channels are not unidirectional. (OECD 2013, p.19) note "these channels often operate simultaneously or in a complementary fashion, underscoring the interaction between tacit and codified flows of knowledge as well as the multidirectional nature of flows. Knowledge flows not only from university to industry but also in the other direction". This has been highlighted as a possible explanation for findings which suggest collaborative research and informal contracts were the most important interaction types between research centres and industry partners. Table 5.5 shows the research output indicators and metrics included in the IMPACTS framework

**Table 5.5 Research Centre Output Indicators: Scientific Excellence**

| Indicator | Metric(s) | Details | Impact Channel | Studies used |
|---|---|---|---|---|
| **Publications** | Number of Peer-reviewed journal articles | The total number of peer-reviewed publications | S | (Sarli, Dubinsky, and Holmes 2010, Spaapen and Van Drooge 2011, Griniece, Reid, and Angelis 2015, American Evaluation Association 2015, Harland and O' Connor 2015, Lähteenmäki-Smith et al. 2013) |
| | Number of conference publications | The total number of conference publications | S | |
| | Number of publications in high impact journals | The percentage of publications published in the top 10% impact ranked journals | S | |
| | Number of Research reports produced | Total number of research reports produced | S | |
| | Number of non-academic papers published | Total number of non-academic papers published (e.g. policy docs) | S | |
| | Number of peer-reviewed publications per unit of funding | Total peer-reviewed journal publications divided by total funding | S | |
| | Number of peer-reviewed publications per unit of time | Total peer-reviewed journal publications divided by time | S | |
| | Journal impact factor weighted number of peer review | The average number of times a peer reviewed article published during the last two years has been cited. | S | |
| | Publication in High-Quality Outlets | The percentage of publications published in the top 10% impact ranked journals | S | |
| | Publications in high impact journals | The percentage of publications published in the top 10% impact ranked journals | S | |
| | % of publicly funded publications in top 1% of cited publications | The percentage of total publications in top 1% of highly cited papers in the field | S | |
| | Number of science-industry publications | Total number of publications co-produced with industry partners | S/N | |

Source: Compiled by Author

The traditional justification for investing public funding to conduct research is increasing the stock of useful knowledge in the economy. Bibliometric indicators such as publications and citation counts are considered important indicators of scientific quality. These outputs facilitate knowledge transfer, which may be used by individuals and businesses to increase competitiveness while informing decision-making for policymakers. Publications are extensively cited as a channel through which knowledge may transfer from public research centres to firms in the private sector.

However, the use of publications as a proxy for knowledge transfer between public and private organisations is not without limitations of using publications as a proxy for knowledge transfer. Firstly, the notion that public-funded research centres produce knowledge which then absorbed by private enterprises and transformed into commercially viable ends is based on the linear model is flawed. Research impact is not a simple, unidirectional process but rather a dynamic, complex process which incorporates forward and backward linkages and feedback mechanisms.

Secondly, codified outputs such as publications may underestimate the extent to which knowledge is embodied within a researcher. Firms may lack the necessary absorptive capacity to take advantage of the information provided by publications. Thirdly, publication counts are insufficient measures of scientific quality as counts of publications do not indicate how often public and private enterprises have utilised research findings. Finne et al. (2009, p.11) argue that “neither bibliometric nor patent counts are measures of knowledge transfer, since there is no information on whether or not firm employees read the article or patent, or even if read, has any influence on firm activities”.

Table 5.6 presents citation metrics that may potentially be used to capture scientific excellence.

## Table 5.6 Scientific Excellence: Citations

| Indicators | Potential Metric(s) | Details | Impact Channel | Studies used |
|---|---|---|---|---|
| | Citations in top 10% of field | Total number of citations in the top 10% impact ranked journals | S | (Sarli, Dubinsky, and Holmes 2010, Spaapen and Van Drooge 2011, Griniece, Reid, and Angelis 2015, American Evaluation Association 2015, Harland and O' Connor 2015, Lähteenmäki-Smith et al. 2013) |
| | Total citations to peer-reviewed publications in peer-reviewed journals | Total number of citations in peer-reviewed publications divided by total number of peer-reviewed publications | S | |
| | Normalised citations to publications relative to field average | The ratio between the actual citations received by a publication and the average number of citations received by all other similar publications | S | |
| | Citation velocity of peer-reviewed publications | The weighted average of publications citations during the last three years | S | |
| | Citations in grey literature | Total number of citations in grey literature (e.g., via Google Scholar) | S | |
| | Highly cited Publications | Total number of citations in the top 10% impact ranked journals in the field | S | |
| | Field Analysis of Citations | An examination of the frequency, patterns, and graphs of citations | S | |
| | Media citations | Total number of citations across media (e.g. newspapers, radio etc.) | S | |
| | Highly cited publications (% total publications) | The percentage of total publications in the top 10% highly cited publications in the field | S | |
| | Average Relative Citations (ARC) | Normalised score calculated for every country in particular field. ARC score above 1 indicates above average performance | S | |
| | Share of International Co-Publications to total Publications | The share of publications involving international collaborators relative to total publications | S | |
| | Number of Countries represented by citations | Total number of countries represented by citations | S | |
| | % of international citations | The share of publications involving international collaborators relative to total publications | S | |
| | % of industry citations | The percentage of total citations from industry | S | |
| | H-index | The number of publications for which an author has been cited by other authors at least that same number of times | S | |

Source: Compiled by Author

Section 3.3 discussed the strengths and limitations of bibliometric measures of impact measurement and therefore they will only be discussed here briefly. The key strengths of citation counts are that they are well established and accepted across the scientific community, many databases exist which reduce the burden of data collection, suited to repeated analysis and allows for comparability. However, citation counts are subject to several limitations including citation counts take several years to accumulate so may not favour early career researchers, citation counts are subject to highly skewed distributions, citations do not necessarily imply the quality and may incentive gaming behaviour.

Table 5.7 identifies several metrics used in the literature to capture conference attendance and conference organisation.

**Table 5.7 Scientific Excellence: Conferences**

| Indicator | Metrics | Details | Impact Channel | Studies |
|---|---|---|---|---|
| Conferences | Conference Presentations | Total number of conference presentations | S | (Sarli, Dubinsky, and Holmes 2010, Spaapen and Van Drooge 2011, Griniece, Reid, and Angelis 2015, American Evaluation Association 2015) |
| | Presentations at specialist conferences | Total number of invites to present at specialist conferences | S | |
| | Number of scientific events organised | Total number of scientific events organised | S/N | |

Source: Compiled by Author

Conferences have been identified as an important knowledge transfer channel between public and private sectors (Bekkers and Freitas 2008, Schartinger et al. 2002). Bekkers and Freitas (2008) found that 67% of industrial managers identified conferences as an important knowledge transfer channel, while 89% of university R&D performers identified conferences as highly important.

Training skilled graduates has been identified as a key function of publicly funded research centres (Salter and Martin 2001). Table 5.8 highlights indicators and metrics of training skilled graduates.

**Table 5.8 Scientific Excellence: Graduates**

| Indicators | Potential Metrics | Details | Impact Channel | Studies |
|---|---|---|---|---|
| Graduates | Number of masters Graduates | Total number of new masters graduates | S/H | (Panel on Return on Investment in Health Research 2009, Spaapen and Van Drooge 2011, Mostert et al. 2014) |
| | Number of PhD graduates | Total number of new PhD graduates | S/H | |

Source: Compiled by Author

Salter and Martin (2001) identify training skilled graduates as an important mechanism for increasing the stock of knowledge in society and transferring knowledge from the public to the private sectors of innovation systems. The mobility of skilled graduates from publicly funded research centres to the private sector increases *both* firms potential and realised absorptive capacity as graduates embody tacit knowledge that increases a firm's ability to absorb, assimilate, transform and exploit new knowledge into economic and commercial impacts.

### Research Centre Output and Activity Indicators: Collaboration

Collaboration refers to the process of working with someone with the aim of achieving a shared goal. Collaboration between research centres and other actors in the innovation system is important for the generation of new ideas, the transfer of knowledge and expertise and may be used to leverage new funds. The role of clusters, networks and linkages have been increasingly highlighted as important mechanisms through which benefits of publicly funded research can be potentially derived.

Staff mobility refers to opportunities available to research centre staff to work within industry, to learn about a new culture, share expertise and capacity building. Indicators of collaboration and mobility capture the various linkages between research centres and firms. The IMPACTS framework collects data on the type of collaboration, as well as the frequency and intensity of the interaction as key indicators of knowledge transfer which improves the potential absorptive capacity, both firms and within the system in general.

**Table 5.9 Research Centre Output Indicators: Collaboration**

| Indicators | Potential Metrics | Details | Impact Channel | Studies used |
|---|---|---|---|---|
| Networking | Frequency of interactions | Frequency of interaction between research centres and end users | N | Harland and O' Connor (2015), Mostert et al. (2014), Panel on Return on Investment in Health Research (2009) |
| | Number of collaborations | Total number of collaborations with end users. | N | |
| | Value of collaborations | Total value of collaborations with end users | N | |
| | Repeat collaborations | The total number of collaborations involving repeat collaborative partners | N | |
| | Duration of collaborations | Total duration of collaboration with end users | N | |
| | New collaborations developed | New (or improved) strategic industrial alliances (achieved, expected, time to market) | N | |
| | Improvements to collaboration networks | Improved networks, new networks with public/private organisations | N | |

Source: Compiled by Author

The role of clusters, networks and linkages have been increasingly highlighted as important mechanisms through which benefits of publicly funded research can be potentially derived. Hughes and Martin (2012) state that from an innovation systems perspective, "the impact of publicly funded research will be substantially affected by the capacity of other actors in the economic and innovation system to access, understand and use the research outputs produced with public sector support". As such, increasing emphasis is placed on the interaction between various stakeholders in the innovation system and "how best to understand and manage the connections between differently funded and motivated research efforts in an overall system of knowledge production and innovation" (Hughes and Martin, 2012, p.13).

The development of intellectual property is a key objective for research centres at various Technological Readiness Levels (TRLs). Intellectual property refers to creations of the human mind such as inventions, prototypes, images, designs, symbols, and logos which are protected by law using patents, trademarks, copyright, and licences. Table 5.10 highlights potential indicators and metrics of intellectual property commonly used in research impact assessment exercises.

**Table 5.10 Research Centre Outputs: Intellectual Property Outputs**

| Indicators | Potential Metrics | Details | Impact Channels | Studies used |
|---|---|---|---|---|
| Patents | Number of patent applications | Total number of patent applications | T | (American Evaluation Association 2015, Kuruvilla et al. 2006, Finne et al. 2009, Finne et al. 2011, Lähteenmäki-Smith et al. 2013, OECD 2013, Spaapen and Van Drooge 2011, Harland and O' Connor 2015) |
| | Number of patents granted | Total number of patents granted | T | |
| | Patents granted per unit of program funding | Total number of patents granted divided by total funding | T | |
| | Patents granted per unit of time | Total number of patents granted divided by time | T | |
| | Number of currently active patents | Total number of currently active patents held by research centre | T | |
| | Number of patents exploited to form spin-out or new companies | Total number of patents exploited to form spin-out companies | T | |
| Licensing | Number of licences granted | Total number of licenses granted | T | (Kuruvilla et al. 2006, Finne et al. 2009, Sarli, Dubinsky, and Holmes 2010, Finne et al. 2011, OECD 2013, Harland and O' Connor 2015) |
| | Revenue generated from licenced technologies | Total revenue generated through licensing | T | |
| | Number of licenses sold to third parties | The total number of licenses sold to third parties | T | |
| | New licensing agreements | The total number of licensing agreements | T | |
| Invention Disclosures | Number of invention disclosures | The total number of invention disclosures | T | (Finne et al. 2011, Finne et al. 2009, OECD 2013, Harland and O' Connor 2015) |

Source: Compiled by Author

The sale and licensing of intellectual property is a key income source for publicly-funded research centres whilst providing a key mechanism for the transfer of knowledge from publicly funded research centres to private firms. Research has highlighted the importance of patents as a potential channel of knowledge transfer between publicly funded research centres and firms (McMillan, Narin, and Deeds (2000).

Although many scholars argue that patenting represents only a small fraction of knowledge transferred from research institutes, evidence suggests the total economic value transfer from patenting, is quite significant (Agrawal and Henderson 2002). The findings of Agrawal and Henderson (2002) suggest that most university researchers estimate that patents account for less than 10% knowledge transferred from their labs, while Cohen, Nelson, and Walsh (2002) find that only about 11% of the knowledge obtained from university research was transferred through patents.

Several limitations to patents as a measure of knowledge transfer have been identified in the literature. Firstly, Pakes and Griliches (1980, p.378) point out that "patents area flawed measure (of innovative output); particularly since not all new innovations are patented and since patents differ greatly in their economic impact". Similarly, Griliches (1990, p.1669) notes that although "we might hope that patent statistics would provide a measure of the (innovative) output [...] the reality, however, is very far from it".

Some authors have pointed to an overestimation of the impact of innovation indicators such as patents (Branstetter and Ogura 2005). For example, Branstetter and Ogura (2005, p.3) state "recent patent surge could potentially be explained by an increase in the propensity of Americans to patent inventions, rather than an increase in the productivity of American research and development". This is an example of Goodheart's Law which states "once a measure becomes a target, it ceases to be a good measure" (Muller 2018). As such, researchers and research centres may be incentivised to try and increase their output of required indicators without increasing their quality or potential use by firms.

Table 5.11 outlines potential indicators and metrics to capture instruments and methodologies.

**Table 5.11 Research Centre Outputs: Instruments and Methodologies Outputs**

| Indicators | Potential Metrics | Details | Studies used |
|---|---|---|---|
| Databases | New databases created | Total number of new databases created | (Kuruvilla et al. 2006, Sarli, Dubinsky, and Holmes 2010, Spaapen and Van Drooge 2011, Griniece, Reid, and Angelis 2015) |
| Methodologies | New novel research methodologies | The total number of new novel methodologies developed | |
| Instruments and Tools | New instruments and tools developed | Total number of new instruments and tools developed | |
| Software | New software developed | Total number of new software developed | |

Source: Compiled by Author

There have been relatively few attempts to evaluate the economic and commercial impacts relating to the creation of new scientific instruments and methodologies. Salter and Martin (2001) highlight an attribution issue in that innovation surveys rarely include instrumentation as an impact measure because of the limited ability of private sector R&D managers to recognise the contribution of publicly funded research at early stages of research process.

**Table 5.12 Research Centre Outputs: Spin-offs**

| Indicators | Potential Metrics | Details | Impact Channels | Studies used |
|---|---|---|---|---|
| Spin-offs | Number of new spin-offs | The total number of spin-offs from the research centre during last three years | E | (Roper, Hewitt-Dundas, and Love 2004, Kuruvilla et al. 2006, Finne et al. 2009, Sarli, Dubinsky, and Holmes 2010, Mostert et al. 2014, Harland and O' Connor 2015) |
| | Survival rates of spin-offs | The average survival rates of spin-offs from research centre | E | |
| | Average number of employees | The average number of employees employed in spin offs from research centre | E | |
| | Average duration of spin-off companies | The average duration of spin-offs from the research centre | E | |

Source: Compiled by Author

The creation of new firms, through spin-offs and start-ups, have been identified as a potential benefit from investment in publicly funded research. However, studies examining this issue tend to be mixed. Roper, Hewitt-Dundas, and Love (2004) note spin-offs represent a significant research impact channel for transferring knowledge from publicly funded research centres into economic and commercial ends. The next sub-section outlines indicators and metrics to measure potential absorptive capacity.

### 5.3.3 Potential Absorptive Capacity

Most studies measure absorptive capacity based on indicators of R&D intensity and levels of R&D investment. These measures appear overly simplified to capture a multidimensional concept such as absorptive capacity. The absence of indicators for firm-level capabilities, or how firms innovate, and indicators for knowledge flows major 'gaps' in RIA studies. As such, the IMPACTS framework incorporates firm-level indicators of both potential and realised absorptive capacity when measuring and evaluating the economic impacts of publicly funded research centres.

Table 5.13 below shows the firm-level inputs into the innovation process, i.e. potential absorptive capacity and outlines the indicators and proxies used to measure potential absorptive capacity.

**Table 5.13 Firm Level inputs: R&D Expenditure**

| Indicators | Potential Metrics | Details | Studies used |
|---|---|---|---|
| **R&D Expenditure** | Total expenditure on R&D | The total value of firm expenditure by a firm on R&D activities | (Cohen and Levinthal 1990, Rocha 1999, Muscio 2007, de Jong and Freel 2010, Schildt, Keil, and Maula 2012) |
| **R&D Intensity** | R&D (% of Sales) | The expenditures by a firm on its R&D divided by the firm's sales | (Tsai 2001, Stock, Greis, and Fischer 2001, Muscio 2007, Vega-Jurado, Gutiérrez-Gracia, and Fernández-de-Lucio 2008) |

Source: Compiled by Author

The most common proxies for a firm's absorptive capacity include measures of R&D expenditure (Cohen and Levinthal 1990, Rocha 1999, Muscio 2007, de Jong and Freel 2010) and R&D intensity i.e. total expenditure on R&D divided by sales (Tsai 2001, Stock, Greis, and Fischer 2001, Muscio 2007, Vega-Jurado, Gutiérrez-Gracia, and Fernández-de-Lucio 2008). The justification for these measures assumes that firm investments in R&D increase both internal capabilities within the firm as well as the capacity of the firm to absorb and assimilate knowledge from external sources. Thus, increasing a firm's potential absorptive capacity is necessary to facilitate the use of external knowledge for their own commercial needs.

Studies focusing solely on R&D proxies as measures of absorptive capacity benefit from advantages in relation to the operationalisation of the concept, certain limitations of these measures should be considered. Firstly, R&D proxies provide one-dimensional measure of absorptive capacity while the concept itself is multidimensional. Secondly, R&D proxies relate to firm-level processes, while absorptive capacity is related to both firm-level and collaborative processes (Schildt, Keil, and Maula 2012).

Thirdly, "measures based on R&D proxies can only be used for large companies because, for time and financial reasons, most SMEs do not have a specific R&D budget and do not follow patent registration policies" (Chauvet 2014, p.1-2). Finally, R&D proxies undervalue the 'tacitness' of knowledge, i.e. the extent to which knowledge is embodied within individual researchers and institutional networks, which is not easily transferable.

One of the key conceptual contributions of 'absorptive capacity' is the identification of the complementarity between internal capabilities and external collaboration (Lund Vinding 2006). There is increasing consensus that a firm's economic and innovative performance is influenced by its embeddedness within an innovation system, characterised by linkages and interaction with other entities. Schildt, Keil, and Maula (2012) emphasise the significance of both firm-level processes and collaboration processes in building absorptive capacity while Knudsen, Dalum, and Villumsen (2001) find participation in research collaboration, as well as R&D intensity are important as prerequisites for knowledge access.

Collaboration is a key mechanism for the growth and development of a firm's potential and realised absorptive capacity. However, firms engage in many types of relationships with actors within an innovation system, and the type, frequency, intensity, and duration of these relationships must be considered when analysing their contribution to the creation of economic and commercial impacts, both within the firm and within the system. Furthermore, the research process is non-linear, uncertain, and dynamic process characterised by considerable time lags and complementarities. As such, it is important, where possible, that research centres and firms engage in long term relationships characterised by frequent meetings and discussions to gain maximum benefit from the interactions.

Table 5.14 highlights measures of firm-level human capital including measures of educational attainment and R&D employees.

**Table 5.14 Firm-Level inputs: Human Capital**

| Indicators | Potential Metrics | Details | Studies used in |
|---|---|---|---|
| **Educational Attainment** | Masters staff (% total employees) | The percentage of employees within the firm with masters as their highest level of education | (Knudsen, Dalum, and Villumsen 2001, van der Heiden et al. 2015) |
| | PhD staff (% total employees) | The percentage of employees within the firm with PhD as their highest level of education | |
| **R&D Employees** | Researchers (% total employees) | The ratio of employees working in research relative to total employees within a firm | Gao, Xu, and Yang (2008) |
| | R&D staff (% total employees) | The ratio of employees working in R&D relative to total employees within a firm | |

Source: Compiled by Author

The levels of human capital within an organisation is an important indicator of a firm's potential and realised absorptive capacity (Lund Vinding 2006, Islam 2009). Education attainment of employees (Knudsen, Dalum, and Villumsen 2001, van der Heiden et al. 2015) and the research intensity of firm, i.e. researchers as a percentage of total employees (Gao, Xu, and Yang 2008) have been identified as proxies for human capital. Higher levels of education and participation in R&D activities should increase an employee's ability to absorb knowledge from sources, both internal and external to their own industry.

### 5.3.4 Realised Absorptive Capacity

Realised absorptive capacity is defined as a firm's ability to transform and exploit knowledge into commercial ends. Under the IMPACTS framework, the transformation and exploitation of knowledge and outputs into commercial ends is labelled intermediate outcomes. Intermediate outcomes could be considered midterm and intermediate effects, with 'impact' longer-term and ultimate effect. Jaffe (2015) highlights the usefulness of identifying intermediate outputs which are not 'impacts' in themselves, yet their achievement would contribute towards achieving the ultimate desired impact.

Under the IMPACTS Framework, outcomes are considered impacts which are internal to the business, e.g. increases in profitability, reductions in costs, and the production new products sales etc., while impacts are considered broader in nature affecting the wider economy and society in general. Table 5.15 highlights the research outcome indicators included in this study.

**Table 5.15 Intermediate Outcome Indicators**

| Indicators | Potential Metrics | Details | Impact Channel | Studies Used |
|---|---|---|---|---|
| Sales | Turnover from sales | Total turnover generated through sales | E | Mansfield (1991), Beise and Stahl (1999), (Becker and Dietz 2004), Belderbos, Carree, and Lokshin (2004), Nieto and Santamaría (2007), Şener et al. (2015), Yu and Rhee (2015), |
| | Turnover from new product sales | Total turnover generated through new product sales | E | |
| Profitability | Total profitability | Total firm profitability earned during the last three years | E | Sougiannis (1994), Eberhart, Maxwell, and Siddique (2004), VanderPal (2015) |
| Spin-Offs | Turnover in spin-offs | Total turnover generated through spinoff companies | E | (Møen 2002, Audretsch and Lehmann 2005, Audretsch, Aldridge, and Oettl 2006, Acs et al. 2009) |
| Cost Saving | Total cost savings | Total cost savings created during last three years | E | Sarli, Dubinsky, and Holmes (2010) |
| Processes | New processes | Total number of new processes implemented | E | European Commission (2015), Kuruvilla et al. (2006) |

Source: Compiled by Author

Research outcomes relate to shorter-term impacts to the firm resulting from the commercialisation of research outputs. These indicators are primarily business impacts resulting from investment in publicly funded research activities, e.g. increased turnover, profitability, turnover from new products etc. While these outcomes may provide marginal impacts to the wider economy, most of the benefits are accrued internally within the firm.

The impact of publicly funded research on business turnover has been widely studied. Mansfield (1991) finds that 10% of appraised innovations in the United States would not have been possible without recent academic research. Beise and Stahl (1999) produce similar results when examining the impact of publicly funded research institutes on industrial innovation in Germany. The findings suggest that 10% of new products would not have been developed without public research institutions. Similar studies have been conducted in Germany (Becker and Dietz 2004), Spain (Nieto and Santamaría 2007), Turkey (Şener et al. 2015), Korea (Yu and Rhee 2015) with findings indicating a positive relationship between firm collaboration with public research centres and innovation output/ sales.

Studies analysing the impact of public research centres on the financial performance of firms tend to be more scarce. Arnold, Clark, and Jávorka (2010) analyse the impacts of European Research and Technological Organisations (RTOs) based on a combination of secondary data, interviews with research centre personnel and economic modelling. The authors noted that although an exact number is difficult to establish, significant economic and commercial impacts of European RTOs are clearly evident. George et al. (2001) examine the impact of the relationship between biotechnology firms and research institutions on firms' operations. The results indicate that companies with relationships with public research institutes have lower R&D expenses while having higher levels of innovative output.

Spin-offs have been identified as an important mechanism for the commercialisation of knowledge. Spin-offs are closely aligned with labour mobility and knowledge spillovers. The creation of a spin-off is generally associated with the movement of labour from the parent organisation to the new firm, taking with them ideas, skills, knowledge and experience developed whilst employed in the parent organisation. Thus, spin-offs may facilitate the transfer of knowledge considered 'tacit' in nature, i.e. knowledge embodied within people. Several studies have estimated the potential spillover of knowledge through entrepreneurship and spin-off companies (Møen 2002, Audretsch and Lehmann 2005, Audretsch, Aldridge, and Oettl 2006, Acs et al. 2009). However, the results of these studies tend to be mixed.

### 5.3.5 Economic Impacts

Research Impact is defined as broader, longer-term impacts of research in comparison to intermediate outcomes. While intermediate research outcomes may be classified as 'narrow impacts' generated at the micro/meso level, research impacts are 'wider impacts' produced at the macro level. Table 5.16 potential indicators to capture wider economic impacts of publicly funded research.

**Table 5.16 Economic Impact Indicators**

| Indicator(s) | Potential Metrics | Details | Impact Channel | Studies used |
|---|---|---|---|---|
| Job Creation | Total number of jobs created | The total number of direct and indirect jobs generated through research centre activities | E | (Barge-Gil and Modrego 2011), (Zhang and Peterson 2007), Lenihan, Mulligan, and Perez-Alaniz (2018) |
| | Total number of high-value jobs created | The total value of high-value jobs generated through research centre activities | E | DJEI (2015) |
| Job Retention | Total number of jobs saved attributed to the research centre | The total number of jobs retained, that would otherwise have been lost, as a result of research centre activities | E | DJEI (2015) |
| GDP | The total contribution of a research centre to GDP | The total contribution of research centre's activities to national productivity | E | Guellec and Van Pottelsberghe de la Potterie (2004), Carr, Natcher, and Olfert (2013), Zhang and Peterson (2007), Lenihan, Mulligan, and Perez-Alaniz (2018) |
| Foreign Direct Investment (FDI) | Increased FDI attributable to the research centre | The total value of FDI generated through research centre activities | E | Branstetter (2006) |
| Exports | Increase in export value from firms attributable to the research centre | The total increase in value of firm-level exports attributable to research centre activities | E | Barge-Gil and Modrego (2011) |
| R&D Investment | Induced R&D investment attributable to the research centre | The total increase in firm-level R&D attributable to research centre activities | E | Barge-Gil and Modrego (2011) |

Source: Compiled by Author

It is widely accepted today that knowledge creation and diffusion are key drivers of economic growth and competitiveness. Endogenous growth theory (Romer 1986, Lucas 1988, Aghion and Howitt 1990) is focused on the importance of knowledge for economic growth. As such, publicly funded research centres would be expected to contribute to economic growth at the national, regional and local level. Few academic studies have examined the impact of publicly funded research centres on economic growth, employment, FDI and exports.

The next sub-section highlights the potential metrics used to measure structural absorptive capacity. The structural absorptive capacity is comprised of five dimensions: R&D and innovation expenditure, human capital, student enrolment, scientific excellence, intellectual property rights.

### 5.3.6 Structural Absorptive Capacity

R&D expenditure refers to the expenditure by the government on R&D. New Growth Theory, outlined by Romer (1986), highlights the importance of knowledge for driving the economic growth and development of a country. Investments in R&D is considered a key mechanism for increasing the stock of knowledge within a country. As such, increasing investment in R&D is considered essential to increasing the knowledge and innovative capacity of an economy. Data on the scale, growth and nature of R&D investments can be easily collected, which allows to easily benchmark across countries. R&D investments are comprised of gross expenditure on R&D (GERD), business expenditure on R&D (BERD), government expenditure on R&D (GBOARD) and expenditure on R&D from foreign sources.

The quality of personnel and human capital in a country is an important indicator of a country's innovative and absorptive capacities. Educational attainment is often captured as an indicator of human capital. Bibliometric indicators such as publications and citations may be used as indicators of research quality. Research quality is an essential element of a country's structural absorptive capacity. Countries which perform better across indicators of research quality have a greater capacity to absorb, assimilate, transform and exploit knowledge from external sources.

Table 5.17 presents potential indicators and metrics to measure regional structural absorptive capacity.

**Table 5.17 Structural Absorptive Capacity Indicators**

| Category | Potential Metrics | Details |
|---|---|---|
| **R&D and Innovation Expenditure** | Gross expenditure on R&D (€ millions, growth) | The total expenditure on R&D carried out by all resident companies, research institutes, university, and government laboratories, etc., in a country. |
| | Gross R&D expenditure per capita | The total expenditure on Gross R&D divided by total population. |
| | Government Expenditure on R&D | The total expenditure on R&D carried out by components from the government sector. |
| | Business Expenditure on R&D | The total expenditure on R&D carried out by components from the business sector. |
| | Higher Education Expenditure on R&D | The total expenditure on R&D carried out by components from the higher education sector. |
| **Human Capital** | Number of scientists and engineers in the labour force | The total number of scientists and engineers in the labour force. |
| | Scientists and engineers as % labour force | The ratio of scientists and engineers in labour force relative to total labour force. |
| | Number of scientists and engineers per capita | The ratio of scientists and engineers in the labour force relative to total population. |
| | Total number of doctoral graduates | The total number of doctoral graduates within a country. |
| | Number of doctoral graduates per capita (25-36) | The ratio of total doctoral graduate to the population of people aged between 25 and 36. |
| **Student Enrolment** | Number of young people enrolled in Higher Education | The total number of young people (15-24) enrolled in higher education. |
| **Scientific Excellence** | Total number of publication counts | The total number of publications during the last three years. |
| | Total number of publications in top-ranked journals | The total number of publications in 3* and 4* journals during last three years. |
| | Total number of citations | The total number of citations during the last three years. |
| | Number of citations in top-ranked journals as % of total | The total number of citations from 3* and 4* journals during the last three years |
| **Intellectual Property Rights** | Number of patent applications | The total number of patent applications during the last three years. |
| | Number of patents granted | The total number of patents granted during the last three years |
| | Number of invention disclosures | The total number of invention disclosures during the last three years |

Source: Compiled by Author

The next section outlines the process of testing and operationalising the IMPACTS framework.

## 5.4 Operationalising the IMPACTS framework

This section highlights the steps involved in testing and operationalising the IMPACTS framework. Too often, poorly designed research evaluation criteria are "dominating minds, distorting behaviour and determining careers" (Wilsdon et al. 2015). The IMPACTS framework provides a multidimensional dynamic structure that traces the research process from initial inputs through short-term outputs and wider economic and societal impacts.

A comprehensive list of potential indicators for each stage of the research impact process are presented in Section 5.3. Research centres are differentiated based on disciplines, missions, objectives, technological readiness levels (TRLs) and life cycles. The comprehensive list of indicators provides research centre managers and funding bodies with a more complete set of indicators which allows research centres to tailor their research impacts based on specific missions and objectives.

**Preparing for Research Impact Assessment: Selecting Indicators**

Research impact indicators should be agreed upon at an early stage during the grant application process. This helps ensure that key stakeholders in the research process have the required knowledge and awareness of indicators, which reduces inefficiencies of data collection. The IMPACTS framework adopts a systems-based approach to impact assessment and views industry partners as key stakeholders in generating impacts. As such, impact indicators need to be communicated to industry partners when entering into collaborative agreements with research centres. It is easier to collect data prospectively than to search for it retrospectively (OECD, 2019, p.29). The earlier industry partners are made aware of data requirements from the research centre, the more efficient data collection processes should become.

Benchmarking research centre impact requires a common set of indicators for comparative analysis. Table 5.18 presents the indicators and metrics selected to test the feasibility of the IMPACTS framework in this thesis. The core impact indicators may be used to assess research impact across most research centres and provide a useful starting point in RIA exercises.

A pragmatic approach was adopted when selecting indicators to test the RII. The indicators were selected based on their comparability, usefulness and ease of data collection. The impact indicators chosen to test the RII are already collected by SFI funded research centres as part of their research centre awards and reviews. Research centres are required to provide many of the indicators in funding applications, annual reviews and evaluations thus reduces the likelihood of misunderstanding concerning metrics and increasing the response rate to questions included in the survey instrument.

Each metric provides a proxy measure of research centre performance across various stages of the research impact process. RIA is associated with significant burden in gathering, analysing, developing and reporting of metrics. Therefore, any changes in metrics to measure research impact would need to phase in gradually and requires input from multiple stakeholders including research centre directors and management, industry partners, university representatives and funding agencies. As such, tentative steps are taken in this thesis towards this goal with recommendations towards future directions of impact indicators. Table 5.18 presents the indicators and metrics selected to test the feasibility of the IMPACTS framework in this thesis.

**Table 5.18 Standardised Indicators to Measure Research Impact**

| Standardised Indicators | Details | Dimension of Impact |
|---|---|---|
| # Publications | Total number of publications | Scientific |
| # Citations | Total number of citations | Scientific |
| # ERC Awards | Total number of ERC awards | Scientific |
| # Conferences | Total number of conference publications | Scientific |
| # Patents | Number of patents granted | Technical |
| # Licensing agreements | Number of licencing agreements | Technical |
| # New Products | Total number of new products developed | Technical |
| # Prototypes | Total number of prototypes developed | Technical |
| # Industry first destination | Number of graduates that transferred to industry | Human Capital |
| # PhD graduates | Total number of PhD graduates | Human Capital |
| € Employment | Total number of jobs attributed to research centre | Economic |
| € Turnover | Total value of turnover attributed to centre | Economic |
| € R&D Investment | Total value of R&D investment attributed to centre | Economic |
| # Spin offs | Total number of spin outs attributed to research centre | Economic |

Source: Compiled by Author

**Data Collection**

The challenges associated with data collection for RIA exercises are presented in Section 3.2. The design of two questionnaires developed to gather data from research centres and their industry partners. Self-reported data provides rich, contextual data that is unavailable through desk research. Section 6 outlines the fieldwork undertaken to develop, pilot, implement and analyse the two research instruments, Research Centre Impact Questionnaire and Industry Partner Impact Questionnaire.

**How to use indicator data: Research Impact Index (RII)**

The RII is a novel tool developed to guide thinking and decision-making in relation to funding allocation decisions. The benchmarking tool should be used to complement critical thinking; not as a replacement for it. Measuring and evaluating research impact requires transparency from evaluators regarding the limitations of measurement tools to capture impact. The complexities associated with RIA require robust, flexible tools that may be implemented in diverse institutional and disciplinary settings. The RII does not provide an economic valuation of impacts generated by research centres but rather provides a standardised score that allows funding bodies to compare the performance and impacts generated by research centres.

**How to use indicator data: Qualitative Indicators and Narratives**

Hicks et al. (2015, p.30) highlight the danger in the shift towards metrics-based approaches to research impact assessments, noting:

> "As scientometricians, social scientists and research administrators, we have watched with increasing alarm the pervasive misapplication of indicators to the evaluation of scientific performance".

Metrics-based approaches are open to gaming behaviour by research centres such as 'slicing the salami' where researchers report the results of their projects across multiple publications, so the same data may be counted multiple times which increases publication counts. Furthermore, Goodheart's Law states "when a measure becomes a target, it ceases to be a good measure". Therefore, research centres and researchers are incentivised to adapt behaviour to hit targets which may not be the most effective or impactful strategy.

The RII is a quantitative tool to measure and evaluate the diverse impacts generated through investment in publicly funded research centres. However, there are limitations to the extent that research impact may be demonstrated through metrics-based approaches. As such, Hicks et al. (2015) recommend using a combination of both quantitative and qualitative approaches to measuring research impacts. Therefore, the IMPACTS framework approach suggests the use of Research Impact Statements to gather qualitative data on research impacts to compliment the findings of the RII. Research Impact Statements provide a qualitative description of research centre impacts which allow researchers to describe the impacts generated through public investment in research centres.

The impact statements provide research centres with an opportunity to demonstrate the depth and breadth of the impacts generated by the centre. This reduces the risk associated with an overreliance on metrics-based approaches to RIA. Therefore, triangulation between RII Impact Score, RII Efficiency Score and Impact Statement provides robustness to the analysis and helps evaluators make informed, evidence-based decisions.

## 5.5 Conclusion and Next Steps

The objective of this chapter was to develop a framework to measure and evaluate the economic impacts of publicly funded research centres, thus addressing the demands from policymakers, funding bodies and the public for greater justification for investment in research activities. This framework contributes to the literature on RIA in several ways.

Firstly, an important, and to date underappreciated, the element of the impact of research, is its contribution to the system within which it operates. The current frameworks to measure and assess research impact undervalue the influence of the system in which individual researchers, departments and institutions operate on their research impact. The strength of the system in which an individual, department or research centre operate in is an important input and platform for success. However, the system is not exogenous to the researcher or institutes, as the strength of the system is influenced by the research activities of entities within it. As such, when evaluating research impact across regions, these regional-specific, contextual factors play an important role in the potential magnitude of impact.

Secondly, whilst current frameworks have identified the importance of relationships, interactions and linkages between researchers and firms and other entities in generating research impact, the ability of firms to exploit the results of the research has been undervalued. Thus, the IMPACTS framework explicitly captures both a firms' *potential* and *realised* absorptive capacity, i.e. their ability to absorb, assimilate, transform and exploit knowledge.

Thirdly, the IMPACTS framework provides an approach to RIA exercises that aims to minimise common RIA challenges such as attribution, time lags and additionality. The IMPACTS framework measures research centre impacts across several dimensions including scientific, technical, human capital and economic. Measuring and evaluating research impacts across these dimensions allows evaluators to identify short, medium and long-term impacts generated along each stage of the research process. As such, benchmarking exercises across research centres may be tailored to 'fit' both organisational and contextual factors that influence a research centres ability to deliver impacts.

The next chapter presents the fieldwork undertaken in the development of two survey instruments, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire. The development of the survey instruments was informed by the findings of Chapter 3, 4 and 5. The data generated through the survey instruments is used to construct a novel, multidimensional index to measure the economic impact of publicly funded research centres, the Research Impact Index (RII).

# Chapter 6: Fieldwork – Conducting a Survey to Measure the Economic Impact of Publicly Funded Research Centres

The objective of the IMPACTS framework is to measure and evaluate both the process and magnitude of economic impacts generated by publicly funded research centres. As such, this means that putting the framework into practice requires data on research centre study requires a mixed-method approach, combining quantitative and qualitative data to provide a clear picture of the process of impact generation, from initial ideas and objectives through to the generation of economic and commercial impacts. This chapter outlines the fieldwork undertaken in the development of two survey instruments than is structured as follows. The rationale for using a web-based questionnaire is outlined, and the design and administration of the survey instrument are presented.

The data gathered through the survey instruments is used to test and implement the IMPACTS framework presented in the previous chapter. The IMPACTS framework is a systems-based approach to research impact assessment (RIA). As such, a research centre's impact capacity will be influenced by both the innovative capacity of their industry partners and the strength of the system which it is embedded within. Therefore, measuring research centre impact requires data collection across the research centre, external partners and the research and the innovation system.

The objective of the two survey instruments developed in this chapter, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire, is to gather necessary data to test the IMPACTS framework. The framework is tested on an SFI-funded research centre, Research Centre X, to test the feasibility of the IMPACTS framework, survey instruments, and the Research Impact Index (RII) presented in Chapter 7.

The rest of the chapter is structured as follows. Section 6.1 outlines key considerations when developing survey instruments including the types of questions that may be included in questionnaires and the modes of data collection available. Furthermore, this section highlights key innovation surveys that act as a guide for the development of the two questionnaires developed in this thesis, Research Centre Questionnaire and Industry Partner Questionnaire. Section 6.2 presents the process of testing the method of administering the survey, constructing a survey sample, and conducting the survey.

Section 6.3 describes the final questionnaire following pilot-testing and substantive changes made to the questionnaire during the pilot testing stage. Section 6.4 provides descriptive statistics of the data collected through the survey instruments. Section 6.5 concludes the chapter.

## 6.1 Designing a Survey Instrument

### 6.1.1 Types of Questions

Survey questions may be categorised into two main categories: close-ended questions and open-ended questions. Four main types of close-ended questions are commonly included in questionnaires: dichotomous, multiple-choice questions, scale ratings and demographic or firmographic questions.

- Dichotomous: Responders are asked to choose between two alternatives, e.g. YES/NO
- Multiple choices: Responders are asked to choose between multiple alternatives.
- Scale ratings: Respondents assess the issue based on given dimensions. Each dimension is given a score which can be used to analyse results. Typically, answers are provided on a Likert scale (five-point, seven-point, and nine-point). Respondents may be asked the degree to which they agree or disagree with a statement, the degree of importance and degree of significance.
- Quantitative data: quantitative data related to the attributes of firms (number of employees, turnover, etc.).

Open-ended questions are less structured than closed-ended questions and allow greater autonomy to responders. However, open-ended questions tend to be more time consuming to answer and more difficult to standardise, which makes analysis more problematic. The type of survey question influences the analysis, which can be conducted on the data gathered. Table 6.1 provides comparisons between survey question types across several key dimensions.

**Table 6.1 Comparison of Types of Survey Questions**

| | Dichotomous | Multiple Choice | Rating-Scale | Quantitative | Open-ended |
|---|---|---|---|---|---|
| Type of Data | Nominal or categorical | Nominal or categorical | Ordinal | Interval | Text |
| Analysis of Potential | Frequency Distributions | Frequency Distributions | Cumulative frequency, median, mode | Add, subtract, average | Frequency distributions with tally sheets |
| Time Consumption | Low | Low | Low | Moderate | High |
| Potential Ambiguity | Low | Low-Moderate | Low-Moderate | Moderate | High |
| Comparison across responses | Easy | Easy | Easy | Easy | Difficult |
| Degree of Sensitivity | Low | Low | Low | Moderate | High |
| Standardised Answers | Easy | Easy | Easy | Moderate | Difficult |
| Degree of Quantifiable | High | Low | Moderate | High | Low |
| Allowance for Detail | Low | Low | Low | Moderate | High |

Source: Compiled by author

### 6.1.2 Mode of Data Collection

Traditionally three forms of data collection are possible through surveys – mail, telephone, and face-to-face interview. Recently, increasing internet coverage and availability has contributed to internet surveys becoming a very popular source of data collection. Furthermore, the creation of online software packages, such as SurveyMonkey, have made data collection and analysis much easier compared to traditional methods. Combinations of any of these are also possible.

The survey instrument utilised to implement the IMPACTS framework is a questionnaire, circulated through email using an online survey development software package, SurveyMonkey. The study made several considerations when choosing the survey method, including response rates, costs, and time scales. Table 6.2 consolidates the main features of different types of data collection methods across a set of selected comparative dimensions.

**Table 6.2 Methods of Data Collection**

| | **Mail** | **Telephone** | **Face-to-face Interview** | **Internet** |
|---|---|---|---|---|
| Cost to sender | Low | Moderate | High | Moderate |
| Facilities needed? | No | No | Yes | No |
| Speed | Short | Short | Longer | Short |
| Response rate | Poorest | Good | Very High | Good |
| Require training | No | Yes | Yes | No |
| Sensitive topics | Good | Moderate | Poorest | Good |
| Permits follow up question | No | Yes | Yes | No |
| Standardise responses | Yes | Possible | Difficult | Yes |

Source: Compiled by author

Web-based surveys provide many advantages over traditional survey methods such as pencil and paper surveys and telephone surveys. Firstly, the design, dissemination and storage of data for web-based surveys are efficient and user-friendly (Greenlaw and Brown-Welty 2009) Secondly, web-based surveys allow for the collection of a large number of responses in a short period of time at relatively low cost (Schonlau, Ronald Jr, and Elliott 2002). Greenlaw and Brown-Welty (2009, p. 471) found that "the web-based administration produced greater results than did the paper-based administration overall and was substantially less costly to administer". Thirdly, web-based surveys can improve response rates which may lead to more valid analysis of the data collected.

A potential drawback of using web-based surveys is the assumption that each respondent is computer literate and could complete the survey instrument. This issue would be considered more problematic when surveying the general population. For the purposes of this study, the population under consideration are the management of high-tech companies that are collaborating with our test centre, Research Centre X.

The development of the two questionnaires developed in this thesis was guided by a review of well-established surveys, particularly surveys examining variables of interest, as they can provide ideas for the researcher to adopt in their own study (Fowler, 1995, 2002).

### 6.1.3 Key Surveys used as a Guide

Key surveys in the areas of Science, Technology and Innovation were used as a guide in the development of both the Research Centre Impact questionnaire and the Industry Partner questionnaire. Some examples of the surveys reviewed are outlined in Table 6.3.

**Table 6.3 Innovation Surveys used to Guide Development of Questionnaires**

| Survey | Scope | Key Indicators Identified |
|---|---|---|
| **Community Innovation Survey** | The CIS is a survey of innovation activity in enterprises. The harmonised survey is designed to provide information on the innovativeness of sectors by type of enterprises, on the different types of innovation and on various aspects of the development of an innovation. | -Innovation questions<br>-Degree of innovation<br>-Turnover % of sales<br>-Process innovation<br>-Spending on R&D<br>- IP Rights<br>- Turnover<br>- Number of employees |
| **National Science Foundation (NSF) Business R&D and Innovation Survey** | The survey is divided into six sections. Each section asks questions about different aspects of R&D or innovation at your company | -Financial Information<br>-R&D<br>-R&D employee counts<br>-R&D partnerships<br>-Patent-related data |
| **Annual Knowledge Transfer Survey** | Covers a range of Knowledge Transfer (KT) activities including licensing, spin-out company creation, IP, commercialisation and business engagement. | -Research expenditure, research agreements and consultancy<br>-IP and IP transactions<br>-Spin-out companies |
| **HE Business and Community Interaction Survey** | Provides a detailed picture of interactions between UK higher education providers and businesses and the wider community. | -Collaborative research -<br>Contract research<br>-Joint research<br>-IP Income |

Source: Compiled by author

The Community Innovation Survey (CIS) is conducted every two years by EU member states to measure science and technology indicators. Compiling CIS data is voluntary for each country, which means that in different survey years, different countries are involved. The CIS measures innovation activity in businesses and provides data on the innovativeness of sectors by type of business, on the different types of innovation and on different aspects of the development of an innovation e.g. the sources of information, the public funding, the innovation expenditures etc.

The National Science Foundation (NSF) Business R&D and Innovation Survey collects R&D data on businesses operating in the United States. The five main subject areas are "financial measures of R&D activity; company R&D activity funded by others; R&D employment; R&D management and strategy; and intellectual property, technology transfer, and innovation" (NSF, 2018). The surveys ask questions related to the last three years of operation. The survey is very detailed and contains considerable explanations of concepts which leads to the final survey being 98 pages long. As such, the expected time of completion is 90 minutes.

The Annual Knowledge Transfer Survey (AKTS) is produced by Knowledge Transfer Ireland in conjunction with the Higher Education Authority (HEA). The AKTS covers the range of Knowledge Transfer (KT) activities that include licensing, spin-out company creation, intellectual property commercialisation and business engagement such as collaborative research, consultancy services and use of facilities and equipment.

The Higher Education Business and Community Interaction survey highlights collaborations between higher education institutes and businesses in the UK. The survey gathers data on multiple knowledge transfer channels including spin-offs and start-ups, intellectual property, consultancy and contract research

The next section discusses the development of two survey instruments, the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire. The survey instruments were developed to collect the data needed to implement the IMPACTS framework.

## 6.2 Survey Administration

This section describes the process of designing and testing the two survey instruments, constructing a survey sample, and implementing the survey.

### 6.2.1 Pilot Testing

Chapter 5 discussed the development of the IMPACTS framework, to measure the economic and impact of publicly funded research centres. The framework was used to inform the development of two pilot questionnaires, Research Centre Impact Questionnaire and Industry Partner Impact Questionnaire.

The pilot took place over a six-month period (May-December 2017). The initial aim was to identify two research centres to take part in the pilot study. The suitability of each research centres for inclusion in the pilot study was determined based on whether they had received public funding during the last five years. The research centres varied in terms of activities conducted, Technological Readiness Levels (TRLs) and geographic locations. Each research centre manager was asked to provide contact details for two industry partners to take part in the pilot exercise. Participants were sent the questionnaires through email and were given the option of returning the questionnaires by email or directly free of charge by post free of charge. Contact details were provided to participants in case they had any questions while completing the questionnaires.

The aim of the pilot was to test the face validity of the questionnaires and to help refine the wording and layout of the questionnaires. The feedback related to the structure and formatting of the questions, terminology used, the potential for high non-response rates given the detail, and sensitivity of information sought. Table 6.4 outlines the pilot testing schedule.

**Table 6.4 Schedule for Piloting of Questionnaires**

| Date | Event |
|---|---|
| 16th Jun 2017 | The pilot surveys were completed and ready to be sent out on the 16th of June 2017. |
| 23rd Jun 2017 | Contacted Research Centre Manager A and Research Centre Manager B regarding completing the questionnaire. RC Manager A contacted on 10th July to say they would be happy to fill out the survey. |
| 18th Jul 2017 | A second email was sent to Research Centre Manager B as we received no correspondence to our original email. |
| 26th Jul 2017 | Contact was made with three further Research Centre managers: Research Centre Manager C, Research Centre Manager D, Research Centre Manager E. However, we did not receive any response from the research centre managers. |
| 27th Jul 2017 | Phone call was made to follow up with Research Centre manager B regarding suitable industry partners to send the survey to. The manager indicated that the research centre was weary of overburdening their industry partners with data requests and would be unwilling to send the questionnaires to their industry partners. They would, however, provide feedback regarding the Industry Partner questionnaire in addition to completing the Research Centre questionnaire. |
| 1st Sept 2017 | The questionnaires were edited in line with the feedback from Research Centre manager A |
| 10th Oct 2017 | Meeting with Research Centre X manager to discuss the Research Centre questionnaire |
| 14th Dec 2017 | Meeting with the Research Centre X manager to discuss the Industry Partner questionnaire. |
| 20th Apr 2018 | Meeting with Research Centre Manager to discuss final changes to the questionnaire. |

Source: Compiled by author

On 23rd June 2017, two research centre managers were initially contacted, Research Centre Manager A and Research Centre Manager B, regarding participation in the pilot survey. Research Centre Manager A replied on 10th July 2017, indicating that he would be happy to fill out the Research Centre questionnaire and would consider suitable industry partners to participate in the pilot. On July 18th, 2017, a second email was sent to Research Centre Manager B, as we received no correspondence to our original email. On July 26th, 2017, contact was made with three alternate research centre managers: Research Centre Manager C, Research Centre Manager D and Research Centre Manager E.

On July 27th, 2017, a phone call was made to follow up with Research Centre Manager A regarding suitable industry partners to send the survey to. The Research Centre manager indicated that their research centre would be unwilling to forward the questionnaire to their industry partners at that time. The reasoning was twofold. Firstly, industry partners are already heavily burdened with data requests from the research centre. Secondly, the research centre manager was worried about questions included in the questionnaire related to the financial performance of their industry partners. The manager felt that these questions were unlikely to be answered by their industry partners and that they may not appreciate being asked for such sensitive information. However, the research centre manager said that he would be happy to go through the Industry Partner questionnaire and provide comments and feedback.

On August 16th, 2017, a meeting was arranged with Research Centre Manager A to discuss potential issues related to the centre survey. The key issues arising from the initial pilot of the Research Centre Impact Questionnaire are summarised in Table 6.5.

**Table 6.5 Recommendations for Research Centre Questionnaire based on Pilot 1**

| Question | Issue | Action (Questions for Pilot1) |
|---|---|---|
| Please indicate the total value of funding generated by your Research Centre from the following sources during the last three years: Public funding, industry funding, international funding. | The grant received by the research centre was awarded five years ago so would not be captured in this question. | The question was revised and rather than asking the value of funding for each of the last three years; the question asked the average annual funding over the last five years. |
| Please indicate the percentage of your employees working in the following occupations: R&D scientists, engineers, and managers; R&D technicians and technologists; R&D support staff | Confusion around terminology, specifically, whether support staff are classified as technicians, managers etc. or whether they are classified as admin and non-scientific managerial positions such as IP, education and outreach, finance etc. | The question was amended, and categories were reclassified in line with the feedback from the research centre manager. |
| Please indicate the value of the following infrastructural resources by your research centre during each of the last three years: infrastructure grants, facilities purchased, specialist machinery, specialist equipment | The question is very difficult to answer, and responders are unlikely to attempt to answer the question. | The question was removed from the questionnaire and questions related to investment in research infrastructure were moved to the business questionnaire as qualitative questions related to the benefits of collaboration with the centre. |
| Please indicate the total revenue received by your research centre from R&D sources for the use of its facilities and equipment. | The question is very difficult to answer, and responders are unlikely to attempt to answer the question. | The question was removed from the questionnaire and questions related to investment in research infrastructure were moved to business questionnaire as qualitative questions related to benefits of collaboration with Centre. |
| Does your research centre have a designated Knowledge Transfer Office (KTO)? | No Research Centre in Ireland has this – some Centres have an IP manager but are all part of universities or institutions with TTOs | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested e.g. staff numbers etc. |

| | | |
|---|---|---|
| Please indicate which year the KTO began operations | No Centre in Ireland has a dedicated Knowledge Transfer Office thus unable to provide answers for this question. | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested |
| Please indicate the organisational relationship between your research centre and the KTO | No Centre in Ireland has a dedicated Knowledge Transfer Office thus unable to provide answers for this question. | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested |
| In the past three years, please indicate the total number of staff employed in the KTO | No Centre in Ireland has a dedicated Knowledge Transfer Office thus unable to provide answers for this question. | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested |
| Please indicate whether the head of the KTO has previously worked in industry? | No Centre in Ireland has a dedicated Knowledge Transfer Office thus unable to provide answers for this question. | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested |
| Does the KTO outsource some or part of the following activities? (i) Preparing patent applications (ii) Legal work for research contracts (iii) Legal work for licensing contracts | No Centre in Ireland has a dedicated Knowledge Transfer Office thus unable to provide answers for this question. | The question was removed as research centres in Ireland do not have a standalone KTO. The research centres use the universities Technology Transfer Offices (TTO) but would not have information being requested |
| How important are the following sources of collaboration for your research centre over the last three years? | Distinction should be made between universities and host University of research centre (where applicable) | A distinction was made between the host university, if applicable and other universities as sources of collaboration. |
| On average, what is the average length of collaborati between your research centre and R&D partners? | Distinction should be made between research centres in Ireland and research centres outside Ireland. | The category research centre was expanded into two subsets – i) research centres in Ireland ii) research centres outside of Ireland. |

Source: Compiled by author

The key issues arising from the initial pilot of the Industry Partner Impact Questionnaire are summarised in Table 6.6.

**Table 6.6 Recommendations for Industry Partner Questionnaire based on Pilot1**

| Question | Issue | Action (Questions for Pilot1) |
|---|---|---|
| Please select the primary sector in which your business operates. | The industry classification was based on the OECD industry classifications. The responder indicated that the classifications chosen were not common for innovation surveys. | The industry classifications were changed to the 14 Research Prioritisation Areas outlined in Ireland's latest innovation strategy, Innovation2020 |
| Was any R&D undertaken in your business between 2015 and 2017? | Unclear as to whether the question relates to information on the whole organisation, or the business unit that respondent is from. | An introductory statement was included at the beginning of the questionnaire to indicate that all questions relate to the business unit of responder only. |
| Please indicate between 2015 and 2017 the total number of outputs and the importance your business attributes to each output for its innovation activities. | This information will be almost impossible to gather for a large organisation e.g. pharma company. I suggest deleting the requirements for numbers, and just working with the importance level. | The number of scientific outputs were removed, and the question was amended to ask for the importance of each output. Important outputs (e.g. hiring of research centre postgraduates) were included as separate questions. |
| In the past three years, please indicate the total value of the following Intellectual Property (IP) outputs produced by your business. | Would really urge you to only ask for necessary information rather than nice-to-have stuff because the respondent will get fed up if he/she must go looking for information like this | The question was amended to request information on the total number of patents, trademarks and licenses rather than value. |
| Please estimate the total number of employees working in the following occupations and average wages received by employees in each classification. | The nonresponse rate is likely to be very high as company will not provide estimates of average wages of employees. | The question was amended but eventually removed from the final questionnaire following pilot 2. |

Source: Compiled by author

**Revisions to questions: changes from the first to the second pilot**

Table 6.5 and Table 6.6 highlight the changes to both the research centre and Industry Partner questionnaires. The feedback provided was considered, and several key decisions were made at this stage. Firstly, the decision to reduce the number of financially sensitive questions that were not critically important for the overall aim of the study, e.g. value of patents, licenses and trademarks during the last three years. Secondly, the length of the questionnaires was reduced significantly. The Research Centre manager A (RCA from here on) suggested that the questionnaire was too long and diverse, which would likely contribute to a high nonresponse rate from industry partners. As such, only questions that were considered critically important to measure economic and commercial impacts were included.

Thirdly, the RCA strongly recommended the use of SurveyMonkey or a similar online system for ease of completion. The manager suggested the formatting of the questionnaires were messy when you start inputting responses or ticks – which will negatively affect response rate and annoy respondents. Fourthly, an accompanying email was drafted to be sent along with the questionnaires including an upfront statement on confidentiality, how responses will be handled (and by whom), and what the objective of the questionnaire is  i.e. to assess business impacts of research centres programme to date, or to inform the development of a business impact assessment framework or both. All these changes were made with the aim of reducing burden on respondents providing information and increasing the response rates.

A summary of specific changes made at this stage are highlighted below.

**1. Some questions were removed as they were considered too difficult to answer or requested financially sensitive information that was unlikely to be provided.**

The RCA felt that the sensitivity of financial questions, the length of the questionnaire, and ambiguity in the interpretation of specific questions would likely lead to a high non-response rate from businesses. Three questions were removed that related to the value of research centre infrastructure including grants, facilities, specialist equipment and specialist machinery. RCA indicated that it would be virtually impossible to provide accurate data on these indicators and would lead to respondents skipping the question.

Seven questions were removed that related to the relationship between Knowledge Transfer Offices (KTOs) and research centres. These questions included the number of staff, relationship between research centre and KTO, functions of the KTO and whether head of KTO had previously worked in industry. RCA indicated that no research centre in Ireland has a dedicated KTO but rather they use their host university's KTO. As such, they would not have the relevant information related to KTO activities and this would result in very high non-response rates for these questions.

One question was removed that related to the value of contract research, joint collaborations and consultancy for each of the last three years. The question is financially sensitive and would require the responder to go searching for the required information which they would be unlikely to do. As such, the non-response rate for this question would likely be very high.

Three questions were removed from the industry partner questionnaire based on the feedback received. Firstly, the question related to the number of scientific outputs produced by the business during each of the last three years was removed as it was suggested business are unlikely to be very interested in scientific outputs and may not have the information on hand. This would likely lead to high non-response rate. As such, the number of scientific outputs were removed, and the question was amended to ask for the importance of each output. Outputs that were identified as very important (e.g. hiring of research centre postgraduates) were included as separate questions.

Secondly, the question related to the average wages of employees across different categories was removed as it was suggested businesses would be unwilling to provide this financially sensitive information. Also, the research centre manager suggested some of this information may be sourced in business accounts or through online databases.

Thirdly, the question related to the value of various measures of IP was amended to request information on the total number of patents, trademarks and licenses rather than value. This would likely increase the willingness of the respondent to answer the question.

**2. New questions were added where the second pilot failed to address an issue considered to be of importance**

RCA identified differences in Technological Readiness Levels (TRLs) and associated time lags as having a potentially large effect on a research centre's ability to deliver economic and commercial impacts in the short term. As such, more subtle and less tangible impacts that these types of partnerships can have on a business need to be captured e.g. development of ideas and early scientific support for a new product concept, reputational benefits from collaborating with a world-renowned research centre, and the provision of scientific evidence to kill a product in early development and therefore save costs for company. Human capital impacts (training, exchange of knowledge etc.) and companies using the open innovation paradigm to tap into research centres expertise and SFI co-funding to de-risk early R&D investment are key impact pillars.

**3. Wording was amended to make it clearer and to prevent misunderstanding**

The initial pilot highlighted potential issues and confusion surrounding the terminology used in certain questions. Firstly, the categories of employees within the research centre included: R&D scientists, engineers, and managers, R&D technicians and technologists, and R&D support staff. RCA suggested breaking down research centre employees is difficult as many Principal Investigators come from the host university and would not be considered research centre employees even though they are vitally important for research centre projects. The categories were amended to try and minimise confusion for the respondent.

Secondly, the initial industry classification was based on the OECD industry classifications. The respondent indicated that the classifications chosen were not common for innovation surveys and suggested that the industry classifications be changed to align with the 14 Research Prioritisation Areas outlined in Ireland's innovation strategy.

Thirdly, the question related to the importance of specific sources of collaboration for the research centre over the last three years required an expansion of two answer categories. The category university was expanded into two subsets – i) host university, if applicable and ii) other universities. Also, the category research centre was expanded into two subsets – i) research centres in Ireland ii) research centres outside of Ireland. These changes would reduce confusion and misunderstanding on the part of the respondent.

Between 6th September 2017 and 4th October 2017, both research centre and business questionnaires were edited in line with the feedback received from research centre manager A. Following the completion of the editing process, a second pilot test was organised with Research Centre manager X. Pilot 2 consisted of sending the amended questionnaires to Research Centre manager X and organising a face to face meeting to discuss potential issues and recommended changes to the questionnaires. On 10th October 2017, I had a meeting with Research Centre Manager X to discuss the research centre pilot questionnaire.

The key issues arising from the initial pilot of the research centre Impact Questionnaire are summarised in Table 6.7.

**Table 6.7 Changes to Research Centre Questionnaire following Pilot 2**

| Question | Issue | Action (Questions for Pilot 2) |
|---|---|---|
| Please select the primary area in which your research centre operates | The categories are based on academic disciplines and research centre managers may find it difficult to identify the most suitable area. | The industry classifications were changed to the 14 Research Prioritisation Areas outlined in Ireland's innovation strategy, Innovation2020. |
| How important were the following objectives for your research centre over the last three years? | Two categories – Generating Collaboration and Raising research centre profile should be expanded to capture different effects | Generating collaborations was broken down into two subsets – i) academic collaborations ii) industrial collaborations. Raising Research's profile was broken down into two subsets – i) Raising national profile ii) raising international profile |
| Please indicate average annual funding from each of following sources | State competitive funding (e.g. SFI, EI) should be broken down by source of funding as key differences should appear between Centres receiving different sources of funding | State competitive funding was broken down into two subsets – i) SFI funding and ii) EI funding. |
| Please indicate average annual funding from each of following sources | University funding should be broken down into two subsets – host university and other universities. This is an important distinction as relationship with host university likely to be significantly different to other universities. | The question was amended to include both host university and other universities as an option. |
| Please indicate the percentage of your employees in following categories | The terminology used is inconsistent with general employee categories. | The categories were amended to include Principal Investigators, researchers, postdoctoral researchers, PhDs/Masters, non-research staff. |
| Please indicate the number of PhD graduates at your research centre for each of the last three years | The numbers do not change significantly from year to year and may be more work for responder to check up annual figures as opposed to total figure. | The question was amended to ask for the total number of PhD graduates over the last three years rather than an annual figure. |
| How important are the following sources of collaboration for your research centre during last three years? | Potentially important categories are not included such as Research Performing Organisations (RPOs), hospitals and clinicians | Categories were expanded to include new collaborative partners. |

Source: Compiled by Author

The key issues arising from the pilot of the Industry Partner Impact Questionnaire are summarised in Table 6.8.

**Table 6.8 Changes to Industry Partner Questionnaire following Pilot 2**

| Question | Issue | Action (Questions for Pilot2) |
|---|---|---|
| Name of company | The survey is anonymous so asking the companies to provide their names may lead to a lower response rate as a result of worries around sensitive information. | The name of the company was not requested but the address of the company was included. |
| When did your business begin operations in Ireland? | The company may not be operating in Ireland. research centre may be collaborating with clients abroad. | The question was changed to when your business began operations. |
| Please indicate the business main objective for entering into collaboration with research centre X | An extra option should be included - To increase access to postgraduate level trainees. Demand for PhD level trainees from industry over the last years and this is likely to continue to grow and will be one of the main value-adds for centres. | The option of increasing access to postgraduate level trainees was included as a potential objective of collaboration with research centre X. |
| Please indicate the importance of collaboration with research centre X on the following investments. | Suggest adding expansion/rewording to include R&D team, R&D facilities, Advanced manufacturing team, Manufacturing facility etc. | The question was reworded in line with suggestions |
| To what extent would you agree that collaboration with research centre X has increased my business' ability to recruit well-qualified graduate students | Suggest adding the same point but for postgraduate students in order to differentiate the research centre from RPOs. | Graduates and postgraduates were included as separate options in the question. |

Source: Compiled by Author

**Revisions to questions: changes from the second pilot to final questionnaires**

Based on inspection of the pilot data, the following changes were made to the Research Centre and Industry Partner questionnaires.

**1. Some questions were removed as they were considered too difficult to answer or requested financially sensitive information that was unlikely to be provided.**

One question was removed from the Industry Partner questionnaire following the second pilot exercise. Research Centre Manager X suggested removing the name of the business at the beginning of the survey. The survey is anonymous, and businesses may be more willing to provide potentially sensitive information if they do not have to provide the name of their company.

**2. New questions were added where the second pilot failed to address an issue considered to be of importance**

Research Centre Manager X indicated that the most pertinent omission from the questionnaire was related to training as a research centre output. While training had previously been included as a sub-part to another question, research centre manager X indicated that it should be included as a separate question and noted that centres were already required to gather this information for funding applications so the data would be on hand. Questions related to country of origin and first employment destination after leaving the research centre were also included. Staff mobility has been identified as key indicator of knowledge transfer between public and private institutions (Salter and Martin 2001).

Potential benefits to research centre collaboration such as whether the business has co-located part of their team at the centre and/or if they directly utilise the centre equipment and facilities were an important omission from the pilot questionnaire. These benefits are important as given the time lags associated with research centre impacts, short-term measures give an important indication of potential future impact.

**3. Wording was amended to make it clearer and to prevent misunderstanding**

Research Centre Manager X provided suggestions to improve the questionnaires particularly related to terminology of certain questions e.g. typologies of staff etc. The research centre manager suggested that generating potential collaborations should be expanded into two subsets - i) academic collaborations ii) industrial collaborations. Also, the objective of raising a research centre's profile should be broken down into two subsets – i) raising national profile ii) raising international profile. The reasoning is that these subsets are likely to identify different goals and strategies of the Centre and allows the respondent to answer the question with greater certainty.

Ambiguity was highlighted in the question related to the sources of funding. The research centre manager suggested breaking down state competitive funding into two subsets – i) Science Foundation Ireland funding and ii) Enterprise Ireland funding, as key differences will likely to be found across research centres receiving funding from different funding agencies. Furthermore, the research centre manager suggested breaking down university funding into two subsets – host university funding and other university funding. This is an important distinction as the relationship between research centre and their host university is likely to be significantly different to that of other universities.

The employee categories were amended based on recommendations of the research centre manager. The terminology used in pilot 2 was found to be inconsistent with generally accepted employee categories. The categories were changed in order to reduce uncertainty and confusion for the responder and to increase the question response rate. The categories were amended to include Principal Investigators, researchers, postdoctoral researchers, PhDs/Masters, non-research staff.

**Summary of Pilot Testing**

The pilot testing of the survey instruments has led to significant changes being implemented for the final questionnaires. The main changes relate to (i) questions being removed as a result difficulty associated with answering, (ii) questions being added related to important topics previously overlooked and (iii) wording of questions being amended as a result of ambiguity.

The resulting changes have led to the development of two questionnaires, research centre Impact Questionnaire (Appendix A4) and Industry Partner Impact Question (Appendix A5). The data gathered from these questionnaires will be used to develop the Research Impact Index (RII), an evaluative tool to be used by policymakers and funding bodies to benchmark the performance of research centres.

## 6.3 Survey Instruments

This section describes the final questionnaire following pilot-testing and substantive changes made to the questionnaire during the pilot testing stage.

### 6.3.1 Research Centre Impact Questionnaire

The Research Centre Impact questionnaire contains 20 questions. The questions were categorised across five key areas – Research Centre characteristics, Research Centre objectives, Research Centre inputs, Research Centre outputs, and sources of collaboration. Section A contains 4 questions on Research Centre characteristics and objectives, Section B contains 1 question on Research Centre objectives, Section C contains 8 questions related to Research Centre inputs, Section D contains 3 questions on research outputs, and Section E contains 4 questions related to collaboration activities.

QA.1 asks respondents to rate, using a scale, the importance of different types of research activities conducted within the centre ranging from pure basic research to full commercial application. These typologies of research are closely related to the Technological Readiness Level (TRL) of the Research Centre. The aim of this question is to determine the extent to which the Research Centre is scientifically-driven and/or commercially-driven.

The degree to which research activities are commercially driven is an important determinant of time lags of research impacts. The issue of time lags have been identified as a key issue in previous efforts to measure and evaluate research impact (Salter and Martin 2001, Martin and Tang 2007, Guthrie et al. 2013). A general rule of thumb is that scientifically-driven Research Centres (i.e. TRL 1-3) tend to exhibit longer time lags between outputs and impacts than more commercially-driven centres (i.e. TRL 7-9) in the generation of economic and commercial impacts. As such, the TRL of the centre must be given significant consideration when benchmarking Research Centre performance.

QA.2 asks respondents to identify the year in which the Research Centre began operations in Ireland. The age of the centre is an important determinant of a centre's ability to deliver impact. with older centres developing greater critical mass through experience, investment and networking effects. The development of the research centre landscape in Ireland is relatively recent, with major investment in research activities only occurring in the last twenty years.

QA.3 asks respondents to identify the Research Prioritisation Area, which best aligns with their Research Centre operations. The Research Prioritisation Strategy in Ireland aims to focus most competitive funding to key strategic areas. These disciplinary areas are discussed further in Section 1.3. Differences across disciplines have been identified as a key issue when assessing the impacts generated by publicly funded research centres. The generation of economic impacts is demonstrated more easily across STEM (Science, Technology, Engineering and Maths) disciplines compared with arts, humanities and social science (Meagher and Martin 2017, Rau, Goggins, and Fahy 2018).

QA.4 asks how many Research and Performing Organisations (RPOs) the research centre is based across. An RPO is a research institute such as a university, Institute of Technology or State research organisation. Some research centres operate within single RPOs while other research centres operate across multiple RPOs. This question examines whether differences in impact generation are evident in research centres that are more concentrated or dispersed.

Section B relates to the strategic objectives of the Research Centre. The objectives of a Research Centre will influence funding bodies investment decisions and businesses choice of collaboration partner, e.g. Research Centres with strategic goals related to income generation, impact economic growth and new product development are more likely to attract short-term contract research from industry partners while centres with goals of increasing the stock of knowledge and advancing science are likely to attract long term collaborative industry partners.

Section C relates to Research Centre inputs, i.e. resources required to achieve strategic objectives and deliver economic and commercial impacts. QC.1 asks respondents to provide details on the average annual funding generated by the Research Centre. The composition of funding has been identified as a key metric when assessing Research Centre performance (SFI, 2016). The composition of research funding varies from centre to centre, and in different research systems.

For example, the Fraunhofer Centres in Germany adopt a model which aims to generate a third of funding from public sources, a third from industry sources, and a third from competitive funding. The generation of industry and competitive funding is considered a key indicator of Research Centre quality as it is a measure of its competitiveness against international centres, as typically a national centre is a leading actor in the field in which it operates, in the country within the country, in which it is based (Research Centre Manager X, Pilot II).

Financial investment from industry, particularly industry cash, has been identified as a key input into the Research Centre impact process (Research Centre Manager X, Pilot II). Here the firm makes a financial contribution on the basis that the economic value of the further developed knowledge/Intellectual Property (IP) will be enhanced through their inputs and that they have preferential access terms. Inputs include detailed final product specifications, production process and costing.

The next six questions are related to the level of human capital within the research centre. Human capital refers to the stock of knowledge, skills, and other intangible assets of individuals which may be used to create economic value for the individual, employer, economy, and society. Human capital resources provide key inputs into the process of generating research centre impacts.

QC.3 asks respondents how many staff worked within the research centre during each of the last three years. This provides information on the size and growth of the research centre during the period.

QC.4 relates to employment categories within the centre, e.g. Principal Investigators, researchers, post-doctoral researchers, PhD students, and non-research staff. These categories are important when estimating expenditure on wages by the research centre, which contributes to economic impacts. Furthermore, evidence suggests that higher wages are likely to provide spillover benefits for the region (Porter 2003, Delgado, Porter, and Stern 2014)

QC.5 asks respondents to indicate the percentage of staff that are foreign nationals. A research centre's ability to attract top-class international talent acts as a proxy for the quality of the centre. The recruitment of scientists and engineers from international competitors allows research centres entre to import scientific and technological knowledge, which may not be available in the domestic market. This enhances the absorptive capacity of both the research centre and the innovation system.

QC.6 asks respondents to indicate the total number of doctoral graduates at the research centre during each of the last three years. Training skilled graduates has been identified as a key function of research centres both in Ireland and globally (Salter and Martin 2001, Hughes and Kitson 2012) Training skilled graduates contributes to increases in stock of knowledge, both scientific and technical, ability to solve complex problems, the development of new instruments and methodologies, and enhanced absorptive capacity in both the centre and the innovation system in which it is embedded.

QC.7 asks respondents to indicate the percentage of doctoral graduates by country of origin during the last three years. The ability of research centres to attract both national and international students provides an indication of the attractiveness and quality of the research centre.

QC.8 asks respondents to indicate the first employment destination of doctoral graduates from the centre. The mobility of graduates has been identified as a key knowledge transfer mechanism between public and private entities within an innovation system (Salter and Martin 2001). research centre graduates are the embodiment of the knowledge, skills, and expertise developed throughout their training. Knowledge developed within the centre may be transformed and exploited into economic and commercial impacts in firms. Science Foundation Ireland’s Agenda 2020 aims to increase the percentage of SFI trainees moving to industry as a first destination to 50% by 2020.

Section D relates to research centre outputs. QD.1 and QD.2 focus on the quantity and quality of research centre outputs produced during the last three years. QD.1 asks research centre managers to provide information on the total number of research outputs, while QD.2 asks research centre managers to indicate the importance of specific outputs for the research centre objectives.

QD.3 relates to the intellectual property (IP) developed by the research centre in the last three years. Intellectual property refers to creations of the human mind such as inventions, prototypes, images, designs, symbols, and logos which are protected by law using patents, trademarks, copyright, and licences. research centre managers are asked in QD.3 to provide information on the number of IP outputs including patents, trademarks and licensing. The development of IP is a key objective for research centres at various Technological Readiness Levels (TRLs) as the sale and licensing of IP is a key source of income for publicly funded research centres whilst providing a key mechanism for the transfer of knowledge from publicly funded research centres to private firms.

Section E relates to the sources of collaboration for the research centre. Collaboration between research centres and other entities within the innovation system is important for the generation of new ideas, facilitation of knowledge transfer and the leveraging of new research funding. The importance of collaboration in the generation of research centre impact and the strengthening of the innovation system cannot be understated. QE.1 to QE.4 relate to the type, frequency, and intensity of collaboration between research centres and other entities within the innovation system.

QE.1 asks respondents to rate the importance of different sources of collaboration for research centre activities. The composition of collaborative partners will likely affect the magnitude of economic and commercial impacts generated by the research centre.

QE.2 relates to the frequency of interaction between the research centre and their collaborative partners. The duration and frequency of external collaboration are important determinants of the success of knowledge transfer between research centres and their collaborative partners. A greater degree of experience and higher frequencies of interaction may reduce barriers to knowledge transfer and increase potential impacts generated through the relationship. Schartinger et al. (2002, p.318) note “if there is a level of experience in external, industry-oriented knowledge interactions in a certain field of science, institutional and individual barriers to knowledge interactions are likely to be less important than in the case of fields of science with little experiences so far”.

QE.2 asks respondents to identify the percentage of collaboration involving international partners. Attracting international partnerships has been identified as a key objective for research centres in Ireland as international collaboration acts as a signal of scientific excellence. Science Foundation Ireland (2016) find that of the 3,179 collaborations involving SFI researchers, 72% were with international partners.

QE.3 relates to barriers to knowledge transfer between the research centre and its collaborative partners. Respondents were asked to indicate the significance of barriers to knowledge transfer between the research centre and their industry partners.

Respondents were required to answer on a five-point Likert scale ranging from not at all significant to very significant. Adopting an approach that goes beyond binary 'YES/NO' answers is useful as it provides an indication of the degree of significance of barriers, which is important when designing policies to overcome these barriers. The barriers range from indicators of absorptive capacity (quality and usefulness of knowledge, knowledge base of partner), to quality of interaction (low quantity of interaction, low quality of interaction, point of contact) to institutional (difference in culture) and geographical (distance between partners) barriers.

### 6.3.2 Industry Partner Questionnaire

The industry partner survey contains 29 questions. The questions are categorised across four key areas – business characteristics, the innovation capacity of the business, sources of collaboration, and benefits of collaboration with the research centre. Section A contains 6 questions on business characteristics, Section B contains 9 questions on the innovation capacity of the business, Section C contains 2 questions related to collaboration, and Section D contains 12 questions on Benefits of Collaboration with a research centre.

Firm-level characteristics have been identified as an important prerequisite for developing absorptive capacity (Dyer and Singh 1998, Schildt, Keil, and Maula 2012). QA.1 to QA.6 relate to the characteristics of the business surveyed.

QA.1 asks respondents to indicate whether the business is a stand-alone business or a member of a group of companies. If the company is a member of a group of companies, the respondent is asked to provide information on the location of the company HQ. The duality of the Irish economy in terms of Irish and foreign-owned economic activity has been widely studied. O'Connor, Doyle, and Brosnan (2017) find foreign-owned firms remain substantially more productive than indigenous enterprises. Furthermore, Doran and O'Leary (2016) find that indigenous and foreign-owned businesses innovate or source innovation in different ways.

QA.2 asks which year the company began operations in Ireland. The age of the company has been identified as an important factor when analysing the benefits of collaboration between firms and publicly funded research centres. There is evidence that start-up firms particularly tend to benefit through collaboration with public research centres (Cohen, Nelson, and Walsh 2002).

QA.3 asks respondents whether the company is a spin-off company from the research centre for whom the evaluation is being conducted or another research centre. The number of spin-offs created has been identified as a key output of public investment in research centres (Salter and Martin 2001, Martin and Tang 2007, Hughes and Kitson 2012). However, this indicator reveals very little about the nature of the impact of the spin-off. In order to capture research impacts, as opposed to simply outputs, information regarding job creation and financial performance across key categories such as turnover, new product development and innovative capacity.

QA.4 asks the number of employees employed in the business during the last three years. The size of the business, as measured by the number of employees, has been identified as a key characteristic influencing the propensity of firms to collaborate with publicly funded research centres. The majority of studies find that larger businesses are more likely to benefit from collaboration with publicly funded research (Cohen, Nelson, and Walsh 2002, Arundel and Geuna 2004, Fontana, Geuna, and Matt 2006, Nieto and Santamaría 2010).

QA.5 asks respondents to indicate the absolute value of business turnover in 2017. The importance of providing a turnover figure is twofold. Firstly, important indicators to capture the absorptive capacity of the business are measured as a percentage of turnover. For example, the R&D intensity of the business is measured as R&D as a percentage of turnover, rather than asking the respondent to provide exact figures for R&D expenditure. The feedback received from the pilot surveys indicated that respondents felt overburdened by questions related to financial information and would likely result in a low response rate. Secondly, business turnover is an important indicator when measuring the magnitude of economic and commercial impacts generated by firms as a result of their collaboration with the research centre.

QA.6 asks the respondents to indicate the Research Prioritisation Area, which best aligns with the business. The propensity to collaborate, the suitability of knowledge transfer activities and benefits of collaboration vary significantly across sectors. Firms operating in different industries make use of diverse types of knowledge in different ways and for different purposes. Pavitt (1984) shows that firms learn and innovate differently across industrial sectors distinguishing between the sources of learning, sources of technological improvement and patterns of innovation development.

Meyer-Krahmer and Schmoch (1998) analyse mechanisms which facilitate knowledge transfer between universities and industry in Germany. The findings indicate that the closest public-private relationships are evident in application-oriented fields, whereas relations in science-based fields appear to be relatively weak. Furthermore, Doran and Jordan (2016) find that sources of innovation differ across sectors in Ireland.

QB.1 to QB.9 relate to the innovative capacity of the business. The impact of publicly funded research is dependent on private sector capacities and investments (Hughes and Kitson 2012). As such, it is important to consider whether businesses have the internal capabilities to absorb and assimilate knowledge from publicly funded research centres.

QB.1 asks respondents whether their business has engaged in R&D activities over the past three years. The question is framed as a 'YES/NO' question with respondents skipping to question QB.6 if the business has not engaged in any R&D activities over the previous three years. The likelihood that businesses included in the study did not engage in any R&D activity during the period is expected to be small. These companies would not have sufficient absorptive capacity to absorb, assimilate, transform and exploit complex scientific and technological knowledge to economic and commercial impacts. QB.2 asks whether the business had a formal R&D department.

QB.3 asks respondents to indicate how many employees were engaged in R&D activities in the business in 2017. Human capital has been identified as a key indicator of the innovative capacity of the firm. The research intensity of the firm measured as the number of researchers as a percentage of total employees has been used as a proxy for human capital (Gao, Xu, and Yang 2008, Cantner, Conti, and Meder 2010). Higher levels of engagement in R&D activities should increase a business' ability to absorb knowledge from internal and external sources.

QB.4 asks respondents to estimate spending on research and development (R&D) as a percentage of turnover. The most common proxies for a business' innovative capacity include measures of R&D expenditure (Cohen and Levinthal 1990, Rocha 1999, Muscio 2007, de Jong and Freel 2010) and R&D intensity i.e. total expenditure on R&D divided by sales (Tsai 2001, Stock, Greis, and Fischer 2001, Muscio 2007, Vega-Jurado, Gutiérrez-Gracia, and Fernández-de-Lucio 2008). The justification for these measures assumes that firm investments in R&D increase both internal capabilities within the firm as well as the capacity of the firm to absorb and assimilate knowledge from external sources.

QB.5 asks respondents to estimate the business' average annual expenditure on collaboration activities with the research centre during the last three years. Financial investment from industry has been identified as a key input into the research centre impact process. Here the firm makes a financial contribution on the basis that the economic value of the further developed knowledge/Intellectual Property (IP) will be enhanced through their inputs and that they have preferential access terms.

QB.6 asks respondents to indicate the number of patents, trademarks and licenses produced by the business during the last three years.

QB.7 asks respondents to indicate the importance of the several mechanisms of knowledge transfer between their business and the research centre. Respondents are asked to rate the importance of each output to business activities on a five-point Likert scale ranging from not at all important to very important. The order of outputs are randomised for each individual respondent, which reduces the likelihood of ordinal bias in data collection. The mechanisms include publications, citations, conferences etc.

QB.8 asks respondents to indicate the percentage of employees with a master and/or PhD as their highest qualification. Education attainment of employees has been identified as a key indicator of human capital (Knudsen, Dalum, and Villumsen 2001, van der Heiden et al. 2015). The levels of human capital within an organisation is an important indicator of a firm's potential and realised absorptive capacity (Lund Vinding 2006, Islam 2009).

QB.9 asks the responder to indicate the number of research centre graduates hired by their company during the last three years.

QC.1 and QC.2 relate to the sources of collaboration for the business. A key conceptual contribution of absorptive capacity is the identification of the complementarity between internal capabilities and external collaboration (Lund Vinding 2006). As such, the success of the firm in generating economic and commercial impacts is strongly influenced by its relationship with other actors within the innovation system.

QC.1 asks respondents to identify the importance of eight sources of collaboration for the R&D activities of the business during the last three years. QC.2 asks respondents to indicate the frequency of interaction between their business and their innovation partners. Innovation partners include the research centre being evaluated, other research centres in Ireland, research centres outside Ireland, SMEs, multinationals, competitors, suppliers, and innovation support agencies.

The importance of each innovation partner is ranked on a five-point Likert scale from not at all important to very important. The frequency of interaction is ranked on a five-point scale ranging from never to continuously. The importance and frequency of interactions with innovation partners is an important determinant of potential economic and commercial impacts.

Section D relates to the benefits to the business from collaboration with the research centre. These questions assess the extent to which businesses were successful in transforming and exploiting publicly funded research into economic and commercial impacts. Barge-Gil and Modrego (2011) develop a firm-level survey to measure the impact of research and technology organisations (RTOs) on firm competitiveness in Spain. The findings suggest that industrial partners can recognise the influence of research organisations on several different impacts including technical, economic, investment and intangible impacts. As such, the questions included in Section D aim to identify the contribution of the research centre in the generation of economic and commercial impacts by their industry partners.

QD.1 asks respondents to indicate the main objectives of the business for entering into a collaboration with the research centre. Businesses enter external collaborations for diverse reasons ranging from access to scientific and technical knowledge and complex problem-solving skills, to the development of new products and increased productivity. The objectives of the business will influence the type, magnitude, and process of impact generation.

QD.2 asks respondents to indicate the extent to which collaboration with the research centre has improved business outputs such as improvements in scientific capabilities, improved ability to recruit new graduates, reduced costs, and/or improved processes.

The indicators are difficult to quantify but provide qualitative data on the impact of the research centre across multiple dimensions of impact. Respondents are asked to indicate on a five-point Likert scale, ranging from strongly disagree to strongly agree, the extent to which collaboration with the research centre has influenced each indicator.

QD.3 asks respondents whether the business has introduced any new products during the last three years. Respondents are asked to answer a ‘YES/NO’ question.

QD.4 asks respondents to indicate the main types of innovation facilitated by collaboration with the research centre. The types include new to business innovations and new to industry innovations at both national and international levels. The option ‘none yet but expected’ is also included as the process of impact generation is characterised by significant time lags which need to be considered during impact evaluations.

QD.5 asks respondents whether the business has introduced any processes during the last three years and QD.6 asks respondents to indicate the extent to which the business introduced new processes during the last three years. This question relates to the frequency and intensity of process innovation. Respondents are asked to indicate the frequency of new processes on a scale from continuously to never.

QD.7 asks respondents to indicate the importance of collaboration with the research centre for the variation in several economic and commercial impacts. Answers are provided on a five-point Likert scale ranging from not at all important to very important to assess the impact of collaboration with Research Centre X on sales, job creation, exporting, number of clients, and market share.

QD.10 asks respondents to indicate approximately the average annual growth across the economic and commercial impacts included in the previous questions. The aim of the question is to gather quantitative data on the changes in economic and commercial impacts over the last three years.

QD.11 asks respondents to estimate the average annual growth in each several indicators in the absence of collaboration with the research centre. The aim of the question is to address the issues of additionality and attribution by creating a counterfactual situation, thus isolating the effect of collaboration with the research centre has had on changes in economic and commercial impacts generated by industry partners.

Please estimate what the average annual growth in each of the following indicators would have been **in the case that your business HAD NOT collaborated with Research Centre X (%)**

| | |
|---|---|
| Turnover | |
| Employment | |
| Exports | |
| Profits | |
| R&D Investment | |
| Market Share | |

This question provides a rough quantitative estimate of the economic and commercial impacts generated by publicly funded research centres. The aim the question is not to provide a definitive monetary estimate for economic impacts generated by the research centre. Rather, the question provides comparable data across multiple research centres which may be used in the Research Impact Index (RII) to benchmark research centre performance and impacts. The next section presents the descriptive statistics derived from the testing of the two questionnaires developed in this thesis.

## 6.4 Descriptive Statistics for Research Centre X

When the two survey instruments are administered across the scientific community then descriptive statistics for comparison can be easily reported as set out in this section. Although the descriptive statistics are not sufficient for measuring research impacts, they are useful for understanding the developments across these elements of the innovation system. The next sub-section provides descriptive statistics for our test centre, Research Centre X.

### 6.4.1 Research Centre Questionnaire – Descriptive Statistics

This section presents descriptive statistics on the characteristics of the test centre, including the goals and objectives, research orientation, size and composition of funding. Furthermore, the research outputs generated by the research centre and their main sources of collaboration are highlighted.

#### 6.4.1.1 Characteristics of Research Centre

Table 6.9 highlights the self-reported importance of research activities along the Technological Readiness Level (TRL) scale.

**Table 6.9 Technological Readiness Level of Research Centre**

| Technological Readiness Level (TRL) | Importance |
|---|---|
| TRL 1 Basic Research | Somewhat important |
| TRL 2 Technology Formulation | Somewhat important |
| TRL 3 Applied Research | Very important |
| TRL 4 Small Scale Prototype Development | Very important |
| TRL 5 Large Scale Prototype Development | Somewhat important |
| TRL 6 Prototype System | Somewhat important |
| TRL 7 Demonstration System | Neither important nor unimportant |
| TRL 8 First of its kind commercialisation | Neither important nor unimportant |
| TRL 9 Full Commercial Application | Neither important nor unimportant |

Source: Author's survey

The research centre is primarily focused on research at the lower TRL levels with applied research and small-scale prototype development the most important research activities. Closer to market research activities (TRL7-9) are not considered important for research centre operations. Research activities at the lower end of the TRL scale tend to be associated with longer time lags than research on higher end of TRL scale. This needs to be considered when evaluating research centre impacts as longer-term impacts such as job creation and increased competitiveness may take several years to generate and thus should not be expected in short-term assessment cycles.

Table 6.10 shows the number of employees in the research centre between 2015 and 2017.

**Table 6.10 Research Centre Employees**

| | 2015 | 2016 | 2017 |
|---|---|---|---|
| Number of employees | 135 | 150 | 156 |

Source: Author's survey

The number of employees has increased from 135 in 2015 to 156 in 2017. This represents an increase of 15.56%.

Table 6.11 shows the composition of employees across job specifications.

**Table 6.11Employees by Employment category**

| Role | % |
|---|---|
| Principal and funded Investigators | 10 |
| Researchers | 5 |
| Postdoctoral researchers | 33 |
| PhD/ Masters students | 48 |
| Non-research staff (e.g. centre management and administrative staff) | 4 |

Source: Author's survey

Table 6.11 shows 48% of employees within the research centre are students, either PhD or masters. The next highest category of employees are postdoctoral researchers who make up 33% of employees. Table 6.12 shows the average annual funding generated by the research centre between 2012 and 2017.

**Table 6.12 Composition of Research Centre Funding**

| Source of Funding | Value |
|---|---|
| Science Foundation Ireland funding | 6,000,000 |
| Enterprise Ireland funding | 900,000 |
| International competitive funding (e.g. Horizon2020) | 4,000,000 |
| Industry funding | 2,000,000 |
| of which is industry cash | 1,500,000 |
| Host university funding, if applicable | 0 |
| Other university funding | 0 |

Source: Author's survey

An important objective of SFI research centres is to increase the proportion of funding from non-exchequer sources. The proportion of funding generated through industry cash has been identified as a key performance indicator for research centres in Ireland. The average annual funding received from SFI was €6 million per annum. The research centre was successful in generating €4 million per annum from international competitive funding such as Horizon2020.

Table 6.13 outlines the country of origin of each doctoral student within the research centre. Chapter 4 identified attracting and maintaining high quality postgraduate students as a significant issue for research centres in Ireland. As such, the composition of doctoral students within research centres are increasingly international in scope.

**Table 6.13 Doctoral students by Country of Origin**

| PhD by Country of origin | % |
|---|---|
| Ireland | 40 |
| United Kingdom | 0 |
| Rest of Europe | 20 |
| North America | 5 |
| South America | 5 |
| China | 15 |
| India | 15 |
| Rest of World | 0 |

Source: Author’s survey

Table 6.14 shows the first destination of graduates from the research centre. The number of doctoral gradates entering industry as a first destination is an important KPI for SFI Research Centres. The mobility of graduates from research centres to businesses facilitates the transfer of tacit knowledge, skills and talent embodied within researchers from the public sector to the private sector.

**Table 6.14 First Destination of doctoral students upon graduation**

| First Destination after PhD completion | % |
|---|---|
| Academia | 30 |
| Industry | 64 |
| Government | 3 |
| Non-Profit | 3 |

Source: Author’s survey

Industry is the most popular first destination of graduates from Research Centre X with 64% of graduates opting to join the private sector. Almost a third of graduates went into academia as a first destination with relatively few graduates entering government or the non-profit sector.

### 6.4.1.2 Research Centre Outputs

Table 6.15 and Table 6.16 highlight the number of research outputs produced by our test centre, Research Centre X, and the perceived importance the centre places on each output indicator.

**Table 6.15 Research Outputs generated by Centre between 2015 and 2017**

| Research outputs | N |
|---|---|
| Peer Reviewed journal publications | 245 |
| Public-private co-publications | 60 |
| Number of citations | - |
| Other publications (e.g. policy documents etc.) | - |
| Attendance at conferences, workshops and seminars | 137 |
| Spin-off companies established | 1 |
| European Research Council awards | 0 |
| Prototypes developed | 60 |
| Start Up companies established | 0 |

Source: Author’s survey

**Table 6.16 Importance of Research Outputs for Research Centre**

| Research output | Importance |
|---|---|
| Peer Reviewed journal publications | Somewhat important |
| Public-private co-publications | Somewhat important |
| Number of citations | Somewhat important |
| Other publications (e.g. policy documents etc.) | Neither important nor unimportant |
| Conferences, workshops and seminars organised | Somewhat important |
| Number of PhD projects financed | Very important |
| Spin-Off companies established | Somewhat important |
| European Research Council awards | Somewhat important |
| Prototypes developed | Somewhat important |
| Start-up companies established | Somewhat important |

Source: Author’s survey

Research Centre X produced 245 peer-reviewed publications between 2015 and 2017. Peer-reviewed journal publications are a key indicator of scientific impact. However, peer-reviewed journal publications do not distinguish between the quality of the paper, the quality of the journal or whether the publication reached a large audience. As such, the publication of peer-reviewed papers alone is only a partial indicator of scientific impact. Conferences, workshops and seminars have been identified as important mechanism of knowledge transfer between public and private institutes, particularly tacit knowledge. Conferences are important networking opportunities that allow participants to forge new working relationships while keeping up to date with the research within a disciplinary field.

Table 6.17 highlights the intellectual property (IP) outputs generated by Research Centre X during the period.

**Table 6.17 IP Outputs generated by Research Centre between 2015 and 2017**

| IP Outputs | N |
|---|---|
| Patents filed | 9 |
| Trademarks filed | 0 |
| Licenses, options and assignments | 15 |

Source: Author's survey

Research Centre X filed nine patents between 2015 and 2017, as well as fifteen licenses, options and assignments.

### 6.4.1.3 Sources of Collaboration

Table 6.18 shows the importance of each collaboration partners for helping Research Centre X develop research impacts.

**Table 6.18 Importance of Sources of Collaboration**

| R&D Partner | Importance |
|---|---|
| Research Centres | Somewhat important |
| Universities | Somewhat important |
| Host university, if applicable | Somewhat important |
| Hospitals/Clinicians | Very important |
| Research Performing Organisations (RPO) | Somewhat important |
| Irish Small and Medium Enterprises (SMEs) | Very important |
| Foreign-Owned Multinationals (MNCs) | Very important |
| Funding Agencies (e.g. SFI, EI, IRC) | Very important |

Source: Author's survey

Table 6.19 outlines the most important barriers to knowledge transfer between Research Centre X and their collaborative partners.

**Table 6.19 Barriers to Knowledge Transfer**

| Knowledge Transfer Barrier | Significance |
|---|---|
| Quality, relevance and usefulness of knowledge | Very significant |
| Lack of scientific knowledge base in partner | Somewhat significant |
| No designated contact person | Neither significant nor insignificant |
| Low quantity of interaction | Neither significant nor insignificant |
| Poor quality of interaction | Neither significant nor insignificant |
| Differences in culture | Neither significant nor insignificant |
| Geographic distance between organisations | Somewhat significant |

Source: Author's survey

The quality, relevance and usefulness of knowledge was identified as the most significant barrier to knowledge transfer between research centres and the private sector. Also, the absorptive capapcity of the collaboration partner and the geographic distance between organisations were identified as being somewhat significant barriers to knowledge transfer. Several studies have empirically tested the relationship between knowledge spillovers and geographic proximity. With a few exceptions (Beise and Stahl 1999), evidence suggests that knowledge transfer between public research centres and private businesses decreases with geographical distance.

The presence of barriers to knowledge transfer limits a research centre's impact capacity. However, solutions to knowledge transfers barriers requires system-focused, rather than centre-focused, strategic planning. As such, measuring research centre impacts requires data collection across multiple stakeholders across the innovation system. Therefore, the next sub-section presents descriptive statistics for Research Centre X's industry partners.

### 6.4.2 Industry Partner Questionnaire – Descriptive Statistics

This section is structured as follows. Section 6.4.2.1 highlights the characteristics of the research centre's industry partners including the average turnover, employment, age and growth. These characteristics are analysed by the type and age of businesses. 6.4.2.2 highlights the characteristics of innovative capacity of industry partners including the percentage of staff engaged in R&D, R&D investment, cash investments to the research centre, levels of educational attainment and commercialisation outputs. 6.4.2.3 relates to the mechanisms of knowledge transfer and importance of different types of collaborative partners. Section 6.4.2.4 relates to the impact of collaboration with Research Centre X on the scientific and technical quality, investments and economic impacts of their industry partners.

#### 6.4.2.1 Characteristics of Business

The first section of the industry partner questionnaire relates to the characteristics of Research Centre X's industry partners. QA.1 asks respondents to indicate whether the business is a stand-alone business or a member of a group of companies. If the company is a member of a group of companies, the respondent is asked to provide information on the location of the company HQ. Table 6.20 shows the composition of respondents by types of business.

**Table 6.20 Types of Businesses**

| Type of business | Percentage | Total number of businesses |
|---|---|---|
| A single-plant company | 54.55% | 6 |
| A parent or group HQ | 9.09% | 1 |
| A subsidiary business in a group | 36.36% | 4 |

Source: Author's survey

Responses were collected from 11 research centre industry partners. Six of the companies (54.55%) were single plant indigenous companies, four of the companies (36.36%) were subsidiary businesses and one company (9.09%) was a parent company. Given that only one parent company is included in the study it made sense to merge this data with another business type to avoid issues of confidentiality. The characteristics of the parent company were positively correlated with single plant businesses to a much greater extent than subsidiary businesses. As such, data from single plant companies and the parent company have been merged together for the analysis. Table 6.21 shows the breakdown of companies by nationality.

**Table 6.21 Respondents by Nationality**

| Business type | Frequency | Percentage |
|---|---|---|
| Indigenous | 7 | 64% |
| Foreign Owned | 4 | 36% |
| Total | 11 | |

Source: Author's survey

Almost two-thirds of the respondents were Irish companies. All subsidiary businesses surveyed were foreign-owned while the remaining businesses were indigenously owned. Table 6.22 sets out the nationality of the foreign-owned businesses included in the study. Three-quarters of foreign owned businesses headquarters were based in the United States with the remaining business based in the Netherlands.

**Table 6.22 Nationality of Foreign owned business**

| Business type | Frequency | Percentage |
|---|---|---|
| North America | 3 | 75% |
| Netherlands | 1 | 25% |
| Total | 4 | |

Source: Author's survey

Table 6.23 reports the industry partner by Research Prioritisation Area in which they are engaged. The area was self-reported. The respondents may state they were engaged in more than one Research Prioritisation Area. Studies suggest that the type and magnitude of research impacts, and the time lags between inputs and impacts differs across research disciplines (Schartinger et al. 2002, Cohen, Nelson, and Walsh 2002, Bekkers and Freitas 2008).

**Table 6.23 Respondents by Research Prioritisation Area**

| Research Prioritisation Area | Number | Percentage |
|---|---|---|
| Future Networks & Communications | 4 | 36% |
| Diagnostics | 3 | 27% |
| Processing Technologies and Novel Materials | 2 | 18% |
| Smart Grids & Smart Cities | 2 | 18% |
| Medical Devices | 2 | 18% |
| Manufacturing Competitiveness | 1 | 9% |
| Digital Platforms, Content & Applications | 1 | 9% |

Source: Author's survey

Future networks & communication was the leading research prioritisation area with 36% of respondents engaged in this research area. The businesses engaged in this research area is evenly spread between indigenous (50%) and foreign owned (50%) businesses. Diagnostics (27%) was the second most popular research area with 27% of respondents engaged in research in this area. Two subsidiary businesses and one single-plant business.

The research prioritisation areas not included in the responses were: Connected Health and Independent Living, Innovation in Services and Business Processes, Therapeutics: Synthesis, Formulation, Processing and Drug Delivery, Data Analytics, Management, Security & Privacy, Food for Health.

QA.2 to QA.5 relate to the business characteristics of the research centre's industry partners. QA.2 asks which year the company began operations in Ireland. The average age of the total sample of industry partners was ten years. However, significant variation exists across different types of businesses.

**Table 6.24 Business Characteristics by Type of firm: Mean Responses**

| Variable | Single Plant or Parent | Subsidiary Business | Total |
|---|---|---|---|
| Age (in years) | 6 | 17 | 10 |
| Employment 2015 | 5 | 1051 | 386 |
| Employment 2017 | 10 | 1026 | 379 |
| Employment Growth (%) | 34 | -4 | 19 |
| Turnover 2017 (€) | 1,278,571 | 658,826,250 | 240,386,818 |

Source: Author's survey

The average age of subsidiary businesses is almost three times that of single plant or parent businesses. The majority of the businesses included in the analysis were established relatively recently. Cohen, Nelson, and Walsh (2002) suggest the benefit derived from public research by start-up companies may be greater than that of other types of businesses. Two firms (18%) were established in 2017 during the final period of the study, over half of the businesses (55%) were formed less than five years ago and eight firms (73%) were formed less than 10 years, with a further three businesses (27%) formed more than 15 years ago.

QA.3 asks respondents whether the company is a spin-off company from public research institutes such as a research centre or university. Table 6.25 reports the businesses in the analysis formed through spin-offs.

**Table 6.25 Companies formed through Spin offs**

| Spin-off Category | Percentage (%) |
|---|---|
| Not formed through spin-off | 46 |
| University spin-off | 45 |
| Research centre spin-off | 9 |
| Research Centre X spin-off | 0 |
| Total | 100% |

Source: Author's Survey

45% of companies were formed through spin-offs from universities. 46% of companies were not spin-outs and 9% of companies were spin-offs from research centres. None of the companies were spin-offs from Research Centre X.

#### 6.4.2.2 Innovative Capacity of Industry Partner

QB.1 to QB.9 relate to the innovative capacity of the business. The IMPACTS framework highlights the importance of a firm's potential and realised absorptive capacity to absorb, assimilate, transform and exploit knowledge generated in publicly funded research centres into economic and commercial impacts. Therefore, gathering data on the innovative capacity of industry partners is required to test and operationalise the IMPACTS framework.

Table 6.26 shows the innovative characteristics of the businesses. The data is broken down by type of business to identify differences between indigenous and foreign owned businesses. The findings suggest that on average the innovative capacity of single plant and parent companies are very similar to that of foreign owned subsidiary businesses.

**Table 6.26 Innovative Capacity of Business: Mean Responses**

| Variable | Single Plant or Parent | Subsidiary Business | Total |
|---|---|---|---|
| R&D Employees (% total) | 75 | 69 | 73 |
| Research Centre X expenditure (€) | 40,857 | 40,667 | 40,800 |
| Research Centre X industry cash inv. (€) | 15,857 | 39,000 | 22,800 |
| Masters (% total) | 19 | 20 | 20 |
| PhD (% total) | 46 | 48 | 46 |
| Patents | 31 | 6 | 24 |
| Licensing | 0 | 2 | 1 |
| Research Centre X postgraduates hired | 1 | 1 | 1 |

Source: Author's survey

QB.3 asks respondents to indicate how many employees were engaged in R&D activities in the business in 2017. The ratio of total employees to employees engaged in R&D may be used as a proxy for the innovative intensity of a business. Table 6.26 shows for the overall sample 73% of business employees are engaged in R&D. There was little variation across types of companies with 75% of indigenous single plant and parent company's employees engaged in R&D and 69% of subsidiary companies engaged in R&D. The highest level of employees engaged in R&D was 100%. However, it should be noted that this company had only one employee. The lowest reported level of employees engaged in R&D as a percentage of total employees was 33.33%.

QB.4 asks respondents to estimate spending on research and development (R&D) as a percentage of turnover. R&D expenditure and R&D intensity have been identified as key proxies for innovative capacity of businesses (Cohen and Levinthal 1990, Rocha 1999, Tsai 2001, Muscio 2007, Vega-Jurado, Gutiérrez-Gracia, and Fernández-de-Lucio 2008, de Jong and Freel 2010).

QB.5 asks respondents to estimate their business' average annual expenditure on collaboration activities with Research Centre X during the last three years. The average expenditure on collaborative activities with Research Centre X across the entire sample of businesses was €40,800. The findings suggest similar levels of investment were made across different types of businesses with single plant businesses investing €40,857 and subsidiary businesses investing €40,667. The largest investment was €100,000 with the lowest investment was €0.

There is more variation evident between different types of business when we consider average annual expenditure which is given in industry cash. For the overall sample the average industry cash investment is €22,800. However, on average subsidiary businesses invest almost two and a half times (2.46) more industry cash than single plant businesses. The average subsidiary invests €39,000 in cash while single plant business invests €15,857.

QB.6 asks respondents to indicate the number of IP outputs (e.g. patents, and licenses) produced by the business during the last three years. On average, industry partners produced 24 patents during the last three years. These results are highly skewed with one business filing 200 patents. In the absence of this business, the average industry partner filed 4.1 patents during the last three years.

QB.7 asks respondents to indicate the percentage of employees with a masters and/or PhD as their highest level of educational attainment. The findings suggest that 46% of employees have a PhD as their highest qualification while a further 20% have a masters. The results are very similar across single plant and subsidiary businesses.

QB.8 asks respondents to indicate the importance of the several mechanisms of knowledge transfer between their business and the research centre. Codified measures of knowledge transfer (e.g. publications) and tacit transfer mechanisms (e.g. conferences, informal meetings and personnel exchange).

Table 6.27 shows the importance of different knowledge transfer channels for the overall sample of businesses.

**Table 6.27 Knowledge Transfer Channels by Respondent: Total Respondents**

| | Very important | Important | Neither important nor unimportant | Unimportant | Very unimporta nt |
|---|---|---|---|---|---|
| Collaborative Research | 54.55% | 36.36% | 9.09% | 0.00% | 0.00% |
| Informal meetings, talks and communication | 54.55% | 36.36% | 9.09% | 0.00% | 0.00% |
| Contract research | 36.36% | 18.18% | 27.27% | 0.00% | 18.18% |
| Employment of research centre PhDs | 27.27% | 9.09% | 45.45% | 0.00% | 18.18% |
| Personnel exchange between your business and research centre | 27.27% | 9.09% | 27.27% | 0.00% | 36.36% |
| Conferences, workshops and seminars | 18.18% | 36.36% | 27.27% | 0.00% | 18.18% |
| Consultancy | 18.18% | 18.18% | 9.09% | 18.18% | 36.36% |
| Co-publications with research centre | 9.09% | 45.45% | 18.18% | 0.00% | 27.27% |
| Licensing of Research Centre IP | 9.09% | 36.36% | 36.36% | 18.18% | 0.00% |

Source: Author's survey

Collaborative research and informal meetings, talks and communications were the most important knowledge transfer mechanisms between Research Centre X and the total sample of their industry partners. These two knowledge transfer channels were identified as either important or very important by 90.91% of the industry partners surveyed. Contract research was the third most important knowledge transfer channel with 54.54% respondents considering contract research either important or very important. Consultancy was the least important knowledge transfer channel identified with 54.54% of respondents indicating that this channel was either unimportant or very unimportant. Co-publications with research centre was highlighted as a less important knowledge transfer channel with 27.27% of businesses finding this channel very unimportant.

Table 6.28 shows the importance of different knowledge transfer channels single plant companies.

**Table 6.28 Knowledge Transfer Channels by Respondent: Single Plant companies**

| Total | Very important | Important | Neither important nor unimportant | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| Collaborative Research | 57.14% | 28.57% | 14.29% | 0.00% | 0.00% |
| Contract research | 57.14% | 28.57% | 14.29% | 0.00% | 0.00% |
| Consultancy | 28.57% | 14.29% | 14.29% | 28.57% | 14.29% |
| Co-publications with research centre | 14.29% | 42.86% | 28.57% | 0.00% | 14.29% |
| Personnel exchange between your business and research centre | 42.86% | 0.00% | 42.86% | 0.00% | 14.29% |
| Informal meetings, talks and communication | 71.43% | 28.57% | 0.00% | 0.00% | 0.00% |
| Conferences, workshops and seminars | 14.29% | 42.86% | 28.57% | 0.00% | 14.29% |
| Employment of research centre PhDs | 28.57% | 14.29% | 57.14% | 0.00% | 0.00% |
| Licensing of Research Centre IP | 14.29% | 42.86% | 28.57% | 14.29% | 0.00% |

Source: Author’s survey

Single plant companies indicated that informal meetings, talks and communications were the most important knowledge transfer channel for their businesses. The entire sample of industry partner (100%) indicated that this transfer channel was either very important or important. Collaborative research and contract research were identified as the second most important channels with 85.67% of the sample indicating that these channels were wither very important or important.

Table 6.29 shows the importance of different knowledge transfer channels for subsidiary businesses.

**Table 6.29 Knowledge Transfer Channels by Respondent: Subsidiary businesses**

| | Very important | Important | Neither important nor unimportant | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| Collaborative Research | 50.00% | 50.00% | 0.00% | 0.00% | 0.00% |
| Informal meetings, talks and communications | 25.00% | 50.00% | 25.00% | 0.00% | 0.00% |
| Conferences, workshops and seminars | 25.00% | 25.00% | 25.00% | 0.00% | 25.00% |
| Employment of research centre PhDs | 25.00% | 0.00% | 25.00% | 0.00% | 50.00% |
| Contract research | 0.00% | 0.00% | 50.00% | 0.00% | 50.00% |
| Consultancy | 0.00% | 25.00% | 0.00% | 0.00% | 75.00% |
| Co-publications with research centre | 0.00% | 50.00% | 0.00% | 0.00% | 50.00% |
| Personnel exchange between your business and research centre | 0.00% | 25.00% | 0.00% | 0.00% | 75.00% |
| Licensing of Research Centre IP | 0.00% | 25.00% | 50.00% | 25.00% | 0.00% |

Source: Author's survey

The findings suggest that subsidiary businesses exploit more narrow channels of knowledge transfer than single plant companies. Collaborative research is identified as the most important knowledge transfer mechanism by subsidiary businesses with all respondents indicating this channel is either important or very important. Informal meetings, talks and communications is identified as the second most important knowledge transfer channel with 75% of industry partners surveyed indicating that this channel is either an important or very important knowledge transfer channel between Research Centre X and their business.

Personnel exchange and consultancy were the least important knowledge transfer channels identified by industry partners. 75% of the subsidiary businesses surveyed identify this channel as very unimportant. Employment of research centre PhDs, contract research and co-publications were identified as very unimportant sources of knowledge transfer by half of subsidiary businesses surveyed.

#### 6.4.2.3 Sources of Collaboration

QC.1 and QC.2 relates to the sources of collaboration for the business. QC.1 asks respondents to identify the importance of eight sources of collaboration for the R&D activities of the business during the last three years.

**Table 6.30 Importance of Collaboration Partners: Total Sample**

| Total | Research Centre X | RC in Ireland | RC outside Ireland | Universities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Very Important | 54.55% | 36.36% | 9.09% | 54.55% | 27.27% | 0.00% | 18.18% | 54.55% |
| Important | 27.27% | 18.18% | 45.45% | 18.18% | 36.36% | 9.09% | 45.45% | 27.27% |
| Neither | 9.09% | 27.27% | 36.36% | 18.18% | 9.09% | 27.27% | 27.27% | 9.09% |
| Unimportant | 0.00% | 9.09% | 9.09% | 0.00% | 18.18% | 9.09% | 9.09% | 9.09% |
| Very unimportant | 9.09% | 0.00% | 0.00% | 9.09% | 0.00% | 45.45% | 0.00% | 0.00% |

Source: Author's survey

Research Centre X and innovation support agencies were identified as the most important source of collaboration for the total sample of industry partners. These sources of collaboration were identified as either important or very important by 82.82% of businesses surveyed. Universities were identified as either an important or very important source of collaboration by 72.73% of industry partners. Competitors were identified as the least important source of collaboration across the entire sample. The results indicate 54.56% of businesses surveyed find competitors either unimportant or very unimportant collaborative partners.

Table 6.31 and Table 6.32 highlight the importance of different sources of collaboration by type of business.

**Table 6.31 Importance of Collaboration Partners: SMEs**

| SME | Research Centre X | Other Research centres in Ireland | Research centres outside Ireland | Univers -ities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Very Important | 57.14% | 28.57% | 14.29% | 57.14% | 42.86% | 0.00% | 28.57% | 85.71% |
| Important | 42.86% | 14.29% | 28.57% | 28.57% | 14.29% | 14.29% | 14.29% | 0.00% |
| Neither | 0.00% | 42.86% | 42.86% | 14.29% | 14.29% | 28.57% | 42.86% | 0.00% |
| Unimportant | 0.00% | 14.29% | 14.29% | 0.00% | 28.57% | 14.29% | 14.29% | 14.29% |
| Very unimportant | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 28.57% | 0.00% | 0.00% |

Source: Author's survey

Table 6.31 shows that Research Centre X was the most important source of collaboration for single plant businesses surveyed. The results are consistent with the total sample of businesses surveys. Research Centre X was identified as the most important source of collaboration by single plant companies with 100% of businesses surveyed identifying Research Centre X as either an important or very important source of collaboration. This is followed closely by innovation support agencies (85.71%) and universities (85.71%). Competitors are the least important source of collaboration with 42.86% of single plant businesses identifying competitors as either an unimportant or very unimportant source of collaboration.

Table 6.32 shows the importance of different sources of collaboration for subsidiary businesses.

**Table 6.32 Importance of Collaboration Partners: MNC**

| MNC | Research Centre X | Other Research centres in Ireland | Research centres outside Ireland | Universities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Very Important | 50.00% | 50.00% | 0.00% | 50.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Important | 0.00% | 25.00% | 75.00% | 0.00% | 75.00% | 0.00% | 100.00% | 75.00% |
| Neither | 25.00% | 0.00% | 25.00% | 25.00% | 0.00% | 25.00% | 0.00% | 25.00% |
| Unimportant | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Very unimportant | 25.00% | 0.00% | 0.00% | 25.00% | 0.00% | 75.00% | 0.00% | 0.00% |

Source: Author's survey

A different pattern emerges when comparing sources of collaboration by subsidiary compared with single plant companies. Suppliers were identified as the most important source of collaboration for subsidiary businesses. Every business surveyed identified suppliers as an important source of collaboration. Only half of the subsidiary businesses surveyed identify Research Centre X as an important source of collaboration (compared to 100% of single plant businesses). Innovation support agencies, research centres outside of Ireland and other research centres in Ireland were identified as either important or very important source of collaboration by 75% of subsidiary businesses. Similar to the findings for single plant businesses, competitors are identified as the least important source of collaboration. 75% of subsidiary businesses indicated that competitors are a very unimportant source of collaboration.

QC.2 asks respondents to indicate the frequency of interaction between their business and their innovation partners.

Table 6.33 shows that suppliers were identified as the most frequent collaborative partner with 72.72% of businesses surveys indicating suppliers were either important or very important. Research Centre X and innovation support agencies were the second most frequent collaborative partner with 63.64% of businesses indicating collaboration was continuous or very frequent. Competitors were the least frequent collaborative partner with 36.36% of respondents indicating they rarely or never collaborated with competitors.

Table 6.34 shows the frequency of interactions with collaborative partners by SMEs. All the respondents (100%) indicated that they collaborated with Research Centre X continuously or very frequently with 71.43% indicating they collaborated with innovation support agencies either continuously or very frequently. SMEs were found to collaborate with universities at a higher rate than MNCs with 85.71% of SMEs collaborating continuously or very frequently, compared 50% of MNCs. The least frequent collaborative partner was research centres outside Ireland with 57.14% of SMEs indicating they rarely or never collaborated with centres outside the country.

Table 6.35 shows the frequency of interaction by collaborative partners for MNCs. Table 6.35 highlights differences between collaborative patterns of MNCs and SMEs. Respondents from MNCs indicated that other research centres and research centres outside Ireland were their most frequent collaborative partners while SMEs indicated they were least frequent collaborative partner. Furthermore, 75% of MNCs indicated they rarely interacted with Research Centre X while al SMEs surveyed indicated interaction was very frequent with the research centre.

### Table 6.33 Frequency of Interaction with Collaborative Partners: Total Sample

| | Research Centre X | Other Research centres in Ireland | Research centres outside Ireland | Universities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Continuously | 27.27 | 18.18 | 0.00 | 36.36 | 18.18 | 0.00 | 36.36 | 0.00 |
| Very frequently | 45.45 | 36.36 | 45.45 | 36.36 | 18.18 | 27.27 | 36.36 | 63.64 |
| Frequent | 0.00 | 27.27 | 18.18 | 9.09 | 45.45 | 36.36 | 9.09 | 0.00 |
| Rarely | 27.27 | 18.18 | 27.27 | 18.18 | 9.09 | 18.18 | 18.18 | 27.27 |
| Never | 0.00 | 0.00 | 9.09 | 0.00 | 9.09 | 18.18 | 0.00 | 9.09 |

Source: Author's survey

### Table 6.34 Frequency of Interaction with Collaborative Partners: SMEs

| SME | Research Centre X | Other Research centres in Ireland | Research centres outside Ireland | Universities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Continuously | 28.57 | 0.00 | 0.00 | 28.57 | 14.29 | 0.00 | 28.57 | 0.00 |
| Very frequently | 71.43 | 42.86 | 28.57 | 57.14 | 14.29 | 28.57 | 42.86 | 71.43 |
| Frequent | 0.00 | 28.57 | 14.29 | 0.00 | 57.14 | 57.14 | 14.29 | 0.00 |
| Rarely | 0.00 | 28.57 | 42.86 | 14.29 | 0.00 | 14.29 | 14.29 | 14.29 |
| Never | 0.00 | 0.00 | 14.29 | 0.00 | 14.29 | 0.00 | 0.00 | 14.29 |

Source: Author's survey

### Table 6.35 Frequency of Interaction with Collaborative Partners: MNCs

| MNC | Research Centre X | Other Research centres in Ireland | Research centres outside Ireland | Universities | RPOs | Competitors | Suppliers | Innovation support agencies |
|---|---|---|---|---|---|---|---|---|
| Continuously | 25.00 | 50.00 | 0.00 | 50.00 | 25.00 | 0.00 | 50.00 | 0.00 |
| Very frequently | 0.00 | 25.00 | 75.00 | 0.00 | 25.00 | 25.00 | 25.00 | 50.00 |
| Frequent | 0.00 | 25.00 | 25.00 | 25.00 | 25.00 | 0.00 | 0.00 | 0.00 |
| Rarely | 75.00 | 0.00 | 0.00 | 25.00 | 25.00 | 25.00 | 25.00 | 50.00 |
| Never | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 50.00 | 0.00 | 0.00 |

Source: Author's survey

### 6.4.3.4 Benefits of Collaboration with Research Centre

Section D relates to the benefits to the business from collaboration with the Research Centre. QD.1 asks respondents to indicate the main objectives of the business for entering into collaboration with the Research Centre. Table 6.36 shows the objectives of interaction with Research Centre X by the type of business.

**Table 6.36 Objective of Collaboration with Research Centre X by type of business**

| | Total | SME | MNC |
|---|---|---|---|
| To improve profitability | 18.18% | 28.57% | 0% |
| To increase efficiency / productivity | 18.18% | 28.57% | 0% |
| To increase market share | 18.18% | 28.57% | 0% |
| To increase access to postgraduate level trainees | 36.36% | 28.57% | 50% |
| To expand geographically | 18.18% | 28.57% | 0% |
| To improve scientific capability of business | 45.45% | 71.43% | 0% |
| To improve employee skills | 27.27% | 42.86% | 0% |
| To create new products | 63.64% | 57.14% | 75% |
| Other | 18.18% | 14.29% | 25% |

Source: Author's survey

The most important objective for entering into collaboration with Research Centre X was the development of new products. Overall, 63.64% of businesses surveyed indicated that new product development was an important objective with 57.14% of SMEs and 75% MNCs ranking this as an important objective. Furthermore, increased access to postgraduate trainees was identified as the second most important objective for MNCs (50%).

Table 6.36 highlights differences in objectives between SMEs and MNCs. 71.43% of SMEs aimed to increase scientific capability of business while none of the MNCs had this objective. Similarly, 42.86% of SMEs aimed to increase their employee's skills while none of the MNCs had this objective. Respondents from MNCs indicated much narrower objectives for collaboration with Research Centre X compared with SMEs. MNCs only identified two main objectives - new product development and access to postgraduate trainees while the objectives of SMEs were much more diverse.

QD.2 asks respondents to indicate the extent to which collaboration with the Research Centre has improved business outputs such as improvements in scientific capabilities, improved ability to recruit new graduates, reduced costs, and improved processes. Table 6.37 shows the results for the entire sample.

**Table 6.37 Collaboration with Research Centre X has improved my businesses: Total Sample**

| Total | Very Significant | Significant | Neither | Insignificant | Very insignificant |
|---|---|---|---|---|---|
| Scientific capability | 18.18% | 63.64% | 18.18% | 0.00% | 0.00% |
| Recruit well-qualified graduate students | 0.00% | 36.36% | 27.27% | 27.27% | 9.09% |
| Establish new strategic partnerships | 27.27% | 45.45% | 9.09% | 18.18% | 0.00% |
| Recruit postgraduate students | 0.00% | 36.36% | 36.36% | 9.09% | 18.18% |
| Improved the quality of strategic partners | 9.09% | 18.18% | 45.45% | 9.09% | 18.18% |
| Helped accelerate the pace of R&D projects | 36.36% | 54.55% | 9.09% | 0.00% | 0.00% |
| Helped the organisation to decide against starting new R&D projects | 9.09% | 36.36% | 27.27% | 18.18% | 9.09% |
| Development of new R&D projects at my organisation | 18.18% | 63.64% | 9.09% | 9.09% | 0.00% |

Source: Author's survey

Table 6.37 highlights the benefits of collaboration for the total sample of businesses surveyed. 90.91% of businesses indicated collaboration with Research Centre X has accelerated the pace of R&D projects with 81.82% of businesses indicated improved scientific capability and development of new R&D projects. 72.73% indicated Research Centre X has improved businesses ability to establish new strategic partnerships.Table 6.38 shows the benefits of collaboration with Research Centre X for SMEs.

**Table 6.38 Collaboration with Research Centre X has improved my businesses: SMEs**

| SME | Very Significant | Significant | Neither | Insignificant | Very insignificant |
|---|---|---|---|---|---|
| Scientific capability | 28.57% | 57.14% | 14.29% | 0.00% | 0.00% |
| Recruit well-qualified graduate students | 0.00% | 42.86% | 28.57% | 14.29% | 14.29% |
| Establish new strategic partnerships | 28.57% | 57.14% | 0.00% | 14.29% | 0.00% |
| Recruit postgraduate students | 0.00% | 42.86% | 42.86% | 0.00% | 14.29% |
| Improved the quality of strategic partners | 14.29% | 14.29% | 57.14% | 0.00% | 14.29% |
| Helped accelerate the pace of R&D projects | 57.14% | 42.86% | 0.00% | 0.00% | 0.00% |
| Helped the organisation to decide against starting new R&D projects | 0.00% | 28.57% | 42.86% | 14.29% | 14.29% |
| Development of new R&D projects at my organisation | 28.57% | 57.14% | 0.00% | 14.29% | 0.00% |

Source: Author's survey

Table 6.38 shows that every respondent from SMEs indicated Research Centre X has accelerated R&D projects with 85.71% of SMEs indicating Research Centre X has improved development of new products, establishing new strategic partners and improved scientific capabilities. Only 42.47% indicated Research Centre X has improved ability to attract new graduates and postgraduates even though this was identified as a key objective by SMEs. Table 6.39 shows the benefits of collaboration with Research Centre X for MNCs.

**Table 6.39 Collaboration with Research Centre X has improved my businesses: MNCs**

| MNCs | Very Significant | Significant | Neither | Insignificant | Very insignificant |
|---|---|---|---|---|---|
| Scientific capability | 0% | 75% | 25% | 0% | 0% |
| Recruit well-qualified graduates | 0% | 25% | 25% | 50% | 0% |
| Establish new strategic partnerships | 25% | 25% | 25% | 25% | 0% |
| Recruit postgraduate students | 0% | 25% | 25% | 25% | 25% |
| Improved the quality of strategic partners | 0% | 25% | 25% | 25% | 25% |
| Helped accelerate the pace of R&D projects | 0% | 75% | 25% | 0% | 0% |
| Helped the organisation to decide against starting new R&D projects | 25% | 50% | 0% | 25% | 0% |
| Development of new R&D projects at my organisation | 0% | 75% | 25% | 0% | 0% |

Source: Author’s survey

Table 6.39 shows that 75% of MNCs indicated Research Centre X has helped accelerate the pace of R&D projects, helped the organisation to decide against starting new R&D projects, development of new R&D projects at my organisation and improved the scientific capability of the company even though this was not specifically highlighted as an objective. Table 6.40 shows the importance of collaboration with Research Centre X on investments in R&D.

**Table 6.40 Importance of Collaboration with Research Centre X on R&D investments: Total Sample**

| | Very important | Important | Neither important nor unimportant | Unimportant | Very Unimportant |
|---|---|---|---|---|---|
| R&D team | 45.45% | 54.55% | 0.00% | 0.00% | 0.00% |
| R&D facilities | 72.73% | 9.09% | 0.00% | 18.18% | 0.00% |
| Advanced manufacturing activities | 27.27% | 45.45% | 9.09% | 18.18% | 0.00% |
| Manufacturing facilities | 27.27% | 36.36% | 18.18% | 18.18% | 0.00% |
| External R&D | 18.18% | 36.36% | 18.18% | 27.27% | 0.00% |
| Acquisition of technology | 9.09% | 9.09% | 54.55% | 18.18% | 9.09% |

Source: Author’s survey

Table 6.40 shows every respondent indicated that collaboration with Research Centre X has been important in investment in its R&D team (100%). Furthermore, 81.82% of businesses indicated collaboration with Research Centre X improved investment in R&D facilities. Table 6.41 highlights the importance of collaboration with Research Centre X on investments in R&D for SMEs.

**Table 6.41 Importance of Collaboration with Research Centre X on R&D investments: SME**

| | Very Important | Important | Neither important nor unimportant | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| R&D team | 57.14% | 42.86% | 0.00% | 0.00% | 0.00% |
| R&D facilities | 100.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Advanced manufacturing activities | 42.86% | 57.14% | 0.00% | 0.00% | 0.00% |
| Manufacturing facilities | 42.86% | 42.86% | 14.29% | 0.00% | 0.00% |
| External R&D | 28.57% | 42.86% | 14.29% | 14.29% | 0.00% |
| Acquisition of technology | 14.29% | 0.00% | 57.14% | 14.29% | 14.29% |

Source: Author’s survey

Every respondent from SMEs indicated that collaboration with Research Centre X led to increased R&D team, R&D facilities and advanced manufacturing investment with 84% indicating collaboration led to increased investment in manufacturing facilities. shows the importance of collaboration with Research Centre X on investments in R&D for MNCs.

**Table 6.42 Importance of Collaboration with Research Centre X on R&D investments: MNCs**

| | Very important | Important | Neither important nor unimportant | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| R&D team | 25.00% | 75.00% | 0.00% | 0.00% | 0.00% |
| R&D facilities | 25.00% | 25.00% | 0.00% | 50.00% | 0.00% |
| Advanced manufacturing activities | 0.00% | 25.00% | 25.00% | 50.00% | 0.00% |
| Manufacturing facilities | 0.00% | 25.00% | 25.00% | 50.00% | 0.00% |
| External R&D | 0.00% | 25.00% | 25.00% | 50.00% | 0.00% |
| Acquisition of technology | 0.00% | 25.00% | 50.00% | 25.00% | 0.00% |

Source: Author's survey

QD.5 asks respondents whether the business has introduced any processes during the last three years. QD.6 asks respondents to indicate the extent to which the business introduced new processes during the last three years. Table 6.43 shows the new processes introduced by businesses during the last three years.

**Table 6.43 New Processes by Type of Business**

| | SME | MNC | Total Sample |
|---|---|---|---|
| Continuously to frequently | 71.43% | 75.00% | 72.73% |
| Rarely or Never | 28.57% | 25.00% | 27.27% |

Source: Author's survey

Table 6.44 highlights the commercialisation activities of businesses surveyed.

**Table 6.44 Commercialisation activities of Industry Partners**

| Variable | Single Plant or Parent | Subsidiary Business | Total |
|---|---|---|---|
| Introduced new product during last three years | 42.86% | 75% | 64.34% |
| Turnover as % new product sales (mean) | 46% | 13% | 36.36% |
| Turnover from new product sales (mean) | €650,714 | €11,236,667 | €3,826,500 |
| Exports as % turnover (mean) | 83% | 67% | 78% |
| Turnover from exports (mean) | €1,267,143 | €111,766,667 | €34,417,000 |

Source: Author's survey

Overall, 64.34% of businesses have developed a new product within the last three years. Two of the businesses that did not develop products during the last three years were only established in 2017. Thus, the overall figure underestimates the actual percentage of industry partners bring new products to market during the period. 75% of MNCs developed new products during the last three years. This figure would be 100% if we only included businesses that were active for each of the last three years.

Table 6.44 shows 42.46% of SMEs developed new products during the last three years. However, many of these businesses are the early stage of the development process. SMEs percentage of turnover derived from new products sales (46%) is over three times MNCs turnover derived from new product sales (13%). On average, the turnover derived from new product sales for the overall sample was 36.36%.

The average turnover derived from new product sales for the total sample of industry partners was €3.83 million. As expected, MNCs turnover from new product sales is significantly larger than turnover from SMEs. On average, MNCs turnover from new product sales was €11.24 million. However, this figure is highly skewed by one multinational with an estimated annual turnover from new product sales of €33.4 million. The average turnover for the remaining MNCs was €135,000 (although only two companies and one was established in 2017). On average, SMEs turnover from new product sales was €650,714. Two of the companies had €0 turnover from new product sales – one developed in 2017 and one with no new products.

Table 6.45 shows the importance of Research Centre X on economic performance of the total sample of businesses surveyed.

**Table 6.45 Importance of Research Centre X on Economic Performance: Total Sample**

| | Very important | Important | Neither | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| Turnover | 18.18% | 27.27% | 18.18% | 0.00% | 36.36% |
| Employment | 9.09% | 27.27% | 45.45% | 0.00% | 18.18% |
| Exports | 18.18% | 18.18% | 27.27% | 0.00% | 36.36% |
| Profits | 18.18% | 9.09% | 36.36% | 0.00% | 36.36% |
| Market Share | 9.09% | 27.27% | 18.18% | 9.09% | 36.36% |
| R&D Investment | 36.36% | 36.36% | 0.00% | 18.18% | 9.09% |

Source: Author's survey

Overall, 64.34% of businesses have developed a new product within the last three years. Two of the businesses that did not develop products during the last three years were only established in 2017. Thus, the overall figure underestimates the actual percentage of industry partners bring new products to market during the period. 75% of MNCs developed new products during the last three years. This figure would be 100% if we only included businesses that were active for each of the last three years.

Table 6.44 shows 42.46% of SMEs developed new products during the last three years. However, many of these businesses are the early stage of the development process. SMEs percentage of turnover derived from new products sales (46%) is over three times MNCs turnover derived from new product sales (13%). On average, the turnover derived from new product sales for the overall sample was 36.36%.

The average turnover derived from new product sales for the total sample of industry partners was €3.83 million. As expected, MNCs turnover from new product sales is significantly larger than turnover from SMEs. On average, MNCs turnover from new product sales was €11.24 million. However, this figure is highly skewed by one multinational with an estimated annual turnover from new product sales of €33.4 million. The average turnover for the remaining MNCs was €135,000 (although only two companies and one was established in 2017). On average, SMEs turnover from new product sales was €650,714. Two of the companies had €0 turnover from new product sales – one developed in 2017 and one with no new products.

Table **6.46** shows the importance of Research Centre X on economic performance of the SMEs surveyed.

**Table 6.46 Importance of Research Centre X on Economic Performance: SMEs**

| | Very Important | Important | Neither | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| Turnover | 28.57% | 28.57% | 28.57% | 0.00% | 14.29% |
| Employment | 14.29% | 28.57% | 57.14% | 0.00% | 0.00% |
| Exports | 28.57% | 14.29% | 42.86% | 0.00% | 14.29% |
| Profits | 28.57% | 0.00% | 57.14% | 0.00% | 14.29% |
| Market Share | 14.29% | 28.57% | 28.57% | 14.29% | 14.29% |
| R&D Investment | 42.86% | 42.86% | 0.00% | 14.29% | 0.00% |

Source: Author's survey

Table 6.46 shows that 85% of SMEs indicated Research Centre X had impact on R&D investment, 56% of SMEs indicated Research Centre X had an impact on turnover and 43% of SMEs indicated Research Centre X had an impact on employment, exports and market share. Table 6.47 shows the importance of Research Centre X on economic performance of the MNCs surveyed.

**Table 6.47 Importance of Research Centre X on Economic Performance: MNCs**

| | Very Important | Important | Neither | Unimportant | Very unimportant |
|---|---|---|---|---|---|
| Turnover | 0% | 25% | 0% | 0% | 75% |
| Employment | 0% | 25% | 25% | 0% | 50% |
| Exports | 0% | 25% | 0% | 0% | 75% |
| Profits | 0% | 25% | 0% | 0% | 75% |
| Market Share | 0% | 25% | 0% | 0% | 75% |
| R&D Investment | 25% | 25% | 0% | 25% | 25% |

Source: Author's survey

Table 6.47 suggests Research Centre X did not have a significant economic impact on MNCs industry partners. 50% of MNCs indicated that collaboration with Research Centre X lead to increased R&D investment with 25% of MNCs indicated Research Centre X impacted turnover, exports, employment etc. However, given the small sample size these impacts were identified by one business.

## 6.5 Conclusion and Next Steps

This chapter presented the fieldwork involved in conducting a survey to measure and evaluate the economic impact of publicly funded research centres. The chapter highlighted the steps involved in designing, piloting, and implementing two questionnaires, the Research Centre Impact Questionnaire and Industry Partner Impact Questionnaire. Section 6.4 provides descriptive statistics of data generated through the two questionnaires. The descriptive statistics outlines the characteristics of research centre and their industry partners, the impact 'pathways' and the impacts generated through collaboration between research centre and their industry partners.

The two questionnaires were used to gather data from the test centre and their industry partners which was used to populate the Research Impact Index (RII), a multidimensional tool developed in this thesis to measure and evaluate research centre impacts. The questionnaires have been designed and tested with Research Centre X and can be implemented as part of the RII approach to ensure consistency in data gathering across all research centres in a standardised RIA exercise.

Chapter 7 outlines the process involved in constructing, testing and operationalising the RII, which draws on the survey data and other secondary sources of data. It shows how the standard data gathered as part of the RIA exercise can be treated flexibly through assigning different weights to reflect different TRLs, objectives, or stages of Irish research centres.

# Chapter 7: Development of Multidimensional Index to measure Economic Impacts of Publicly-funded Research Centres

Chapter 7 presents the research methodology developed in this thesis to measure and evaluate the economic impact of publicly funded research centres. The objective is to outline the process undertaken in the formulation of a multidimensional index to assess and benchmark research centre performance. This chapter makes a key contribution to the literature on impact measurement by demonstrating how composite indicators may improve our understanding of measuring impacts generated by publicly funded research centres. The rest of the chapter is outlined as follows.

Section 7.1 presents the rationale for using composite indicators (CIs) to measure the economic impact of publicly funded research centres. They are a widely used tool to measure complex, multidimensional issues such as innovation (Hollenstein 1996, Carayannis and Provance 2008, Mann and Shideler 2015), absorptive capacity (Tsai 2001, Harvey et al. 2010) and the economy (Nilsson 1987). The strengths and limitations associated with the use of CIs as a measurement tool are highlighted.

Section 7.2 outlines the steps involved in constructing CIs. The most well-known framework for constructing CIs is the OECD-JRC ‘10-steps’ framework (European Commission 2008). Section 7.3 presents a comparative analysis of the most commonly used CIs to identify best practices in terms of number of indicators, normalisation techniques employed, aggregation methods, weighting techniques chosen and dealing with missing values. Section 7.4 and Section 7.5 outline the steps involved in constructing the Research Impact Index (RII).

The RII measures and benchmarks the economic impacts generated by research centres through four composite sub-indices:

i) RII input sub-index
ii) RII impact sub-index.
iii) Overall RII score; and
iv) Impact-efficiency ratio (IER).

Section 7.6 presents the qualitative tool, Research Impact Statements, developed to complement the RII for measuring and evaluating the economic impact of publicly funded research centres. The first principle of the Leiden Manifesto recommends that "quantitative evaluation should support qualitative, expert opinion" (Hicks et al. 2015). As such, the Research Impact Statements offer research centres the opportunity to describe their journey of impact, from initial investment through to the generation of economic and societal impacts. This allows research centres to describe the 'softer' processes involved in generating research impacts including trust, relationships and networks which influence a research centres capacity for generating impacts. The seventh section concludes the chapter.

## 7.1 Rationale for using CIs to measure Research Impact

Composite Indicators (CIs) are "an aggregated index comprising individual indicators and weights that commonly represent the relative importance of each indicator" (Nardo et al. 2005, p.5). Research impact is a multidimensional concept; therefore, no single indicator captures the broad range of pathways through which impact may be achieved. Therefore, CIs provide a useful tool for measuring and evaluating the impact of publicly funded research centres.

CIs allow research evaluators and practitioners to simplify complex and multidimensional issues into underlying dimensions. As such, CIs have become a popular tool for policymakers for informing strategic decisions and communicating results. However, it should be noted that, while seductive, evaluators must be cautious when constructing CIs. The construction of CIs are complicated by numerous conceptual and methodological challenges that, if not addressed, can lead to misinterpretation or manipulation of results. As such, considerable attention must be given to their construction and subsequent use.

Evaluators must be cautious when using CIs to measure constructs in newly emerging policy areas, e.g. research impact, given the lack of consensus regarding best practices, selection of indicators and metrics, and suitable evaluation tools to complement CIs. Nardo et al. (2005) identify transparency as an essential element in constructing robust, reliable indicators. As such, their construction "owes more to the craftsmanship of the modeller than to universally accepted scientific rules for encoding" (European

Commission 2008, p.14). Table 7.1 highlights the strengths and limitations of CIs as a measurement and evaluation tool.

**Table 7.1 Strengths and Limitations of CIs**

| Strengths | Limitations |
|---|---|
| • Summarises complex, multidimensional issues into easily interpretable factors<br>• Reduces size of dataset into more easily interpretable set of indicators<br>• Allows to measure difficult concepts<br>• Allow comparisons across entities which generates public interest<br>• May reduce amount of data without loss of information<br>• Allows comparisons over time<br>• Facilitates communication with general public (i.e. citizens, media, etc.) and promote accountability.<br>• Enable users to compare complex dimensions effectively. | • Loss of information<br>• Importance of choosing the right indicators<br>• Simplification – misleading policy recommendations<br>• Misused or manipulated<br>• Methodological issues – weights, indicators<br>• Subjectivity in choices of indicators and weights<br>• May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored |

Source: Compiled by Author based on Nardo et al. (2005) and European Commission (2008)

## 7.2 Popular Indices

Table 7.2 compares four commonly used CIs across several dimensions identified in the OECD-JRC '10 Step Guide' including number of indicators, normalisation techniques employed, aggregation methods, weighting techniques chosen and dealing with missing values.

**Table 7.2 Characteristics of Popular CIs**

| | Global Innovation Index (GII) | European Innovation Scoreboard (EIS) | Multidimensional Poverty Index (MPI) | Human Development Index (HDI) |
|---|---|---|---|---|
| **Published by** | Cornell University, INSEAD, WIPO | European Commission | Oxford Poverty and Human Development Initiative (OPHI) | United Nations Development Programme (UNDP) |
| **Frequency** | Annually | Annually | Annually | Annually |
| **Concept** | Innovation | Innovation | Poverty | Human development |
| **Structure** | Innovation input sub-index (5 dimensions); innovation output sub-indices (2 dimensions) | 4 pillars (Framework Conditions, Investments, Innovation Activities, Impact) and 10 sub-dimensions | 3 pillars (health, education and standard of living) | 3 pillars (Long and healthy life, access to knowledge and a decent standard of living) |
| **Number of Indicators** | 80 | 27 | 10 | 4 |
| **Aggregation method** | Arithmetic mean | Arithmetic and geometric mean | Arithmetic mean | Geometric mean |
| **Normalisation method** | Min-max transformation | Min-max transformation | Min-max transformation | Min-max Transformation |
| **Missing values** | No imputation of missing values | Nearest available year where possible | Nearest available year where possible | Cross-country regression models |
| **Weighting** | Fixed pre-defined weights | Unweighted | Equal weighting applied across dimensions and indicators | Equal weighting applied across all dimensions |
| **Outliers** | Natural log transformation | Square root transformation | Truncating the top 0.5 percentile of the distribution to reduce the influence of extremely high values. | Truncating the top 0.5 percentile of the distribution to reduce the influence of extremely high values. |
| **Geographical focus** | Global (126 countries) | 28 EU Countries and 8 Non-EU Countries | Global (109 countries) | Global (230 countries) |

Source: Compiled by author

***Global Innovation Index (GII)***

The GII is an annually published report that aims to measure, evaluate and benchmark innovative performance across countries. The report which was originally published in 2007 is a joint project between Cornell University, the World Intellectual Property Organisation (WIPO) and the European Institute of Business Administration (INSEAD). The difficulties associated with measuring complex, multidimensional concepts such as innovation are well known, therefore the GII aims to identify robust metrics and indicators that capture both the processes and impacts of innovation. For example, the GII makes efforts to capture system-level indicators such as infrastructure and climate.

The GII is composed of 80 indicators which are spread across two sub-indices: innovation inputs sub-index and innovation outputs sub-index. The innovation inputs sub-index is composed of five dimensions including: Institutions, Human Capital and Research, Infrastructure, Market Sophistication and Business Sophistication. The innovation output sub-index identifies the results in the economy as a result of innovation activities. The innovation output sub-index is built around two dimensions: Knowledge and Technology Outputs and Creative Outputs. Although the innovation output sub-index only contains two dimensions it receives equal weighting to the innovation inputs sub-index when composing the overall GII score.

The GII calculates four measures of innovation:

i) Innovation Input Sub-Index: Five input pillars capture elements of the national economy that enable innovative activities.

ii) Innovation Output Sub-Index: Innovation outputs are the results of innovative activities within the economy.

iii) The overall GII score is the simple average of the Input and Output Sub-Indices.

iv) The Innovation Efficiency Ratio is the ratio of the Output Sub-Index to the Input Sub-Index. It shows how much innovation output a given country is getting for its inputs.

Cornell University, INSEAD, and WIPO (2018)

The data collected can be utilised across multiple levels including “on the level of the index, the sub-indices, or the actual raw data of individual indicators—to monitor performance over time and to benchmark developments against countries in the same region or income classification” (Cornell University, INSEAD, and WIPO 2018).

***European Innovation Scoreboard (EIS)***

The EIS is an evaluation tool produced annually by the European Commission that aims to measure and compare differences in the strengths of national systems of innovation between EU member states and a selection of Non-EU countries including Iceland, Israel, Macedonia, Norway, Serbia, Switzerland, Turkey and Ukraine (Es-Sadki and Hollanders 2018). The EIS measures innovation across four dimensions: Framework Conditions, Investments, Innovation Activities and Impact – and ten innovation sub-dimensions across twenty-seven indicators (Es-Sadki and Hollanders 2018).

***Human Development Index (HDI)***

The HDI has been produced annually since its launch in 1990. The aim of developing the HDI was to measure human development in a more comprehensive way – moving from measurements based on income toward measurements that includes health and educational indicators. The HDI is a composite indicator focusing on

> “three basic dimensions of human development: the ability to lead a long and healthy life, measured by life expectancy at birth; the ability to acquire knowledge, measured by mean years of schooling and expected years of schooling; and the ability to achieve a decent standard of living, measured by gross national income per capita” (UNDP 2018, p.1).

Over time, other sub-indices were developed to capture different dimensions of human development including Multidimensional Poverty Index (MPI), Inequality adjusted Human Development Index (IHDI) and Gender Inequality Index (GII).

***Multidimensional Poverty Index (MPI)***

The MPI was launched in 2010 by the United Nations Development Programme (UNDP) Human Development Report Office (HDRO) and the Oxford Poverty and

Human Development Initiative (OPHI) at University of Oxford. The objective of the MPI is to measure and evaluate country performance across three key dimensions: health, education and standard of living. The MPI is comprised of 10 indicators and individuals that experience deprivation in at least one third of these weighted indicators fall into the category of multidimensionally poor.

***RAND Impact Index***

The use of multidimensional composite indicators to measure research impact has gained some traction in the last number of years. However, to date none of these indices have been operationalised and as such are not included in Table 7.2. Guthrie et al. (2018) proposed a multidimensional index to measure impacts from research and innovation. The Impact Index aims to conceptualise the broad range of impacts generated through investments in research.

The report highlights the numerous benefits from R&I but suggests that "they are not well measured or, in many cases, not well understood" (Guthrie et al. 2018, iv). The aim of the study was to produce a cross-cutting conceptualisation of the benefits of R&I to facilitate a holistic approach to research evaluation. The Impact Index is presented in Figure 7.1.

**Figure 7.1 RAND Impact Index**

| | Impact on Economy | Commercial Impact | Impact on Policy and services | Impact on Health and wellbeing | Impact on Public engagement | Cultural Impact | Impact on Social Cohesion | Impact on Safety and security | Impact on environment |
|---|---|---|---|---|---|---|---|---|---|
| Aggregate Benefits | | | | | | | | | |
| Benefits to Region | | | | | | | | | |
| Benefits by Sector | | | | | | | | | |
| Benefits for different population groups | | | | | | | | | |
| Benefits over different time periods | | | | | | | | | |

Source: Guthrie et al. (2018, vi)

An important contribution of the framework is the focus on the distribution of benefits across geographies, sectors and population groups, as well as over time. The approach consisted of mapping benefits onto established categories of impact, as well as two characterisations of quality of life from Eurostat (2015) and World Health Organisation (WHO) with the aim of providing a more comprehensive measure of quality of life.

Table 7.3 highlights the main differences between the Impact Index proposed by Guthrie et al. (2018) and the Research Impact Index (RII) presented in this thesis.

**Table 7.3 Differences between RAND Impact Index and RII**

| RAND Impact Index | Research Impact Index (RII) |
|---|---|
| The RAND index captures impact across 10 dimensions including: economic, commercial, public policy, culture, health, societal, education & training, public engagement, safety & security, environment | RII Index more limited in scope: focused on capturing economic impacts but ‘pathway’ approach identifies scientific, technical, human capital impacts as important initial impacts |
| RAND Index remains conceptual in nature | RII Index has been tested using an SFI-funded research centre as a testbed |
| RAND index does not discuss decision-making in constructing index | Transparency in logic and decision-making in construction of index |
| RAND is aimed at impact of innovation and research in general | RII aimed at research centre impact assessment |
| Focused on the UK Research system | Focused on the Irish Research System |
| Quantitative based-approach | Mixed-methods approach |
| Distribution of impact across region, sector, population and time. | Aggregate measure of impact |

Source: Compiled by Author

The next sub-section provides a comparative analysis of methods used in the construction of CIs. The analysis provided guidance when making methodological decisions for the construction of the RII.

### 7.2.1 Comparative Analysis of Methods for Constructing CIs

The construction of CIs is characterised by many pitfalls and challenges which can lead to misinterpretation and misleading policy recommendations. Mazziotta and

Pareto (2013) identify important factors that must be considered when constructing CIs including the types of indicators and aggregation, normalisation approaches, weighting techniques and dealing with outliers. These factors are discussed in more detail below.

*Type of Indicators and Aggregation*

The GII, EIS and MPI utilise compensatory methods i.e. high performance in one indicator may offset poor performance in other indicators. As such, the aggregation of these indices is based on the arithmetic mean. Some decision-making practitioners challenge the use of the arithmetic mean as an aggregation method due to the assumption of perfect substitutability. The GII tested the effect of relaxing the assumption of perfect substitutability by aggregating using geometric averages, which is a partially compensatory method that rewards balanced performance across all pillars. As such, countries are incentivised to improve performance across all pillars not just any pillar (Saisana, Domínguez-Torreiro and Vértesy as cited in Cornell University, INSEAD, and WIPO 2018, p.74). The EIS calculate the overall score by using the unweighted average of the re-scaled scores for all indicators where all indicators receive equal weighting.

The HDI uses the geometric mean rather than an arithmetic mean to calculate the composite index score. The HDI introduced the geometric mean in 2010 to reduce the level of substitutability between indicators and dimensions included in the index. As such, low achievement in one indicator is not compensated by high performance in another indicator. The argument here is that this method is more respectful of the differences across the dimensions than a simple average (UNDP 2018).

*Normalisation*

Normalisation is required prior to any data aggregation as the indicators in a data set often have different measurement units. A discussion on the advantages and limitations of alternative normalisation methods are outlined in Section 7.3. Mazziotta and Pareto (2013, p.72) categorise normalisation methods into two categories ‘absolute’ and ‘relative’.

The most commonly used normalisation method used in the composite indices is the min-max method. The min-max approach provides index scores that fall within the range 0-100, thus making them easily interpretable. However, evaluation practitioners have several approaches to setting the maximum and minimum values of each indicators.

The European Innovation Scoreboards sets the maximum score as the highest value for the indicator over an eight-year period, excluding positive outliers. Similarly, the minimum value is the lowest score found across each country within an eight-year period, excluding negative outliers. The HDI sets the minimum and maximum values of indicators using both available data and expert opinion e.g. the minimum value of life expectancy is set at 20 years and the maximum value is 85 years. The MPI designates each person a deprivation score based on household deprivation across ten indicators. The measures are binary variables i.e. YES or NO answers, thus a counting method is employed which sets 1 as the maximum score 1 and 0 as the minimum score.

*Weightings*

Section 7.3 outlines the diverse weighting methods available to practitioners for constructing CIs. The three broad categories of weighting include i) equal weighting, ii) statistical methods and iii) participatory methods. The choice of weightings is dependent on the objectives of the evaluation, the availability of data and importance of each dimension.

The most commonly used weighting method is equal weighting (EW) adopted by Human Development Index (HDI). The HDI assign equal weighting across the three dimensions (long and healthy life, access to knowledge and a decent standard of living). EW does not indicate that no weighting has been applied but rather makes the implicit assumption that each dimension of a CI shares equal importance. As such, the choice of weighting assumes that each dimension is valued equally by all human beings.

*Outliers*

Knoke, Bohrnstedt, and Mee (2002) define an outlier as “an observed value that is so extreme (either large or small) that it seems to stand apart from the rest of the distribution". Outliers distort the mean, standard deviations and correlation coefficients, which can lead to misinterpretations of results. As such, detection and treatment of outliers is crucial to ensure the robustness and reliability of results. Multiple methods have been developed for identifying outliers in datasets. A common method of identifying outliers is by calculating z-scores for each indicator. The rule of thumb is if the sample size is small (i.e. less than 80 observations), a case is an outlier if the score is two and half times the mean plus two standard deviations (i.e. z-score is $\geq 2.5$).

Table 7.2 highlights the various methods chosen for treating outliers in well-known CIs. The GII adopts a natural log transformation while the MPI and HDI truncating the top 0.5 percentile of the distribution to reduce the influence of extremely high values.

*Missing Values*

Table 7.2 highlights the lack of consensus on the best imputation techniques with each CI adopting a different approach. The EIS and HDI impute missing data using the nearest available years where possible. The GII do not impute missing data, thus missing values are not considered in the sub-index score. However, robustness and sensitivity analysis are conducted by imputing missing data. The MPI adopts a cross-country regression model to impute missing data.

The next section outlines the process of constructing the multidimensional index developed in this thesis to measure and evaluate the economic impact of publicly funded research centres. The Research Impact Index (RII) was developed using the OECD-JRC '10-steps' framework to guide decision-making.

## 7.3 Steps in Constructing CI

The aim of this section is to outline the steps involved in the construction of composite indicators. Section 7.5 discusses how each step was operationalised in the construction of the Research Impact Index (RII). The OECD-JRC '10-steps' framework (European Commission 2008) outlines the 10 steps involved in the construction of a CI. The OCED and the European Commission developed the 'Handbook on Constructing CIs' to provide guidance to policymakers and academics on the construction of CIs (Nardo et al. 2005). Table 7.4 outlines the steps involved in the construction of composite indicators.

**Table 7.4 OECD-JRC's '10 steps' framework to construct CIs**

| Step | Explanation |
|---|---|
| Theoretical framework | Provides the basis for the selection and combination of variables into a meaningful CI under a fitness-for-purpose principle (involvement of experts and stakeholders is important). |
| Data Selection | Should be based on the analytical soundness, measurability, country coverage, and relevance of the indicators to the phenomenon being measured and relationship to each other. The use of proxy variables should be considered when data are scarce (involvement of experts and stakeholders is important). |
| Data treatment | Consists of imputing missing data, (eventually) treating outliers and/or making scale adjustments. |
| Multivariate analysis | Should be used to study the overall structure of the dataset, assess its suitability, and guide subsequent methodological choices (e.g., weighting, aggregation). |
| Normalisation | Should be carried out to render the variables comparable |
| Weighting | Should be done along the lines of the theoretical/conceptual framework |
| Aggregation | Should be done along the lines of the theoretical/conceptual framework |
| Uncertainty and sensitivity analysis | Should be undertaken to assess the robustness of the CI in terms of e.g., the mechanism for including or excluding an indicator, the normalisation scheme, the imputation of missing data, the choice of weights, and the aggregation method. |
| Relation to other indicators | Should be made to correlate the CI (or its dimensions) with existing (simple or composite) indicators as well as to identify linkages through regressions. |
| Visualisation of the results | Should receive proper attention given that it can influence (or help to enhance) interpretability. |

Source: European Commission (2008)

The following section sets out conceptual and methodological considerations that must be considered in the construction of composite indicators.

**Step 1. Theoretical framework**

OECD-JRC's '10 steps' framework identifies a sound theoretical framework as the starting point in constructing CIs. The theoretical framework provides the structure to facilitate informed decision-making throughout each stage of CI construction. The theoretical framework is needed in the selection, weighting and combination of key indicators that make up the CI. However, this process is far from straightforward as "the theoretical underpinning of most CIs is very underdeveloped" (European Commission 2008)

This is particularly relevant for RIA exercises as conceptual and methodological ambiguity means there is no widely accepted definition of research impact. Section 3.4 presents the variety of RIA frameworks developed, each characterised by contrasting objectives, definitions, measurement techniques and impact categories. As such, it is unlikely that there will ever be a one-size-fits all approach to RIA. Therefore, transparency is key to the development of a theoretical framework to capture research impact. The framework should be fit-for-purpose, identifying key stakeholders, dimensions and indicators along the research process from initial idea through to impact while minimising the degree of uncertainty associated with analysis of complex research systems.

**Step 2. Data Selection**

The reliability of CIs is dependent on the quality and robustness of the underlying data. The selection of variables to be included in a composite index should be guided by the theoretical framework and selected on the basis of their "relevance, analytical soundness, timeliness, accessibility" (European Commission 2008). However, there is often a considerable degree of subjectivity in the selection of variables to measure multidimensional concepts such as research impact. Also, research impact evaluation is an emerging field with no commonly accepted grouping of variables available to capture impact. Furthermore, selection of key variables is often constrained by a lack of data availability.

Section 3.2 identified data availability as a key issue in research impact evaluations. Research impact is a complex, non-linear, multidimensional process involving interactions between multiple stakeholders. As such, primary data collection methods such as surveys, interviews and case studies are generally employed in research evaluations studies. In the absence of comparable quantitative data, CIs often include qualitative data from questionnaires or policy documents (European Commission 2008).

Section 6 highlights the importance of ‘softer’ qualitative measures of research centre impact such as the importance of informal communication, contribution of research centre to improved business processes and improvements in businesses ability to identify talent as a result of collaboration with research centre. A significant advantage of using CIs to evaluate research impact is that they allow evaluators to capture these important research centre contributions that are qualitative in nature.

Given that research impact evaluation is an emerging field of study, data collection methods are likely to continue to evolve with the rest of the field. The conceptual challenges associated with the concept of research impact are presented in Section 3.2. This conceptual ambiguity, coupled with limited data availability has contributed to difficulties in selecting robust data comparable across time, space and disciplines.

**Step 3. Multivariate analysis**

Step 3 in constructing CIs relates to multivariate analysis. Multivariate analysis is used to test the underlying structure of the data along several dimensions. The identification, selection and inclusion of variables in a CI is an important decision and should not be taken lightly. Research evaluators and practitioners should use judgement and caution during this selection process as may lead to misleading outcomes and policy recommendations. This environment has been described as being “indicator rich but information poor” (Nardo et al. 2005, p.14).

The construction of CIs requires considerable thought and analysis of the underlying structure of the data and the interrelation between variables. The suitability of the dataset will guide decision making and have implications for methodological choices e.g. aggregation and weighting, during the construction phase of the CI (Nardo et al. 2005, p.14) The three most commonly used techniques to conduct multivariate analysis are (i) Principle Component Analysis (PCA)/ Factor Analysis (FA) (ii) Cronbach’s Coefficient alpha (c-alpha) (iii) Cluster analysis.

### *Principle Component Analysis/ Factor Analysis*

The aim of PCA/ FA is to reduce the overall size of the dataset while maintaining as much information as possible. PCA/FA reduces a large dataset of variables into a small number of underlying variables or *factors* that explain the pattern of correlations within a set of variables (Field 2013). The basic assumption underlying factor analysis is that correlations between many variables can sometimes be explained by a relatively small number of underlying factors.

### *Cronbach's Coefficient Alpha*

Cronbach's alpha is a measure of the 'reliability' or internal consistency of a dataset i.e. how closely related a set of items are as a group (Cronbach 1951). This measure is based on the correlation between individual indicators. As such, a high Cronbach's alpha score indicates that indicators are measuring the same latent variable (European Commission 2008). Cronbach's alpha is calculated by:

$$\alpha = \frac{\mathrm{N} * \bar{\mathrm{C}}}{\bar{\mathrm{V}} + (\mathrm{N} - 1) * \bar{\mathrm{C}}}$$

where, N is equal to the number of items,
$\bar{\mathrm{C}}$ is the average inter-item covariance among the items
$\bar{\mathrm{V}}$ equals the average variance.

However, caution should be taken when interpreting the coefficient of Cronbach's alpha as several commentators have shown that a high value for Cronbach's alpha may be found among variables measuring very different constructs (Cho and Kim 2015).

### *Cluster Analysis*

Cluster analysis (CLA) has been used to group countries based on their similarity across dimensions or sub-dimensions. CLA classifies large quantities of data into manageable sets.

Nardo et al. (2005, p.14) identify four key functions of cluster analysis including:

i) purely statistical method of aggregation of the indicators,
ii) a diagnostic tool for exploring the impact of the methodological choices made during the construction phase of the CI,
iii) a method of disseminating information on the CI without losing that on the dimensions of the sub-indicators, and
iv) a method for selecting groups of countries to impute missing data with a view to decreasing the variance of the imputed values.

Nardo et al. (2005, p.14) warn against "carrying out multivariate analysis if the sample is small compared to the number of indicators since results will not have known statistical properties". Under these circumstances, evaluators may employ expert opinion and correlation analysis to determine the underlying structure of a given dataset. Correlation analysis measures the strength and direction of the relationship between two variables. There are three main measures of correlation depending on the characteristics of the dataset being analysed: (i) Pearson's correlation coefficient (ii) Spearman's correlation coefficient (iii) Kendall's Tao. Pearson's correlation coefficient measures the strength of the relationship between two variables.

Pearson's correlation coefficient is calculated by:

$$r = \frac{(x_i - \bar{x})(y_i - \bar{y})}{(n-1)(s_x s_y)}$$

Pearson's r provides a standardised score ranging from -1 to +1. The strength of the relationship is determined by the value of Pearson's r with value closer to one indicating a stronger relationship between the variables.

Spearman's rank correlation coefficient is the nonparametric alternative to the Pearson correlation coefficient. Spearman's correlation coefficient measures the strength and direction of association between two ranked variables. The assumptions of normal distribution and linearity of relationship between variables which is crucial when calculating Pearson's r may be relaxed when calculating Spearman's rank coefficient.

Spearman's rank is calculated as:

$$r_s = 1 - \frac{6\sum {d_i}^2}{n(n^2-1)}$$

where $d_i$ is the difference between each rank of corresponding values of x and y.

Kendall's Tao is a nonparametric test used to measure the correlation between variables in a small dataset with many tied ranks (Field 2013). Kendall's tau can be calculated as:

$$\tau = \frac{4P}{n(n-1)} - 1$$

where, P is the sum of "concordant pairs" in the two rankings. For the purposes of this thesis, the suitability of each variable included in the Research Impact Index (RII) was assessed based on an extensive literature review, expert opinion and correlation analysis.

**Step 4. Data Imputation**

The fourth step in the OECD-JRC's '10 steps' framework to construct CIs relates to data treatment, consisting of imputing missing data, treating outliers and making scale adjustments. The first stage in treating the data is the imputation of missing values. Missing data, both random and non-random, is a feature of almost all CIs. However, there is often no way of identifying whether data is missing in a random or systematic way. Dempster and Rubin (1983) note

> "the idea of imputation is both seductive and dangerous. It is seductive because it can lull the user into the pleasurable state of believing that the data are complete after all, and it is dangerous because it lumps together situations where the problem is sufficiently minor that it can be legitimately handled in this way and situations where standard estimators applied to real and imputed data have substantial bias"

Table 7.5 highlights the strengths and limitations associated with each method.

**Table 7.5 Data Imputation Techniques**

| Imputation Technique | Description | Strengths | Limitations |
|---|---|---|---|
| Data deletion | Excluding entire records when there are significant levels of missing data. | -no artificially generated data<br>-remaining dataset is complete | - reduced sample size and power<br>- larger standard errors<br>-ignores systematic differences between complete and incomplete samples |
| Mean Substitution | Substituting the mean value of the variable from all available cases. | -sample size is maintained<br>-uncertainty about value of data | - variability in the data is reduced<br>- variance underestimated<br>- magnitude of correlation reduced |
| Regression | using regression techniques based on the values of all available cases to estimate missing values | -preserve distribution shape<br>-may include highly correlated variables<br>-allows higher threshold for missing values | - assumes that the imputed values fall directly on a regression line with a non-zero slope<br>- variances and covariance's are underestimated |
| Multiple imputation | using several sequential regressions with indeterminate outcomes, which are run multiple times and averaged | -Imputation uncertainty is accounted for by creating these multiple datasets.<br>-works well when missing data are MAR<br>-the minimisation of bias | -assumes the data to be missing at random (MAR) |
| Nearest neighbour ('Hot deck) | identifying and substituting the most similar case for the one with a missing value; or | -sample size maintained<br>-replaces the missing data by realistic scores that preserve the variable distribution. | - constrained to only possible values<br>-random component, which adds in some variability<br>-underestimates the standard errors and the variability |
| Ignore them | Ignore missing value and take the average index of the remaining values | -no artificially generated data | -biased estimates in analysis |

Source: Compiled by Author

Data imputation for the purposes of this thesis is less risky as the data generated is only being used to demonstrate the feasibility of the measurement tool and is not considered robust, actual data. However, key decisions must be made on the selection of suitable imputation techniques for large-scale roll out of the RII.

**Step 5. Normalisation**

Normalisation is the process of transforming variables measured at different units, ranges and scales to a common unit of analysis. Normalising allows us to draw comparisons between variables measured at different scales while ensuring we are not comparing "apples and oranges". The selection of the appropriate normalisation technique is not trivial and should be given sufficient consideration. There are many types of normalisation techniques available, while each is illuminating, none are complete.

Firstly, the min-max approach is the most common normalisation method used in the construction of CIs. The popularity of the min-max approach is the relative ease of interpretation of min-max scores. The min-max method produces normalisation scores between 0 and 1 by subtracting the minimum value from the maximum value and dividing by the range of values.

The min-max score is calculated by:

$$\mathrm{min} - \mathrm{max\ score} = \frac{(\mathrm{x} - \mathrm{min})}{(\mathrm{max} - \mathrm{min})}$$

The max value may be set as the maximum value found for the variable within the given dataset or may be set artificially through expert opinion. Practitioners should take caution when using min-max approach to normalise data as extreme values and outliers may distort the transformed data. Alternatively, the min-max approach may widen the range in samples with small variance relative to z-scores.

Secondly, standardisation (or z-scores) is another commonly used normalisation technique. Standardisation converts indicators to a common scale with a mean of zero and standard deviation of one. (European Commission 2008).

The formula for calculating z-scores is:

$$z = \frac{x - \mu}{\sigma}$$

Where μ = mean and σ= standard deviation.

Thirdly, the count method transforms variables with values above/ below the mean. This approach assigns variables with values above the mean a score of 1 and values below the mean a score of 0. The advantages of this approach are its simplicity and that it remains unaffected by outliers. However, the European Commission (2008, p.28) note "arbitrariness of the threshold level and the omission of absolute level information are often criticised"

Fourthly, another normalisation approach is measuring the distance from a reference point. The approach measures the relative position of a given indicator to some reference point. Finally, normalisation approaches using categorical scales have been used for constructing CIs. This approach assigns categories for each indicator. These categories can be numerical, e.g. one, two or three stars, or qualitative, such as 'fully achieved', 'partly achieved' or 'not achieved'.

**Step 6. Weighting**

The weighting assigned to indicators and dimension can have a significant effect on the outcome of benchmarking exercises. The weighting system chosen to weigh individual indicators, according to their importance in measuring and evaluating the phenomenon, is an important consideration when constructing CIs. There is always going to be an arbitrary element to setting weightings and assessing the robustness of the CIs given differences in assigned weightings. Greco et al. (2019, p.61) review methodological issues associated with constructing CIs and suggest "weighting and aggregation are where the paramount criticism appears and where a promising future lies".

Table 7.6 highlights strategies developed by practitioners when developing the most widely used CIs including the easiest (and most common) solution which is to set equal weights to each indicator or alternatively to set 'subjective' weighting based on expert opinion or 'objective' weights based on variability of the indicator. Moreover, European Commission (2019) state “the reader should bear in mind that, no matter which method is used, weights are essentially value judgments and have the property to make explicit the objectives underlying the construction of a composite”.

Table 7.6 highlights various weighting techniques use in the construction of CIs. These techniques may be categorised into three sub-categories: (i) equal weighting (ii) statistical methods and (iii) participatory methods.

**Table 7.6 Weighting Approaches**

| Weighting Category | Method |
|---|---|
| Equal Weighting | Equal weighting (EW) |
| Statistical Methods | PCA/FA |
| | Data envelopment analysis (DEA) |
| | Benefit of the doubt approach (BOD) |
| | Unobserved components model (UCM) |
| Participatory Methods | Budget allocation process (BAP) |
| | Public opinion |
| | Analytic hierarchy process (AHP) |
| | Conjoint analysis (CA) |

Source: Compiled by Author

The most common weighting technique used in constructing CIs is equal weighting. Slottje (1991) calls this an ‘attributes-based’ weighting system. The rationale for applying equal weighting to sub-dimensions or indicators in a composite index may be that each dimension is assigned equal importance in determining the overall composite score or could be the result of a lack of understanding on the relationships between variables, no conceptual or methodological grounds to inform weighting decisions or may be the result of a lack of consensus on alternative solutions. EW does not indicate that no weighting has been applied but rather makes the implicit assumption that each dimension of a CI shares equal importance.

Nardo et al. (2005, p.12) state “weights may also reflect the statistical quality of the data; thus, higher weight could be assigned to statistically reliable data”. However, there is a danger of rewarding easy to measure and readily available indicators, punishing information that is more difficult to access which may also incentivise gaming of the system. Participatory methods assign weights based on the opinion of various key stakeholders including policymakers, experts and citizens.

**Step 7. Aggregation**

The type of indicators chosen are one of the most important factors which affect the aggregation method chosen. Mazziotta and Pareto (2013, p.72-73) identify two types of indicators: substitutable and non-substitutable. The indicators included in a CI are considered 'substitutable' if a deficit in one indicator may be offset by a surplus in another. Contrastingly, if a high value in impact on turnover cannot offset a low value impact on job creation the indicators are considered 'non-substitutable'.

Therefore, aggregation approaches may be considered 'compensatory' or 'non-compensatory' depending on the type of indicators included in the index and sub-indices". Nardo et al. (2005, p.104-105) note "compensability refers to the existence of trade-offs, i.e. the possibility of offsetting a disadvantage on some indicators by a sufficiently large advantage on other indicators". Mazziotta and Pareto (2013, p.72) indicate that aggregation methods based on compensatory approaches are best suited to additive methods, such as arithmetic mean while nonlinear methods, such as geometric mean or multicriteria analysis are more suitable for non-compensatory methods.

**Step 8. Uncertainty and Sensitivity Analysis**

Section 6 highlights the complexities and subjectivity involved in the construction of CIs. The design, construction and outcomes of CIs are determined through several stages in which subjective decisions must be made including the selection of indicators, dealing with missing data, normalisation techniques, dealing with outliers, weightings and aggregation, etc. All these decisions have the potential to alter the outcome and interpretation of CIs which can lead to inefficient outcomes and misleading policy recommendations.

Uncertainty and sensitivity analysis have been identified as important steps to test the overall robustness of the CI results by analysing the effect of alternative decisions-making choices on the final CI score.

The subjectivity associated with CIs is related to the assumptions required during the construction process:

- The selection and inclusion of suitable data to capture complex, multidimensional concepts (e.g. research impact, innovation and organisational capability).
- Dealing with missing data: choices related to data imputation techniques (hot-deck, nearest neighbour, regression analysis)
- Dealing with outliers: choice of transformation techniques
- The choice of normalisation approach (e.g. min-max, standardization, count)
- The choice of weighting approach (e.g. equal weighting, statistical methods, participatory methods)
- The choice of aggregation system (e.g. arithmetic mean, geometric mean, or multi-criteria analysis)

All these decisions influence the results and recommendations conveyed by the CI. As such, evaluators and practitioners must give sufficient time and effort to ensure the results of the CI are analysed and validated through robustness checks. Sensitivity analysis is "the study of how output variation in models such as a CI can be apportioned, qualitatively or quantitatively, to different sources of variation in the assumptions" (Saltelli et al. 2004). A successful application of sensitivity analysis reduces uncertainties associated with CI scores, improves transparency and facilitates more accurate policy recommendations.

Section 6.6.4 demonstrates the range of approaches used to assess the robustness of the Research Impact Index (RII). The section explores the sensitivity of outcomes to changes during the decision-making process. As Nardo et al. (2005, p.13) states "In this way, the CI is no longer a magic number corresponding to crisp data treatment, weighting set or aggregation method, but reflects uncertainty and ambiguity in a more transparent and defensible fashion".

**Step 9. Relation to other indicators**

While CIs measure complex, multidimensional concepts that cannot be measured using any single indicator, they do measure well-known concepts that may be linked to other well-known indicators (European Commission 2008). The relationship between the composite indicator score and related indicators may highlight the predictive power of the composite indicator. However, it should be noted that correlation does not equate to causation. Correlation analysis measures the strength and direction of the relationship between two variables. However, the causality of the relationship between the variables remains unclear.

### 10. Visualisation of Results

Visualisation is an important tool to complement the results of CI. A visual tool may be interpreted more easily by policymakers and the general public and may ensure that the findings of the CI can be communicated more easily. The complexities of CI construction can make interpretation of results difficult however the use of visualisation tools may overcome some of the problems inherent in the interpretation of CI results. Examples include: (i) League tables (ii) Spider charts and (iii) bar charts.

CIs have been widely used in the public sector to create league tables. The public sector has become used to evaluating hospitals, schools, universities, police forces, armies and local authorities in terms of their performance ratings. The use of league tables and rankings are common practice in 'management by numbers' (Hood 2007). League tables rank entities from best to worst based on their CI score.

These tables have significant influence over the reputation of organisations, their ability to generate investments of public funding, attract and retain high quality staff and students. The criticisms of these tables are similar to those aimed at CIs in general. The subjective nature of data selection, normalisation techniques, weighting and aggregation decisions have led to some commentators calling for the abolishment of these ranking tables. The tables are associated with gaming behaviour (Muller 2018), autonomy (Smith, Ward, and House 2011), perverse incentives (Edwards and Roy 2017), and an emphasis on research activities over teaching (Altbach 2006).

## 7.4 Research Impact Index (RII) Development Process

This section outlines the steps involved in the development of the RII. The construction of the RII was guided by the OCED's 'ten-step' framework presented in 7.3. The section presents a discussion on dealing with the key issues facing evaluators in constructing CIs including data selection and imputation, normalisation approaches, aggregation and weighting techniques. Following this, the operationalisation of the RII is presented in Section 7.5.

### 7.4.1 Theoretical framework

The theoretical framework provides the foundation for the selection and combination of variables into a meaningful CI. The development of a novel framework to measure and evaluate the economic impact of publicly funded Research Centres, the **I**mpact **M**easurement and **P**erformance **A**ssessment of **C**entres of **T**echnology and **S**cience (IMPACTS) framework was presented in Chapter 5. The aim of the IMPACTS framework is to measure and evaluate the economic impact of publicly funded research centres. The difficulties in defining and conceptualising research 'impact' have been discussed throughout this thesis. The definition of research centre impact developed in this thesis is "the contribution of research centres, either direct or indirect, short or long term, intentional or unintentional to society and the economy".

The definition of impact adopted by the IMPACTS framework captures both the complex and multidimensional nature of research impact and provides the foundation for the construction of the Research Impact Index (RII). The development of the IMPACTS framework is an important preliminary step in the construction of the RII. The framework provides the theoretical and conceptual foundation for the construction of the RII.

### 7.4.2 Data selection

Selecting data should be based on the "analytical soundness, measurability, firm coverage, and relevance of the indicators to the phenomenon being measured and relationship to each other" (European Commission 2008, p.20). The selection of key performance indicators and metrics was guided by the IMPACTS framework presented in Chapter 5. The framework measures the contribution to the overall innovation system, while simultaneously identifying the strength of the system is an important input and platform for a centre's success.

The development of the two questionnaires used to gather data to construct the RII was previously discussed in Chapter 4. Section 4.1 compares the strengths and limitations of each type of data as this influences the type of analysis that may be conducted using the data. The questions included in the two questionnaires and the rationale for the inclusion of each variable to measure different dimensions along the research process are discussed in Section 6.2.

Table 7.7 and Table 7.8 outline the selection of data used in this thesis to demonstrate the feasibility of the RII. The Tables includes potential metrics to capture data along the research process from initial inputs through to outputs and activities towards outcomes and impacts. Table 7.8 includes potential metrics to capture various dimension of research centre impact. These impact channels include scientific (S), technical (T), human capital (H) and economic (E) impacts.

**Table 7.7 RII Input Sub-Index**

| Research Centre Inputs (50%) | | | | | | | | Business Level Inputs (50%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Funding (50%) | | | | Human Capital (50%) | | | | R&D Investment (50%) | | Human Capital (50%) | |
| € | € | € | € | # | # | # | # | | € | | |
| Exchequer funding | Non-Exchequer funding | In-kind received | Industry cash | PI/FIs | Researchers | Postdocs | PhDs | R&D (% turnover) | RC Contribution | R&D employee (% turnover) | PhD (% total) |
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**Table 7.8 RII Impact Sub-Index**

| Scientific Impacts (25%) | | | | Technical Impacts (25%) | | | | Human Capital Impacts (25%) | | Economic Impacts (25%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # Publications | # Citations | # Conferences | # ERC Awards | # Patents | # Licenses | # Prototypes | # Spin Offs | # PhD Grads (50%) | % Industry first destination (50%) | # Job Creation | € Turnover | € Exports | € R&D Investment | € New Product Sales |
| | | | | | | | | | | | | | | |
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The main criteria for the selection of the metrics included was based on suitability, practicalities and robustness of data. Much of the data included is already gathered by research funding bodies and research centres for their annual reviews. The introduction of new indicators and metrics to capture research impacts and processes would likely result in high non-response rate as gathering the data may be costly and time-consuming. Furthermore, the respondent completing the questionnaire may not have the required information on new data.

Therefore, the selection of data provided by research centres previously for evaluation purposes reduces the likelihood of missing data being an issue as research centres already have much of the data on hand. These metrics should not be considered exhaustive or even best available. Section 5.3 highlights the diversity of metrics available to capture research processes and impacts. The lack of consensus on robust, suitable metrics suggests that the selection of metrics is not a straightforward task. The selection of metrics is complicated by Goodheart's Law which states "when a measure becomes a target, it ceases to be a good measure" (Muller 2018).

Thus, the selection of metrics was guided by practical considerations which would allow us to demonstrate the feasibility of the RII. The metrics selected to measure and evaluate research centre impact require consistent updating and review, in line with best practise in the field. Consultation between key stakeholders within the research sector, including researchers, research centres, funding bodies and government agencies, is required to identify and develop robust metrics to capture research impacts (see Section 8.4 for discussion). This will provide each stakeholder the opportunity to inform the process and allows them to adapt their data gathering systems to ensure required data is collected and reported.

### 7.4.3 Imputing Missing Data

Section 7.4.2 presented a discussion on the selection of metrics included in this study to demonstrate the RII. The selection criteria included practical consideration including identifying robust data that research centres provide for the annual reviews with funding bodies. This ensures data is relevant to research centre impact and reduces the likelihood of missing data. However, it is not possible to eliminate all possibilities of missing data through surveys. Table 7.9 highlights the approaches used to impute missing data for this case study.

**Table 7.9 Imputation Techniques for Missing Data**

| Indicator | Imputation Method |
|---|---|
| Turnover | Data for two companies was sourced from The Irish Time's Top 1000 Company List, an online resource that provides financial information on turnover, assets, profit and employees |
| R&D (% Turnover) | Data for one company was sourced from business annual accounts. The study assumes that R&D investment (% turnover) is the same for the Irish subsidiary as the global business figure. |
| Export Growth | Two companies did not provide figures for export growth but did provide figures for turnover growth. They indicated 100% of turnover was generated through exports thus turnover growth = export growth. |
| Growth in Absence of test centre | Five companies did not provide estimations for growth in absence of test centre |
| R&D Investment 2017 | Calculated as x % turnover in R&D. Calculated as midpoint of range of possible values |

Source: Compiled by Author

The decision-making process used in the formulation of questions included in the industry partner questionnaire was discussed in Section 4.2.2. The final question in the industry partner questionnaire relates to growth rates in the absence of collaboration with the test centre across the economic indicators identified. The question attempts to isolate the influence of collaboration with the research centre on the economic impacts generated by their industry partners. Thus, an estimation of the percentage of growth in each indicator that could be attributed to the relationship with the research centre can be made. However, five companies did not provide figures for business growth in turnover, exports, employment and R&D investment in the absence of the test centre, as shown in Table 7.9.

The choice of imputation technique chosen was influenced by many factors. Firstly, the limited sample size of industry partners included in the study (n=12) prevented certain imputation techniques being utilised due to robustness issues. Data deletion was ruled out as an option as given the small size of the sample we wished to retain as much information as possible. Furthermore, there was an insufficient sample size to perform regression or multiple regression analysis to estimate missing data.

The implementation technique chosen was to conduct a correlation analysis between the economic variables and all other indicators in the sample. shows the results of the correlation analysis to identify the strongest correlations between growth in economic variables and all other variables included in the analysis. Correlation analysis identified potential relationships between variables. The variables with the highest correlation with variable of interest were used to calculate weightings e.g. turnover growth was found to be highly correlated with 'importance of test centre on turnover' (r=0.61), with 'importance test centre on exports' (r=0.65), and with 'importance test centre on market share' (r=0.51).

**Table 7.10 Variables with strongest correlations with growth in economic variables**

| Indicator | Importance weighting | Spearman's r |
|---|---|---|
| Turnover Growth | Importance of RC1 on turnover | 0.61 |
| | Importance of RC1 on exports | 0.65 |
| | Importance RC1 on Profit | 0.5 |
| | Importance RC1 on Market Share | 0.51 |
| Employment Growth | Importance of RC1 on turnover | 0.52 |
| | Importance of RC1 on exports | 0.54 |
| | Importance RC1 on Profit | 0.59 |
| R&D Investment Growth | Importance RC1 on Profit | 0.59 |
| | Importance RC1 on patent, tech, acquisitions | 0.84 |
| | Importance RC1 on scientific capability | 0.63 |

Source: Compiled by Author

Alternative imputation techniques that may be selected for the large scale roll out of the RII which would provide an increased sample size are outlined in Section 7.3. An important consideration in the choice of method is that the one chosen should be applied consistently across all research centres being assessed. Furthermore, if more time had been available a follow-up of nonrespondents may increase the response rate or potentially identify a contact point that may answer the question. The raising of awareness regarding metrics, development of systems of data collection, and the large scale roll out the RII will likely reduce these nonresponse rates as publicly funded research centres become familiar with data requirements of funding bodies for evaluation purposes.

### *Estimating data for Research Centre Comparators*

The RII is a tool to measure and evaluate the economic impact of publicly funded research centres. The aim of developing this tool is to assist policymakers and funding bodies in assessing performance, developing strategy and making funding decisions. Measuring and evaluating research centre performance using the RII requires data on research centre comparators.

In 2017, Indecon consultants were commissioned by Science Foundation Ireland (SFI) to conduct an independent evaluation of SFI's Research Centre Programme. Indecon (2017) focuses on the first seven established SFI research centres covering the period between June 2013 and June 2016. The report provided data for nine indicators included in the RII across seven comparator centres.

Table 7.11 shows the data included in the Indecon report and compares the data to the data gathered through the Research Centre questionnaire and Industry Partner questionnaire developed in this thesis.

**Table 7.11 Comparison of from Primary and Secondary data sources**

| Indicator | Indecon Report | Research Centre Impact Questionnaire | % | Action taken |
|---|---|---|---|---|
| Exchequer funding | €8,700,000 | €6,900,000 | 79% | In order to estimate the exchequer funding for the other six Research Centres the values provided by Indecon was multiplied by 0.79. |
| Non-exchequer funding | €6,400,000 | €6,000,000 | 93.8% | Data obtained though Indecon report was multiplied by 0.938. |
| Number of researchers | 160 | 156 | 97.5% | Data obtained though Indecon report was multiplied by 0.975. |

Source: Compiled by Author

Exchequer funding was calculated by summing together SFI funding and Enterprise Ireland funding. The figure gathered for our test centre from the Research Centre Impact Questionnaire was €6.9 million between 2015 and 2017. The figure provided by Indecon (2017) suggests that RC1's exchequer funding between 2013 and 2015 was €8.7 million. As such, the value generated through the survey is 79% of value provided by report. Therefore, in order to estimate the exchequer funding for the other original six Research Centres the values provided by Indecon was multiplied by 79% to give an estimate for the index.

The figure for non-exchequer funding was supplied by the Indecon report for the initial seven SFI-funded research centres. The IMPACTS questionnaire generated researchers employed for RC1. The figure obtained through the questionnaire was 93.8% of the Indecon Report. As such, data obtained though Indecon report was multiplied by 0.938. The figure for number of researchers employed was supplied by Indecon report for seven originally funded SFI Centres. The IMPACTS questionnaire generated researchers employed for RC1. The figure obtained through the questionnaire was 97.5% of the Indecon Report.

***Data generated through Mean and Standard Deviation***

The Indecon report provided average figures across the seven-research centre for six further variables including number of PhD graduates, number of peer reviewed publications, number of conference publications, number of spin offs, number of ERC awards and number of licenses. These averages combined with a randomly chosen standard deviation allows us to generate a simple random normally distributed dataset.

The test centre provided data for the above variables through the Research Centre Impact Questionnaire. Thus, we can simulate a simple random normally distributed dataset using the mean and standard deviation. Some data was not available in the Indecon report so average figures for some indicators were not available for the seven Research centres. This data was generated randomly to allow us to demonstrate the feasibility of the RII.

The data for research centre comparators generated randomly were:

- Citations (S)
- Prototypes (T)
- Patents filed (T)
- % Staff industry as first destination (H)

The methodologies developed to overcome the ‘attribution problem’ inherent in evaluation studies were outlined in Section 3.3. The methodology used in this study to estimate the portion of overall economic impacts attributable to the research centre has not been used in previous impact assessment studies in Ireland. As such, comparable data for research centre comparators does not exist. Thus, the following data for research centre comparators was generated randomly in order to demonstrate the feasibility of the RII:

- Impact on job creation
- Impact on turnover
- Impact on investment
- Impact on new product sales
- Impact on exporting

Following the imputation of missing data, the next stage in the construction of composite indicators is multivariate analysis.

### 7.4.4 Multivariate Analysis

Multivariate analysis is used to analyse the underlying structure of the data used to construct composite indicators. The small sample size used to test the feasibility and robustness of the IMPACTS framework limits the availability of methodologies such as factor analysis, principle component analysis and cluster analysis. As such, correlation analysis, coupled with a detailed literature review, was conducted to assess the underlying structure of the dataset and impact dimensions. The roll-out of the framework across multiple research centres may present allow evaluators to adopt more advanced statistical techniques.

### 7.4.5 Normalisation

The selection of a suitable normalisation methods is not trivial and deserves special attention (Ebert and Welsch 2004). Different normalisation methods will yield different results. Therefore, RII input sub-index score are constructed using three different normalisation technique to assess the robustness of the results.

Firstly, normalisation scores were calculated using the min-max approach. The min-max approach provides easily interpretable scores (rather than z-scores) that capture the size of deviations (rather than count method) between research centres. Secondly, normalisation scores were calculated using the standardisation approach. This method was not selected as a normalisation approach as poor performing research centres receive a negative score which is problematic when attempting to calculate efficiency scores as a negative score in both the RII Input Sub-Index and RII Impact Sub-Index would lead to positive efficiency ratio, as a negative number divided by a negative number equals a positive number.

Finally, normalisation scores are calculated using a count approach with the research centre receiving a score of one if above the average for an indicator or metric and receives a 0 if below the average. The issue with the counting approach is associated with the significant loss in variance as a result of the counting method. As such, the normalisation method selected for the construction of the RII is the min-max approach. The min-max approach provides easily interpretable scores (rather than z-scores) that capture the size of deviations (rather than count method) between research centres.

### 7.4.6 Weighting

The weighting assigned to indicators and dimensions can have a significant effect on the outcome of benchmarking exercises. The weighting system chosen to weigh individual indicators, according to their importance in measuring and evaluating the phenomenon, is an important consideration when constructing CIs. The aggregation of RII Input Sub-Index Scores and RII Impact Sub-Index Scores derived from research centre and industry partner data is complicated, and entails making many choices related to the weighting of different activities.

To demonstrate the feasibility of the RII, equal weightings were assigned to each metric. This indicates that each metric included in the RII is considered equally important. This assumption does not hold in the real world as research centres and funding bodies have a diverse range of objectives and goals based on the nature of research, technological readiness levels, number of industry partners and types of funding received. These factors have a considerable effect on the importance that researchers and research centres give to each input, output, outcome and impact.

Section 4.3 highlighted the findings of a thematic analysis of the meanings and conceptualisations of research impact across the research sector in Ireland. The findings suggest that there is a perceived overemphasis on economic impacts by funding bodies which skews research centre activities towards achieving these impacts at the expense of impacts related to scientific excellence, capacity building or developing human capital. As one respondent noted

> "*Screw your Nature papers, Science papers, Nobel prizes, to hell with that. The number one thing, or else we aren't going to get funded, or we're in trouble, is going to be this ability to bring in industry money. That is the tone that is set*" (R10, General Manager).

The RII is a flexible tool which allows research centres and funding bodies to adjust weightings based on several factors including the mission of the research centre, objectives of funding body, research discipline, and importance of individual impact metrics. Therefore, the weighting scheme selected will be influenced by the rationale for research impact assessment. Guthrie et al. (2013) identify four rationales for conducting research impact assessment: accountability, analysis, advocacy, and allocation. Table 7.12 highlights alternative weighting schemes that may be applied to the RII depending on the rationale for assessment.

**Table 7.12 Weighting Schemes for RII**

| Rationale | Weighting Scheme | Details |
|---|---|---|
| Accountability | Budget Allocation | Weightings assigned based on contextual factors associated with research centre |
| Advocacy | Budget Allocation | Weightings assigned based on contextual factors associated with research centre |
| Allocation | Budget Allocation | Weightings assigned based on mission of funding agency |
| Analysis | Equal weighting | Equal weighting assigned across all indicators and metrics. |

Source: Compiled by Author

The Research Impact Index (RII) is designed as a flexible assessment tool that may be applied across a large number of research centres for a number of different purposes. Firstly, policymakers, funding bodies and research centres conducting research impact assessment for the purposes of accountability and/or advocacy should consider assigning weightings based on contextual factors influencing each centre. The Irish research landscape is populated by diverse research centres with different aims, structures, and governance. The ability of research centres to deliver impacts is dependent on several factors including the age of the centre, research mission, research discipline, life cycle of technology and Technological Readiness Levels (TRLs).

Given the time it takes for an idea to be developed into a concept, that concept to be developed into a technology, the technology licensed to a company, tested developed into a product and finally brought to market and sold, it is not feasible for research centres to deliver these types of impacts in the short term. As such, funding bodies and evaluators need to assign heavier weightings to shorter-term impacts, such as scientific and technical impacts more heavily in earlier stages of evaluation. These impacts act as a signal of potential longer-term impact in the future.

Secondly, research impact assessment exercises conducted for the purposes of informing decision-making in the allocation of research funding should utilise budget allocation approach. Under this approach, each impact indicator and metrics is assigned a weighting based on its importance to the overall mission of the funding body, programme and/or funding scheme. Policymakers and funding bodies have diverse objectives when designing, implementing, and investing in funding programmes. Therefore, under these conditions, evaluators may weight metrics aligned with the funding scheme more heavily. Uncertainty and sensitivity analysis, presented in Section 7.5.5, illustrates how this approach may be applied in practice using an example of changing of weighting in funding decisions during a financial crisis.

Thirdly, research impact assessment exercises conducted for the purposes of analysis may utilise equal weighting, similar to the approach in the thesis. The aim of the approach is personal and organisational learning rather than informing investment decisions. As such, this approach is useful for identifying the strengths and weaknesses of the research centre compared with national and international competitors.

Therefore, this approach will be useful for supporting the planning, management, and learning processes of a research project, programme, or grant portfolio.

### 7.4.7 Aggregating indicators

Mazziotta and Pareto (2013, p.72-73) identify two types of indicators: substitutable and non-substitutable. Substitutable indicators allow for a deficit in one indicator to be offset by a surplus in another, while non-substitutable indicators do not allow the performance in one indicator to compensate for the performance of another e.g. strong performance in job creation may not compensate for poor performance in value of turnover generated. The RII adopts a 'substitutable' approach as the measurement tool recognises that research impact assessment is not a 'one-size-fit-all' approach. Research centres should not be expected to perform equally well across each indicator, rather research centres performance is influenced by several context specific factors such as nature of research activities, technological readiness levels (TRLs), life cycle of the research process and initial objects of research projects. The next section highlights the process of operationalising the RII.

## 7.5 Operationalising the Research Impact Index (RII)

To compute the RII, the measurement framework distinguishes 27 individual metrics, which are classified into three types (and eight dimensions): Research centre inputs (human resources, finance and support); firm-level inputs (human resources, R&D investments), and impacts (scientific, technical, human capital and economic impacts). The RII measures and compares the impacts generated by research centres through four composite indices:

(i) The RII input sub-index (RC, industry, system)
(ii) The RII impact sub-index (Scientific, Technical, Human Capital, Economic).
(iii) The overall RII score; and
(iv) The impact-efficiency ratio (IER).

The RII is divided into two sub-indices: input sub-indices and impacts sub-indices. The input sub-indices measure the strength of overall inputs relative to comparator research centres. The impacts sub-index measures the strength of impacts delivered by the centre relative to national and international comparators.

### 7.5.1 Calculating RII input sub-index

The data gathered through the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire is used to populate the RII input sub-index. The RII input sub-index is comprised of inputs across three different entities: research centre, industry partners and the research system. The IMPACTS framework identifies research funding and human resources as important inputs into the research process that leads to the generation of research impacts. **.**

Table 7.13 outlines the metrics identified to capture these dimensions. RC1 is our test centre and all data gathered for this centre was obtained through the research centre questionnaire and industry partner questionnaire. The data for the comparator centres was generated through the steps outlined in Section 7.4.3. As such, figures for research centre comparators are simulated in order to demonstrate how the RII may be operationalised by practitioners, policymakers and funding bodies to inform decisions, optimise performance and allocate resources efficiently.

**Table 7.13 RII Inputs Sub-Index: Research Centre inputs**

| | **Funding** | | | | **Human Capital** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Exchequer funding** | **In-kind received** | **Industry cash** | **Non-exchequer funding** | **PIs** | **Researchers** | **Postdocs** | **PhDs** |
| RC1 | 6,900,000 | 2,000,000 | 1,500,000 | 6,000,000 | 16 | 8 | 51 | 75 |
| RC2 | 10,231,034 | 5,444,444 | 3,468,750 | 20,062,500 | 19 | 8 | 20 | 33 |
| RC3 | 12,293,103 | 2,222,222 | 6,000,000 | 4,406,250 | 29 | 33 | 99 | 91 |
| RC4 | 4,044,828 | 1,444,444 | 1,125,000 | 4,312,500 | 34 | 12 | 2 | 21 |
| RC5 | 22,127,586 | 3,111,111 | 2,437,500 | 14,718,750 | 47 | 19 | 52 | 149 |
| RC6 | 7,058,621 | 2,333,333 | 1,125,000 | 7,312,500 | 36 | 22 | 60 | 75 |
| RC7 | 9,834,483 | 4,222,222 | 2,156,250 | 6,562,500 | 24 | 2 | 17 | 27 |

Source: Compiled by Author

Table 7.14 provides descriptive statistics for the seven-research centre included in the analysis.

**Table 7.14 Descriptive Statistics for RII Inputs Sub-Index: Research Centre inputs**

| | Funding | | | | Human Capital | | | |
|---|---|---|---|---|---|---|---|---|
| | Exchequer funding | In-kind received | Industry cash | Non-exchequer funding | PIs | Researchers | Postdocs | PhDs |
| Min | 4,044,828 | 1,444,444 | 1,125,000 | 4,312,500 | 16 | 2 | 2 | 21 |
| Max | 22,127,586 | 5,444,444 | 6,000,000 | 20,062,500 | 47 | 33 | 99 | 149 |
| Mean | 10,355,665 | 2,968,254 | 2,544,643 | 9,053,571 | 29 | 15 | 43 | 67 |
| SD | 5,848,899 | 1,410,884 | 1,735,792 | 5998988 | 10 | 10.53 | 32.8 | 45.28 |

Source: Compiled by Author

The mean funding generated across the seven research centres is €19,409,236. On average, 46% of funding was generated through non-exchequer sources of which 16% was from industry partners. The average centre had 164 employees with the largest centre employing 359 employees and the smallest centre employing 47 employees. Following data collection and imputing missing values, the next step in constructing CI is normalising the data. Normalisation is a necessary step in index construction as it allows for the comparison of data measured at different units. Section 7.3 highlights the variety of normalisation methods available in the literature. Different normalisation methods will yield different results. Therefore, RII input sub-index score are constructed using three different normalisation technique to assess the robustness of the results.

Table 7.15 shows the normalised input data for the seven research centres. The data was normalised into scores between 0 and 1, with a score of 1 indicating that the research centre is the best performing centre across that particular indicator e.g. Table 7.15 shows that RC5 has a min-max score of 1 for exchequer funding. This indicates that RC5 has generated the most exchequer funding of all research centres included in the analysis and comparators centres scores are calculated as a percentage of the max score e.g. the min-max score for RC1 is 0.16. This means that RC1 has generated 16% of total funding generated by the highest performing research centre.

**Table 7.15 Normalising RII Inputs Sub-Index: Research Centre inputs data**

| | Exchequer funding | In-kind received | Industry cash | Non-exchequer funding | PIs | Researchers | Postdoc | PhD |
|---|---|---|---|---|---|---|---|---|
| RC1 | 0.16 | 0.14 | 0.08 | 0.11 | 0.00 | 0.19 | 0.51 | 0.42 |
| RC2 | 0.34 | 1.00 | 0.48 | 1.00 | 0.10 | 0.19 | 0.19 | 0.09 |
| RC3 | 0.46 | 0.19 | 1.00 | 0.01 | 0.42 | 1.00 | 1.00 | 0.55 |
| RC4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.58 | 0.32 | 0.00 | 0.00 |
| RC5 | 1.00 | 0.42 | 0.27 | 0.66 | 1.00 | 0.55 | 0.52 | 1.00 |
| RC6 | 0.17 | 0.22 | 0.00 | 0.19 | 0.65 | 0.65 | 0.60 | 0.42 |
| RC7 | 0.32 | 0.69 | 0.21 | 0.14 | 0.26 | 0.00 | 0.15 | 0.05 |

Source: Compiled by Author

The next step in constructing RII input sub-index is to apply weightings to the data. The choice of weighting has a significant effect on the overall composition of an index. The weighting method is essentially a value judgement based on the perceived importance of an individual indicator or dimension. The weighting method chosen for the RII is based on expert opinion as the weight designated to an indicator or impact dimension will be dependent on the objectives of the funding body, the research activities of the research centre and ex-ante expected outcomes and impacts.

Table 7.16 shows the normalised scores for each once the weighting has been applied. For the purposes of operationalising the RII, equal weighting has been designated to each indicator within each dimension of impact e.g. the four indicators included under funding each receive a weighting of 0.25 (1/4=0.25) while the two indicators included under human capital each receive a weighting of 0.5 (1/2=0.5).

The budget allocation approach provides experts with a “budget” of N points, to be spread across several sub-indicators. The distribution of points is highly correlated with how important each sub-indicator is perceived by experts. The budget allocation is optimal for a maximum of 10-12 indicators. If too many indicators are involved, this method makes allocation decisions much more difficult.

**Table 7.16 Weighting RII Inputs Sub-Index: Research Centre inputs data**

| | Funding | | | | Human Capital | | | |
|---|---|---|---|---|---|---|---|---|
| | Exchequer funding | In-kind received | Industry cash | Non-exchequer funding | PIs | Researchers | Postdoc | PhD |
| RC1 | 0.04 | 0.03 | 0.02 | 0.03 | 0.00 | 0.05 | 0.13 | 0.11 |
| RC2 | 0.09 | 0.25 | 0.12 | 0.25 | 0.02 | 0.05 | 0.05 | 0.02 |
| RC3 | 0.11 | 0.05 | 0.25 | 0.00 | 0.10 | 0.25 | 0.25 | 0.14 |
| RC4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.08 | 0.00 | 0.00 |
| RC5 | 0.25 | 0.10 | 0.07 | 0.17 | 0.25 | 0.14 | 0.13 | 0.25 |
| RC6 | 0.04 | 0.06 | 0.00 | 0.05 | 0.16 | 0.16 | 0.15 | 0.11 |
| RC7 | 0.08 | 0.17 | 0.05 | 0.04 | 0.06 | 0.00 | 0.04 | 0.01 |

Source: Compiled by Author

The next step in constructing RII input sub-index score involves weighting each dimension included in the sub-index (i.e. funding and human capital). Again, participatory methods using various stakeholders may be used to assign weights. The decision may be influenced by the perceived importance of a dimension depending on the strategic objectives, policy priorities or theoretical factors.

Table 7.17 shows the results of the process of calculating RII input sub-index scores. Again, it is assumed for the purposes of operationalising the RII that each dimension is weighted equally. This may not always be the case as stakeholders may perceive some dimension of greater importance than another dimension and thus this dimension will be assigned a heavier weighting. Section 7.4.6 illustrates the effect of changes in weighting has on the construction of the RII.

**Table 7.17 Calculating RII Inputs Sub-Index Score: Research Centre inputs**

| | Funding | Human Capital | Score |
|---|---|---|---|
| RC1 | 0.12 | 0.28 | 20 |
| RC2 | 0.71 | 0.14 | 42 |
| RC3 | 0.41 | 0.74 | 58 |
| RC4 | 0.00 | 0.23 | 11 |
| RC5 | 0.59 | 0.77 | 68 |
| RC6 | 0.14 | 0.58 | 36 |
| RC7 | 0.34 | 0.11 | 23 |

Source: Compiled by Author

The scores of individual dimensions e.g. funding and human capital are calculated as the sum of the weighted normalised values of individual indicators shown in

The overall RII input sub-index score is calculated as:

$$[\text{Dimension}_A\text{*weight}_A + \text{Dimension}_B\text{*weight}_B + \ldots\ \text{Dimension}_N\text{*weight}_N]$$

In this instance, the RII input sub-index is calculated as:

$$[\text{Funding*}0.5 + \text{HumanCapital*}0.5]\text{*}100$$

Table 7.18 ranks each research centre by their RII research centre input sub-index score.

**Table 7.18 RII Inputs Sub-Index Score: Research Centre inputs**

| | **RII Input sub-index scores** | **Rank** |
|---|---|---|
| RC5 | 68 | 1 |
| RC3 | 58 | 2 |
| RC2 | 42 | 3 |
| RC6 | 36 | 4 |
| RC7 | 23 | 5 |
| RC1 | 20 | 6 |
| RC4 | 11 | 7 |

Source: Compiled by Author

The RII inputs sub-index score illustrates the strength of the resources available to the research centre to generate research impact. The RII research centre sub-index score does not explicitly illustrate the performance of the centre, although the ability to generate funding, particularly leveraged industry funding is considered key performance indicators (KPIs) across research centres in Ireland. However, research centres with lower RII sub-index scores should not be considered poor performing centres as centres with fewer resources that deliver significant research impacts may be considered more efficient and cost effective relative to national and international comparators. This is one of the main rationales for the inclusion of the RII Efficiency Ratios in Section 7.5.4.

**RII Inputs sub-index: Industry Partner inputs**

The second dimension of the RII input sub-index is industry partner inputs. The IMPACTS framework outlined in Section 5.3 adopts a systems perspective to measure and evaluate the economic impacts of publicly funded research centres. This perspective asserts that research centres do not deliver impacts in isolation but rather the magnitude of the impact will be influenced by the innovative capacity of industry partners and the strength of the innovation system which the centre is embedded within. As such, the potential absorptive capacity of industry partners influences the impact capacity of research centres. The RII industry partners sub-index is calculated in the same way as RII research centre input sub-index so I will only briefly detail the process.

**Table 7.19 RII Inputs Sub-Index: Industry Partner inputs**

| | **R&D** | | **Human Capital** | |
|---|---|---|---|---|
| | **R&D Intensity (Inv/Turn)** | **RC contribution** | **PhD (% Total)** | **R&D emp (% total)** |
| RC1 | 39 | 40,800 | 46 | 67 |
| RC2 | 55 | 94,350 | 56 | 73 |
| RC3 | 45 | 163,200 | 52 | 70 |
| RC4 | 32 | 30,600 | 38 | 59 |
| RC5 | 42 | 66,300 | 60 | 49 |
| RC6 | 30 | 30,600 | 35 | 40 |
| RC7 | 34 | 58,650 | 40 | 42 |

Source: Compiled by Author

The RII industry sub-index is composed of two dimensions: (i) financing and (ii) human capital. For the purposes of demonstrating the feasibility of the index, the dimensions are each assigned equal weighting. Furthermore, each indicator within the index is assigned equal weighting

**Table 7.20 Descriptive Statistics for RII Inputs Sub-Index: Industry Partner inputs**

| | R&D | | Human Capital | |
|---|---|---|---|---|
| | **R&D Intensity (Inv/Turn)** | **RC contribution** | **PhD (% Total)** | **R&D emp (% total)** |
| MIN | 30 | 30,600 | 35 | 40 |
| MAX | 55 | 163,200 | 60 | 73 |
| MEAN | 40 | 69,214 | 47 | 57 |
| SD | 9 | 47,214 | 10 | 14 |

Source: Compiled by Author

The next step in constructing the industry partner sub-index is data normalisation. The data is normalised using the min-max technique. The min and max values are determined from the available data e.g. research centre's with average industry partner R&D intensity is assigned a score of one and the normalisation score of comparator centres is calculated using this figure as the reference point. For example, Table 7.20 shows that the industry partners of RC2 have the highest R&D intensity. The average R&D investment as a percentage of turnover for these companies is 55%. Therefore, RC2's receives a score of one for industry partner R&D investment. RC6's industry partners have the lowest R&D intensity. The R&D intensity of these companies are 30%. Therefore, RC6 receives a score of 0.

Table **7.21** 7.21 shows the min-max scores for research centre's industry partner's absorptive capacity.

**Table 7.21 Normalising data for RII Inputs Sub-Index: Industry Partner input**

| | R&D Investment | | Human Capital | |
|---|---|---|---|---|
| | **R&D Intensity (Inv/Turn)** | **RC contribution** | **PhD (% Total)** | **R&D emp (% total)** |
| RC1 | 0.35 | 0.08 | 0.46 | 0.80 |
| RC2 | 1.00 | 0.48 | 0.84 | 1.00 |
| RC3 | 0.60 | 1.00 | 0.68 | 0.91 |
| RC4 | 0.08 | 0.00 | 0.12 | 0.58 |
| RC5 | 0.48 | 0.27 | 1.00 | 0.27 |
| RC6 | 0.00 | 0.00 | 0.00 | 0.00 |
| RC7 | 0.16 | 0.21 | 0.20 | 0.06 |

Source: Compiled by Author

The next step in constructing the industry partner input sub-index is weighting the data. The industry partner input sub-index is composed of two dimensions.

The industry partner sub-index score is calculated by:

$$[Dimension_A*weight_A + Dimension_B*weight_B +\dots Dimension_N*weight_N]$$

In this instance, the industry partner input sub-index is calculated as:

$$[Funding*0.5 + HumanCapital*0.5] *100$$

These two dimensions are composed of five indicators. The financing dimension is composed of three indicators: R&D intensity, research centre contribution and whether the business has their own R&D department. The human capital dimension is comprised of two indicators: employees engaged in R&D as a percentage of total employees and percentage of staff that have PhD as their highest level of education.

To demonstrate the feasibility of the RII, each indicator is weighted equally. This may not be the case as evaluators and funding bodies may place greater significance on an indicator and this indicator would receive a greater weighting. The sum of all weightings within a dimension should equal 1.

**Table 7.22 Weighting data for RII Inputs Sub-Index: Industry Partner input**

| | **R&D Intensity (Inv/Turn)** | **RC contribution** | **PhD (% Total)** | **R&D emp (% total)** |
|---|---|---|---|---|
| **RC1** | 0.09 | 0.02 | 0.11 | 0.20 |
| **RC2** | 0.25 | 0.12 | 0.21 | 0.25 |
| **RC3** | 0.15 | 0.25 | 0.17 | 0.23 |
| **RC4** | 0.02 | 0.00 | 0.03 | 0.14 |
| **RC5** | 0.12 | 0.07 | 0.25 | 0.07 |
| **RC6** | 0.00 | 0.00 | 0.00 | 0.00 |
| **RC7** | 0.04 | 0.05 | 0.05 | 0.02 |

Source: Author’s Own

Table 7.23 shows the industry partner input sub-index scores for the seven research centres. Given that each dimension of the sub-index is weighted equally, the industry partner sub-index score is calculated as an average of the financial dimension score and the human capital dimension score.

**Table 7.23 Calculating RII Inputs sub-index: Industry Partner inputs**

| | R&D | Human Capital | RII Industry Partner Sub-Index Score |
|---|---|---|---|
| RC1 | 11 | 32 | 42 |
| RC2 | 37 | 46 | 83 |
| RC3 | 40 | 40 | 80 |
| RC4 | 2 | 17 | 19 |
| RC5 | 19 | 32 | 51 |
| RC6 | 0 | 0 | 0 |
| RC7 | 9 | 7 | 16 |

Source: Compiled by Author

Table 7.24 shows the research centre ranked by the potential absorptive capacity of industry partners from highest to lowest. The IMPACTS framework identifies the absorptive capacity of industry partners are important factor in impact capacity of a research centre.

**Table 7.24 Ranking RII Inputs sub-index score: Industry Partner inputs**

| | RII Industry Partner Sub-Index Score | Rank |
|---|---|---|
| RC2 | 83 | 1 |
| RC3 | 80 | 2 |
| RC5 | 51 | 3 |
| RC1 | 42 | 4 |
| RC4 | 19 | 5 |
| RC7 | 16 | 6 |
| RC6 | 0 | 7 |

Source: Compiled by Author

Table 7.24 shows that RC2's industry partners have the highest potential absorptive capacity. Therefore, this increases the impact capacity of RC2 relative to research centres collaborating with industry partners with weaker absorptive capacity.

### 7.5.2 Calculating RII impact sub-index

The previous sub-section outlined the process of calculating the RII input sub-index. The next step in operationalising the RII is to calculate the RII Impact sub-index. The RII impact sub-index is composed of four dimensions and 16 indicators. The four dimensions of the RII Impacts sub-index are scientific impacts, technical impacts, investment impacts and economic impacts. Section 7.5.1 outlined the process of calculating the RII Inputs sub-index. The RII Impacts sub-index is calculated using the same process. Therefore, the process will only be discussed briefly.

Table 7.25 shows the normalised data. The data was normalised using the min-max method. This is to ensure comparability with the RII inputs sub-index.  Table 7.26 shows the weighted data.  For the purposes of operationalising the RII Impacts sub-index, each individual indicator is given an equal weighting.

## Table 7.25 Normalising data for RII impact sub-index

| | Scientific Impact (25%) | | | | Technical Impact (25%) | | | | Human Capital (25%) | | Economic Impacts (25%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Publications** | **Citations** | **Conferences** | **ERC Awards** | **Patents** | **Licenses** | **Prototype Dev.** | **Spin Offs** | **Industry as first destination** | **PhD Graduates** | **Job Creation** | **Turnover** | **New product Sales** | **Exports** | **R&D Investment** |
| **RC1** | 0.33 | 0.44 | 0.40 | 0.00 | 0.03 | 0.66 | 1.00 | 0.15 | 0.68 | 1.00 | 0.31 | 0.13 | 0.40 | 0.64 | 0.44 |
| **RC2** | 0.37 | 0.68 | 0.90 | 0.95 | 1.00 | 1.00 | 0.73 | 0.20 | 1.00 | 0.79 | 0.00 | 0.70 | 0.38 | 1.00 | 0.31 |
| **RC3** | 0.65 | 0.45 | 0.00 | 0.65 | 0.79 | 0.84 | 0.18 | 0.51 | 0.09 | 0.38 | 0.43 | 0.00 | 1.00 | 0.43 | 0.52 |
| **RC4** | 0.93 | 0.84 | 0.59 | 1.00 | 0.00 | 0.00 | 0.00 | 0.41 | 0.00 | 0.85 | 0.46 | 1.00 | 0.39 | 0.00 | 0.25 |
| **RC5** | 1.00 | 1.00 | 1.00 | 0.60 | 0.14 | 0.86 | 0.27 | 0.45 | 0.14 | 0.83 | 0.87 | 0.23 | 0.27 | 0.63 | 0.00 |
| **RC6** | 0.44 | 0.31 | 0.50 | 0.36 | 0.02 | 0.41 | 0.22 | 1.00 | 0.20 | 0.77 | 0.28 | 0.17 | 0.00 | 0.98 | 1.00 |
| **RC7** | 0.51 | 0.61 | 0.14 | 0.27 | 0.31 | 0.35 | 0.13 | 0.00 | 0.62 | 0.00 | 1.00 | 0.12 | 0.15 | 0.63 | 0.09 |

## Table 7.26 Weighting data for RII impact sub-index

| | Scientific Impact (25%) | | | | Technical Impact (25%) | | | | Human Capital (25%) | | Economic Impacts (25%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Publications** | **Citations** | **Conferences** | **ERC Awards** | **Patents** | **Licenses** | **Prototype Dev.** | **Spin Offs** | **Industry as first destination** | **PhD Graduates** | **Job Creation** | **Turnover** | **New product Sales** | **Exports** | **R&D Investment** |
| **RC1** | 0.08 | 0.11 | 0.10 | 0.00 | 0.01 | 0.17 | 0.25 | 0.04 | 0.34 | 0.50 | 0.06 | 0.03 | 0.08 | 0.13 | 0.09 |
| **RC2** | 0.09 | 0.17 | 0.22 | 0.24 | 0.25 | 0.25 | 0.18 | 0.05 | 0.50 | 0.39 | 0.00 | 0.14 | 0.08 | 0.20 | 0.06 |
| **RC3** | 0.16 | 0.11 | 0.00 | 0.16 | 0.20 | 0.21 | 0.05 | 0.13 | 0.05 | 0.19 | 0.09 | 0.00 | 0.20 | 0.09 | 0.10 |
| **RC4** | 0.23 | 0.21 | 0.15 | 0.25 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.42 | 0.09 | 0.20 | 0.08 | 0.00 | 0.05 |
| **RC5** | 0.25 | 0.25 | 0.25 | 0.15 | 0.03 | 0.22 | 0.07 | 0.11 | 0.07 | 0.41 | 0.17 | 0.05 | 0.05 | 0.13 | 0.00 |
| **RC6** | 0.11 | 0.08 | 0.13 | 0.09 | 0.01 | 0.10 | 0.05 | 0.25 | 0.10 | 0.39 | 0.06 | 0.03 | 0.00 | 0.20 | 0.20 |
| **RC7** | 0.13 | 0.15 | 0.04 | 0.07 | 0.08 | 0.09 | 0.03 | 0.00 | 0.31 | 0.00 | 0.20 | 0.02 | 0.03 | 0.13 | 0.02 |

Table 7.27 shows the RII Impacts sub-index score for the seven research centres.

**Table 7.27 Calculating RII Impacts Sub-Index Score**

| | Scientific Impact | Technical Impact | Human Capital impact | Economic Impact | IMPACTS Sub-Index Score |
|---|---|---|---|---|---|
| **RC1** | 29 | 46 | 84 | 38 | 49 |
| **RC2** | 73 | 73 | 89 | 48 | 71 |
| **RC3** | 44 | 58 | 24 | 48 | 43 |
| **RC4** | 84 | 10 | 42 | 42 | 45 |
| **RC5** | 90 | 43 | 48 | 40 | 55 |
| **RC6** | 40 | 41 | 49 | 49 | 45 |
| **RC7** | 38 | 20 | 31 | 40 | 32 |

Source: Compiled by Author

Table 7.28 shows the seven research centres ranked by their RII sub-index score. The RII impacts sub-index is rated on a scale from 0 to 100. The RII Impacts sub-index score is calculated as the sum of the weighted scores across each dimension of impact.

**Table 7.28 RII impact sub-index score**

| | RII impact sub-index score | Rank |
|---|---|---|
| **RC2** | 71 | 1 |
| **RC5** | 55 | 2 |
| **RC1** | 49 | 3 |
| **RC4** | 45 | 4 |
| **RC6** | 45 | 5 |
| **RC3** | 35 | 6 |
| **RC7** | 32 | 7 |

Source: Compiled by Author

The next sub-section looks at the steps involved in calculating the Overall RII Input Score.

### 7.5.3 Overall RII Input Score

The Overall RII input score is calculated as the average of research centre sub-index score and the industry partner sub-index score.

**Table 7.29 Overall RII Input Score**

| Min-Max | RC Input Score | Firm Input Score | Overall Input Score |
|---|---|---|---|
| RC3 | 58 | 80 | 69 |
| RC2 | 42 | 83 | 63 |
| RC5 | 68 | 51 | 59 |
| RC1 | 20 | 42 | 31 |
| RC7 | 23 | 16 | 19 |
| RC6 | 36 | 0 | 18 |
| RC4 | 11 | 19 | 15 |

Source: Compiled by Author

The results indicate the RC3 has the highest RII Overall Input score. This suggests that RC3 has the highest impact capacity of all research centres included in the study. RC4 has the lowest RII Input Score which suggests that this research centre has the lowest impact capacity of all research centres included in the study.

Table 7.30 shows the calculation for the Overall RII Score. The Overall RII Score is calculated as the average of RII inputs sub-index score and RII impacts sub-index score.

**Table 7.30 Overall RII Score**

| Min-max | Overall Score i.e. average RC input and impact | Overall Score i.e. average overall input and impact |
|---|---|---|
| RC2 | 57 | 67 |
| RC3 | 50 | 56 |
| RC4 | 28 | 30 |
| RC5 | 61 | 57 |
| RC1 | 35 | 40 |
| RC6 | 41 | 32 |
| RC7 | 27 | 26 |

Source: Compiled by Author

The Overall RII Score may be calculated using both the RII research centre sub-input score and the RII overall sub-input score which includes the innovative capacity of the research centre's industry partners.

### 7.5.4 RII Efficiency Ratio

The Impact Efficiency Ratio is calculated as the ratio of inputs to impacts. The magnitude of impact generated by research centres is dependent on several factors including research centre inputs. The assumption underlying the RII Efficiency Ratios is that research centres with higher RII input sub-index scores have a higher capacity to generate RII impacts sub-index scores. For example, two research centres submit grant applications for a new stream of research funding. Both applications demonstrate similar levels of impacts generated. However, research centre A has received half the level of investment as research centre B. As such, although the impacts generated are the same, research centre A is twice as efficient as research centre B ('more bang for your buck').

Table 7.31 shows the RII Efficiency Ratio scores for the seven centres included in the study. The scores may be generated using both research centre inputs and overall inputs, which includes the innovative capacity of industry partners.

**Table 7.31 RII Efficiency Ratios**

| | Efficiency Ratio RC Inputs: IMPACTS | Efficiency Ratio of Overall Inputs: IMPACTS |
|---|---|---|
| RC4 | 3.99 | 2.93 |
| RC6 | 1.25 | 2.49 |
| RC7 | 1.40 | 1.66 |
| RC1 | 2.45 | 1.58 |
| RC2 | 1.67 | 1.13 |
| RC5 | 0.81 | 0.93 |

Source: Compiled by Author

Table 7.31 shows that RC4 is the most efficient research centre of the seven included. The RII Efficiency Score is 2.93 meaning that their impacts score is 3.90 times their RII Inputs sub-index score. Using the efficiency ratio of research centre inputs to impacts their score is 3.99. This score falls to 2.93 when we consider the absorptive capacity of their industry partners. As such, given RC4's industry partners have a strong absorptive capacity, the research centre has higher impact capacity. The assumption is that research centre's ability to generate impacts is dependent on the potential and realised absorptive capacity of their industry partners.

### 7.5.5 Uncertainty and sensitivity analysis

Uncertainty and sensitivity analysis are important steps to test the overall robustness of CI results. Evaluators and practitioners must make many subjective decisions during the construction process which effect the final CIs score. As such, a plurality of scenarios should be considered given it is difficult to say whether on scenario is better than the other. This section has highlighted rationale for decision-making during the construction of the Research Impacts Index. However, uncertainty and sensitivity analysis are conducted in order to test the overall robustness of results and identify the sensitivity of the index to:

- Changes in the weighting scheme selected
- Changes in normalisation method chosen

***Alternative weighting decisions***

Funding bodies have multiple goals for investing public funds in publicly funded research centres ranging from increasing knowledge within society and demonstrating scientific excellence to the creation of new technologies and employment opportunities. A key contribution of the RII is that it allows funding bodies to score research centres based on goals of the funding body and characteristics of research centre.

Research centres specialise in different areas, have different competencies and innovative capacity and are driven by different missions and goals. As such, there is no ‘one size fits all approach’ to research centre evaluation and funding bodies are required to take a more holistic approach to evaluation exercises to avoid comparing ‘apples with oranges’. Therefore, it should follow that different research centres may be the ‘best fit’ depending on the goals and objectives of funding bodies and decision-makers.

The weighting scheme proposed for the RII should be based on expert opinion and may need to be revised on a case by case basis as changes in internal and external environment of research centre should have an influence on efficient allocation of scarce resources. Changes in the weighting of specific dimensions or variables are related to changes in the perceived importance of those dimensions (or indicators) for the overall score. Therefore, we should expect that these changes will influence the overall rankings of the research centres.

For example, suppose the economy has recently experienced a recession and following this the government are forced to implement significant reductions in public funding. Any research projects in receipt of public funding are required to provide increased justification for the allocation of funding and demonstrate value for money. Policymakers are under pressure to demonstrate to the public that investments are contributing to improvements in the economy, creating jobs and increasing future opportunities. Given these conditions, it has been decided to provide funding to projects that can demonstrate significant economic impacts in the next five years.

Using the RII, policymakers decide to assign heavier weightings to economic impacts compared to scientific impacts, technical impacts and impacts on investments. Table 7.32 shows the weighting scheme devised by funding body for evaluation of research centres.

**Table 7.32 Alternative Weighting Scheme for Impact Dimensions**

| **Dimensions** | **Original Weighting** | **New Weighting** |
|---|---|---|
| Scientific Impact | 25% | 15% |
| Technical Impact | 25% | 15% |
| Human Capital Impact | 25% | 20% |
| Economic Impact | 25% | 50% |

Source: Compiled by Author

Table 7.33 shows the new weighting scheme devised for the Economic Impact dimension. Previously, each indicator was assigned an equal weighting (20%). However, the weighting system has been altered in line with the new policy objectives with job creation and revenue generation weighted more heavily than exports, spin offs and industry as first destination.

**Table 7.33 Weighting scheme for indicators in Economic Dimension**

| Economic Dimension (60%) | | | | |
|---|---|---|---|---|
| Job Creation | Turnover | Exports | R&D Investment | New Product sales |
| 40% | 25% | 15% | 10% | 10% |

Source: Compiled by Author

Table 7.34 shows the changes in rankings using the new weighting scheme compared with previous method of assigning equal weights to each dimension. The results show that the rankings have remained steady across both weighting schemes. The reason for this is that research centres which performed well in the RII using equal weighting also were top performers across the economic dimension. As such, when weightings were adjusted the results remained similar with only small changes occurring across the rankings.

**Table 7.34 Calculating RII Impacts Sub-Index Score using alternative weightings**

| | **Scientific Impact** | **Technical Impact** | **Human Capital impact** | **Economic Impact** | **RII Impacts Score** |
|---|---|---|---|---|---|
| **RC1** | 29 | 46 | 84 | 32 | 44 |
| **RC2** | 73 | 73 | 89 | 36 | 58 |
| **RC3** | 44 | 58 | 24 | 42 | 41 |
| **RC4** | 84 | 10 | 42 | 52 | 49 |
| **RC5** | 90 | 43 | 48 | 51 | 55 |
| **RC6** | 40 | 41 | 49 | 35 | 40 |
| **RC7** | 38 | 20 | 31 | 52 | 41 |

Source: Compiled by Author

This highlights the robustness of the RII in that changes in the weighting scheme result in some changes in the overall rankings while maintaining the internal consistency of results.

**Table 7.35 Comparing RII Impacts Sub-Index Score using alternative weightings**

| Research Centre | RII Impacts Sub-Index Score | Rank | Previous Rank | Change |
|---|---|---|---|---|
| RC2 | 58 | 1 | 1 | = |
| RC5 | 55 | 2 | 2 | = |
| RC4 | 49 | 3 | 4 | +1 |
| RC1 | 44 | 4 | 3 | -1 |
| RC7 | 41 | 5 | 7 | +2 |
| RC3 | 41 | 6 | 6 | = |
| RC6 | 40 | 7 | 5 | -2 |

Source: Compiled by Author

***Alternative normalisation methods***

Section 7.4.5 provides a rationale for the selection of the min-max approach to normalise the data included in RII. However, studies have shown that the selection of alternative normalising methods may lead to very different outcomes. This undermines the robustness of the CI and minimises its use to inform strategic planning and decision-making. As such, it is important to consider the effect of alternative normalisation methods on our results.

The two alternative methods chosen are i) standardisation (or z-score) approach and ii) counting method. These approaches and their measurement were previously discussed in Section 7.3. While each approach is illuminating, neither is complete. The min-max approach adopted in the RII is the most popular normalisation method in the literature but standardisation and counting methods are widely used.

Research centres that fall below the average for a given indicator (or dimension) will generate a negative z-score while research centres that over perform relative to the average will generate a positive score. Table 7.36 shows the results of the RII Impacts sub-index score using the standardisation approach.

**Table 7.36 Comparing RII Impacts Sub-index scores by z-score and min-max approaches**

| | RII Impacts sub-index z-score | RII Impacts sub-index z-score Rank | RII Impacts sub-index min-max score Rank | Change |
|---|---|---|---|---|
| RC2 | 68.00 | 1 | 1 | = |
| RC5 | 25.00 | 2 | 2 | = |
| RC1 | 4.00 | 3 | 3 | = |
| RC3 | -5.00 | 4 | 6 | +2 |
| RC4 | -17.00 | 5 | 4 | -1 |
| RC6 | -32.00 | 6 | 5 | -1 |
| RC7 | -43.00 | 7 | 7 | = |

Source: Compiled by Author

Table 7.36 provides a comparison between RII Impacts sub-index scores using z-score normalisation and min-max methods. The results show that research centre rankings are very similar using these approaches. There are two instances where the rankings between research centres are reversed. Firstly, RC5 moves up one place from 4th to 3rd when using z-scores rather than min-max while RC6 falls from 3rd to 4th. Secondly, RC4 moves up one place at the expense of RC1.

Table 7.37 compares the results of the RII Impact sub-index using both min-max normalisation methods and counting method.

**Table 7.37 Comparing RII Impacts Sub-index scores by count and min-max approaches**

| Count | RII Impacts Sub-Index Score | Count Rank | Min-max score Rank | Change |
|---|---|---|---|---|
| RC2 | 78 | 1 | 1 | = |
| RC5 | 60 | 2 | 2 | = |
| RC1 | 59 | 3 | 3 | = |
| RC3 | 48 | 4 | 6 | +2 |
| RC4 | 48 | 5 | 5 | = |
| RC7 | 29 | 6 | 7 | +1 |
| RC6 | 23 | 7 | 4 | -3 |

Source: Compiled by Author

The results show that research centre rankings are very similar using these approaches. The only significant variation between the results is RC6 falls three places using the count normalisation method compared with the min-max approach. Furthermore, RC3 improves their ranking from 6th place to 4th using the count method.

These results highlight the robustness of the RII Index to changes in both weighting and normalisation techniques chosen. This novel tool provides research centres and funding bodies with a robust benchmarking tool to measure and evaluate the economic impacts of research centres. The tool may be used to inform strategic and funding decisions, enhance internal learning and provide accountability for the allocation of public resources. The next section presents a discussion on visualisation techniques that may facilitate researchers, research centres and funding bodies of communication and disseminating the results of their research to the multiple stakeholders involved in the research system, from scientists and experts to the general public.

### 7.5.6 Visualisation of the results

A visual tool may be interpreted more easily by policymakers and the general public and may ensure that the findings of the CI can be communicated more easily. The complexities of CI construction can make interpretation of results difficult however the use of visualisation tools may overcome some of the problems inherent in the interpretation of CI results. The three approaches to visualisation outlined in this section are (i) League tables (ii) bar charts and (iii) spider charts. Table 7.38 presents the results of the analysis carried out in 7.5 in league table format.

**Table 7.38 League Table RII Impacts Sub-Index Score**

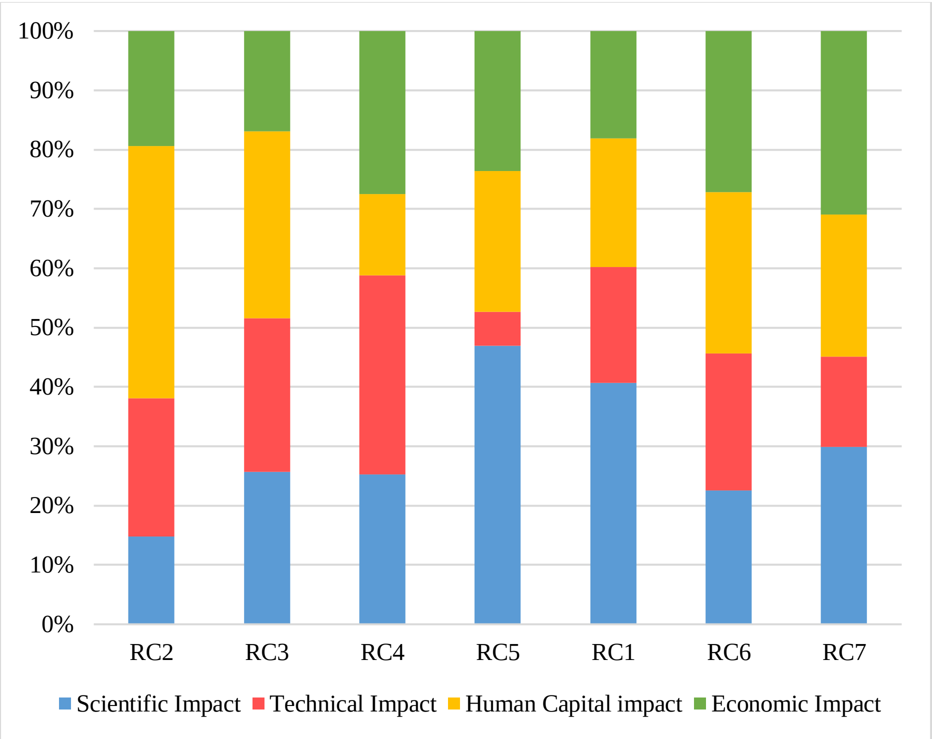
| | **RII Impacts Sub-Index Score** | **Rank** |
|---|---|---|
| RC2 | 71 | 1 |
| RC5 | 55 | 2 |
| RC1 | 49 | 3 |
| RC6 | 45 | 4 |
| RC4 | 45 | 5 |
| RC3 | 43 | 6 |
| RC7 | 32 | 7 |

Source: Compiled by Author

The league table approach allows evaluators to rank research centre by performance across several dimensions. Table 7.38 ranks research centres by their RII Impacts Sub-Index Score. RC2 is the best performing centre with a score of 65, almost 2.25 times higher than the worst performing centre (RC7) with a score of 29.

The second approach to visualising the result of CIs is through bar charts. Bar charts allows to group into high performing and low performing entities by colour coding. Figure 7.2 shows the results of RII Impacts Sub-Index score broken down by categories of impact.

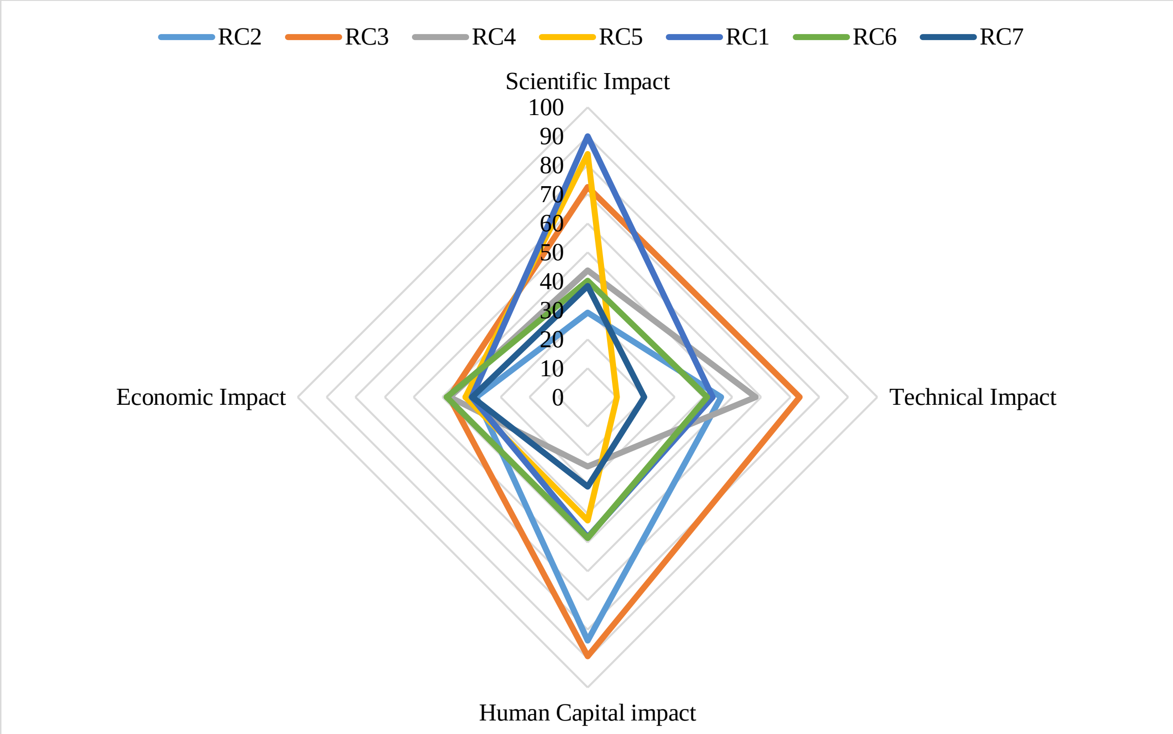
**Figure 7.2 Bar Chart RII Impacts Sub-Index score**




Source: Compiled by Author

The final visualisation tool used in this thesis to demonstrate the results of the RII is spider charts. Similar to bar charts, spider graphs allow evaluators to demonstrate the strength and weaknesses of each research centre across each category of impact. As such, spider graphs allow evaluators to illustrate the strengths and weaknesses of entities across various dimensions. This may be useful to identify potential bottlenecks or weak points that the entity may need to address to improve their score. Figure 7.3 presents a spider chart of each research centres performance by RII Impacts Sub-Index score.

**Figure 7.3 Spider Chart RII Impacts Sub-Index score**




Source: Compiled by Author

The next sub-section provides details of the qualitative tool adopted in thesis to complement the Research Impacts Index (RII) in providing robust measures of the economic and commercial impacts of publicly funded research centres.

### 7.5.7 Incorporating System into RII

This section briefly outlines the process of incorporating the strength of the research centre's innovation system into the RII. The IMPACTS framework highlights an important, and to date underappreciated, element of the impact of research centres, which is its contribution to the system within which it operates. Such centres operate within an innovation system, and as such the strength of the system is an important input and platform for a centre's success. However, the system is not exogenous to the centre, as the strength of the system is influenced by the activities of the research centres within it. As such, when evaluating research centres across regions these regional specific factors play an important role in the potential magnitude of impact.

de Jong and Muhonen (2018) analyse sixty case studies across sixteen European countries. The findings suggest researchers from High Performing Countries (HPCs) have a higher impact capacity than those from Low Performing Countries (LPCs). Therefore, the strength of the innovation system that a research centre is embedded within is an important input in the process of generating economic and societal impacts. As such, systematic evaluations of research centre performance should incorporate the strength of the research centre's innovation system into benchmarking exercises. Research centre's embedded with strong innovation systems have a higher impact capacity than research centre's within weaker innovation systems.

The Research Impact Index (RII) allows for the incorporation of system level inputs into the evaluation exercise. Following de Jong and Muhonen (2018), the assumption is that research centres embedded within stronger innovation systems have a higher impact capacity compared with comparable centre's embedded within weaker innovation systems. The aim of this thesis was to demonstrate the feasibility of the RII to measure the economic impacts of publicly funded research centres. The effectiveness of the RII for benchmarking research centre impact within a country is demonstrated in Section 7.5. This sub-section aims to demonstrate the usefulness of the RII for benchmarking research centre impacts across countries.

Firstly, the strength of the innovation system which the research centre is embedded within is incorporated into the RII Inputs sub-index. There was a trade-off to make when deciding whether to gather primary data on international comparator research centres. The potential indicators and metrics to measure structural absorptive capacity are outlined in Section 5.3.6. However, the availability of suitable secondary data, coupled with time constraints and travel costs contributed to the decision not to gather primary data. Rather, the strength of a research centre's structural absorptive capacity may be sourced using secondary data, for example through the Global Innovation Index (GII).

The GII Score may be incorporated into the RII Input Sub-Index as a measure of system strength. Therefore, research centres embedded within high performing innovation systems are assumed (and expected) to have higher impact capacity compared with research centres embedded within low performing innovation systems, ceteris paribus. The reasons for this are strength of linkages and collaboration networks, absorptive capacity within system - exploit knowledge and technology produced by centre, critical mass, innovative capacity of external actors, policies and institutions.

***Benchmarking Research Centre Performance across Countries***

Evaluators face many challenges efforts to benchmark research centre performance across countries including differences in conceptualisations of impact, research centre structure, aims and objectives, research discipline, indicators and metrics, and strength of innovation system. Therefore, when conducting cross-country benchmarking exercises a review of suitable indicators and metrics is required in order to ensure comparability and identify region-specific differences. Following the selection of suitable indicators, the strength of the research system may be incorporated into the RII Input-Sub-Index following the same process highlighted in 7.5.1.

## 7.6 Research Impact Statements

A comparative analysis between quantitative and qualitative approaches to research impact assessment (RIA) was presented in Section 3.5. Qualitative approaches to RIA offer useful tools to overcome some of the limitations associated with metrics-based approaches. As Grant (2006) states "although metrics can provide evidence of quantifiable changes or impacts from our research, they are unable to adequately provide evidence of the qualitative impacts that take place and hence are not suitable for all of the impacts we encounter".

Additionally, Donovan (2011, p.75) finds "metrics-only approaches employing economic data and science, technology and innovation indicators were found to be behind the times: best practice combines narratives with relevant qualitative and quantitative indicators to gauge broader social, environmental, cultural and economic public value". As such, the use of some form of 'triangulation' of methodologies is generally favoured for research impact assessment exercises.

Triangulation refers to "using more than one particular approach when doing research in order to get richer, fuller data and/or to help confirm the results of the research" (Wilson 2014). The IMPACTS framework aims to overcome the limitations associated with quantitative and qualitative approaches to RIA by moving towards a more integrated, robust and flexible measure of research impact. This approach addresses the first principle set out in the *Leiden Manifesto,* which states "quantitative evaluation should support qualitative, expert opinion" (Hicks et al. 2015).

Triangulation is achieved by using three methods to inform evaluation of the economic impacts of publicly funded research centres. The overall weighting of each element towards the overall impact score is in brackets.

- RII Impacts sub-index score allows evaluators to benchmark research centres across four dimensions of impact: scientific impact, technical impact, human capital impact and economic impact (60 per cent).
- RII Efficiency ratio provides a measure of the efficiency of the research centre in delivering economic impacts. The efficiency ratio is the ratio of a research centre's RII Input Sub-index score and their RII Impacts Sub-index Score. The underlying assumption is that research centres that perform better in the RII Inputs Sub-index have a higher capacity for generating research impacts than research centres with lower RII Inputs Sub-index scores (20 per cent).
- Research Impact Statements allow research centres to provide rich and detailed information on specific topics or events, as well as related and contextual conditions. Each research centre are required to provide evidence of impacts generated through research activities from a list of eleven impact statements. Each research centre is required to rank at least one, and up to five, research impacts. Furthermore, in-depth impact narratives are required to provide support for the impact statements selected (20 per cent).

Table 7.39 outlines the eleven impact statements developed by SFI and adopted by the IMPACTS framework to measure and evaluate the economic impact of publicly funded research centres.

**Table 7.39 Research Impact Statements**

| | Impact Statement | Impact Dimension |
|---|---|---|
| 1. | The research conducted through my award has enabled me to leverage international funding through industry/collaborative research | Economic and Commercial, International |
| 2. | The research conducted through my award has resulted in the start or expansion of a company which has resulted in the creation of high value jobs | Economic and Commercial |
| 3. | The research conducted through my award has attracted developing and nurturing businesses | Economic and Commercial |
| 4. | The research conducted through my award has attracted international scientists and talented people | Human Capacity; International Engagement |
| 5. | The research conducted through my award has resulted in a new policy being implemented and/or an improvement to the delivery of a public service | Public Policy and Services |
| 6. | The research conducted through my award has enhanced the quality of life and health of Irish citizens | Health & Wellbeing, Societal Impact |
| 7. | The research conducted through my award has improved the environment and/or the sustainable relationship between society, industry and the environment | Environmental Impact |
| 8. | The research conducted through my award has increased the knowledge, appreciation and understanding of science, engineering and technology amongst the general public. The research conducted through my award has developed the country's international reputation | Societal Impact, International Engagement |
| 9. | The research conducted through my award has resulted in the creation of employment through directly influencing and inspiring the future workforce and/or the production of a highly educated and relevant workforce in demand by industry and academia | Human Capacity, Economic and Commercial |
| 10. | The research conducted through my award has impacted in other areas not reflected in the choices provided, for example by enhancing the creative output of Irish citizens | Environmental, Professional Services, Societal |
| 11. | The research conducted through my award has not yet realised any significant Impact | |

Source: Science Foundation Ireland (2019)

Each impact statement will be assessed by an expert panel of international experts with specific interest in impact assessment. Traditionally, peer review is used for evaluating the quality of scientific research, however its usefulness for measuring broader economic and societal impacts of research is debateable. Research impact assessment requires a broader panel of experts from across the innovation system including academics, business R&D directors, senior technology transfer personnel, investors in early stage technology companies. Table 7.40 highlights the proposed scoring criteria based on international best practices.

**Table 7.40 Scoring Impact Statements**

| Star | Score | Details |
|---|---|---|
| **Four Star** | **Exceptional** | Ground-breaking or transformative impacts of major value or significance with wide-ranging relevance have been demonstrated |
| **Three Star** | **Excellent** | Highly significant or innovative (but not quite ground-breaking) impacts relevant to several situations have been demonstrated |
| **Two Star** | **Very good** | Substantial impacts of more than incremental significance or incremental improvements that are wide-ranging have been demonstrated |
| **One Star** | **Good** | Impacts in the form of incremental improvements or process innovation of modest range have been demonstrated |
| **n/a** | **Unclassified** | The impacts are of little or no significance or reach, or the underpinning research was not of high quality, or research-based activity within the submitted unit did not make a significant contribution to the impact |

Source: Higher Education Funding Council United Kingdom (2010)

In forming their overall quality judgements, the expert panels will assess three distinct elements of each submission – RII Impact Score (60 per cent), RII Efficiency Ratio (20 per cent) and Research Impact Statements (20 per cent). A significant weighting for the impact statements is important to ensure it is taken seriously by all key stakeholders and to make the benefits of research explicit to policymakers, funding bodies and the general public. It should be noted that the assessment process is likely to be developmental as research centres learn how to provide the evidence and expert panels gain experience. Thus, the weightings may be adjusted for future impact assessment exercises based on feedback and experience gained during initial roll-out.

## 7.7 Conclusion and Next Steps

Chapter 7 outlined the process involved in the construction of the Research Impact Index (RII). The RII makes an important contribution to the literature on research impact assessment by developing a novel tool to measure and evaluate the economic impact of publicly funded research centres. The RII is designed to addresses the issues of attribution, additionalities, and time lags that present difficulties for evaluators when estimating research centre impact.

The RII identifies impact indicators and metrics that are generated at different stages of the research impact process. Therefore, the tool may be adjusted for short, medium- and long-term impacts depending on the stage of the research lifecycle when the evaluation takes place. Furthermore, additionalities are minimised by including a broad range of research impacts including scientific impacts, technical impacts, human capital impacts and economic impacts.

The contributions of the RII includes:

- providing a novel benchmarking tool which allows researchers, research centres and funding bodies comparability, consistency
- improving transparency in logic and decision-making in relation to data selection, indicator weighting and analytical procedure.
- adopting a flexible weighting system which allows evaluators to adjust for research discipline, objectives of research centre objectives, importance of impact indicators and funding body objectives.
- incorporating the strength of industry partners absorptive capacity and strength of innovation system into the evaluation framework.
- measuring research impacts across four indices, which evaluate both the size and efficiency of research impacts generated by research centres.
- visualisation tools to facilitate effective communication and dissemination of results which makes interpretation of results.

The RII was tested on a Science Foundation Ireland funded research centre to assess the feasibility and usefulness of the tool. The results indicate that the RII, combined with qualitative impact statements provide policymakers, funding agencies and research centres with a novel approach to measuring and evaluating the diverse range of impacts generated though investment in publicly funded research centres. The next chapter provides a summary of the findings from this thesis, policy implications and future directions of the research agenda.

# Chapter 8: Conclusion: Findings, Policy Implications and Future Research Agenda

## 8.1 Introduction

The purpose of this Chapter is to provide a summary of the findings of this thesis, identify strengths and limitations of the research findings and propose some fertile ground for future research in the area. Furthermore, the implications of these findings on the future directions of Irish research policy are considered. Section 8.2 provides a summary of the key findings of this thesis. These findings address the three main research questions presented in Chapter 1 of this thesis, namely:

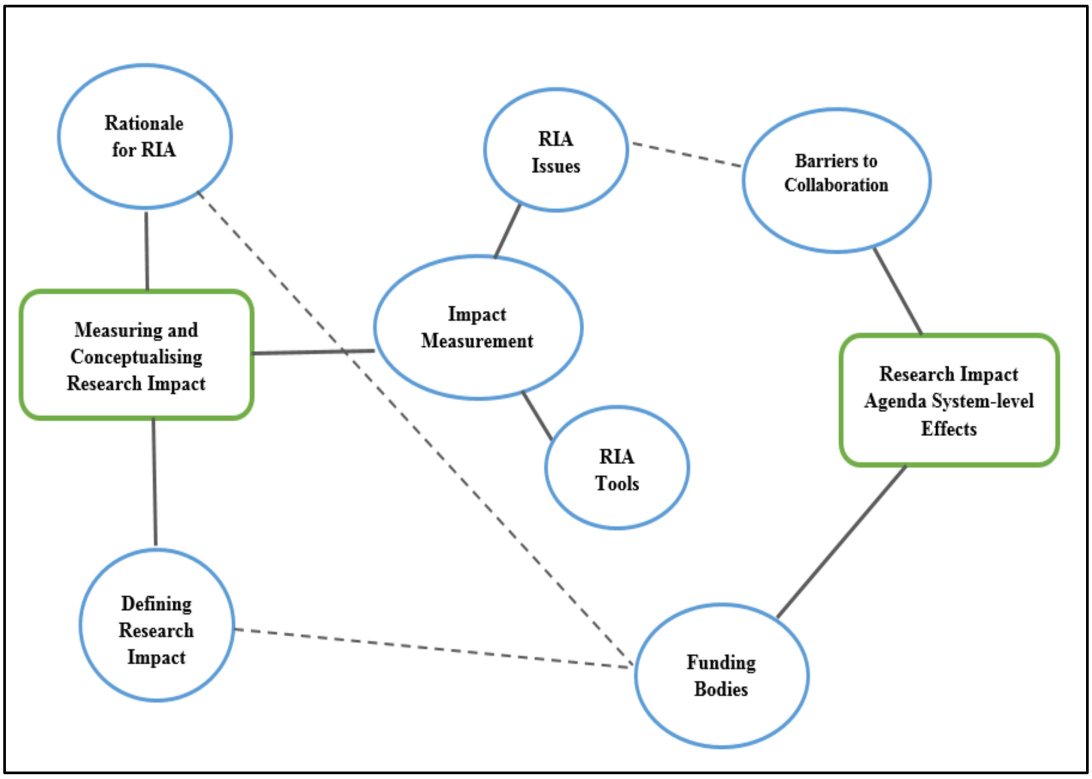
1. What is meant by research impact?
2. How does research impact occur?
3. How can research impact be measured?

## 8.2 Summary of Findings

### 8.2.1 Meanings and Conceptualisations of Research Impact across Irish research sector

Chapter 4 addresses the first research question aimed at exploring what is meant by research impact. This Chapter explores the diverse meanings and conceptualisations of research impact across the Irish research sector. Thirteen semi-structured interviews were conducted with key stakeholders across the research sector including funding bodies, principal investigators, research centre management and directors. Following a detailed thematic analysis of the interview transcripts two overarching themes are identified. The themes highlight significant opportunities and challenges facing funding bodies and research centres in the drive towards the research impact agenda. Figure 8.1 presents the themes and sub-themes identified through the thematic analysis.

**Figure 8.1 Thematic Map**




Source: Compiled by Author

The findings suggest the research impact agenda is still in the early stages of development in Ireland. The interview participants highlighted the need to address key challenges in future RIA exercises including identifying measurement tools that capture wide range of research impacts, indicators and metrics of success, the role of the funding bodies in driving the direction of the research centre sector and a shift towards short term, commercially driven research.

### 8.2.2 IMPACTS Framework

The second research question is focused on understanding how research impact occurs. This question is addressed through the development of an original framework to measure and evaluate the economic impacts of publicly funded research centres presented in Chapter 5. The IMPACTS framework provides the conceptual contribution of this thesis by adopting a holistic, systems-based approach to RIA.

The key features of this approach are:

- Innovation as an evolutionary process
- Research as a capability
- The absorptive capacity of industry
- The new mode of knowledge production
- Creating social and technological variety

From this perspective, research centres are considered a vital cogs within an innovation system. Salter et al. (2000) note “firms do not innovate in isolation”. Similarly, research centres do not generate impacts in isolation. Rather, research impacts are generated through productive interactions with key stakeholders within the innovation system including firms, universities, research centres, funding bodies and government agencies.

This approach considers research as a capability embedded within individuals and collaborative networks. The economic impact generated by research centres is dependent on the capacity of their collaborative partners to absorb and exploit the knowledge in economic and commercially valuable ways. From this perspective, knowledge is a necessary though not sufficient condition to achieve competitive advantage. Rather, it is the capacity of an individual researcher, firm, or government to make best use of available knowledge which provides unique opportunities to increase productivity and innovation capacity.

As such, the IMPACTS framework places significant importance on the absorptive capacity of firms within the innovation system. The neoclassical economics perspective implies that knowledge is “on the shelf, costlessly available to all comers” (Rosenberg 1990, p.165) whereas, the evolutionary perspective asserts that while knowledge is plentiful, it is the capacity to use it in meaningful ways that is in short supply (Salter and Martin 2001). As such, transforming knowledge outputs produced by a research centre into economic and commercial impacts is dependent on the firm’s absorptive capacity i.e. their ability to absorb, assimilate, transform, and exploit knowledge.

Another key feature of the IMPACTS framework is the emphasis on the strength of the innovation system as an important input into the impact capacity of research centres. Structural absorptive capacity refers to regional specific characteristics that influence the ability of a region to identify, assimilate, and exploit knowledge. The strength of the regional innovation system influences a research centre's ability to generate economic and societal impacts (de Jong and Muhonen 2018), thus is an important consideration when conducting benchmarking exercises.

Enhancing structural absorptive capacity is essential for maximising research centre's ability to produce economic and commercial impacts. However, the relationship between research centres' and the innovative system is not unidirectional. A research centre's ability to produce economic impacts is influenced by the strength of the innovation system while the system is also influenced by research centres. Therefore, a comprehensive assessment of impact must move beyond bibliometric and industry-focussed indicators, towards an assessment of the extent to which research centres contribute to the entire system.

This study sets out an important, and to date underappreciated, element of studies examining the economic impact of publicly funded research centres, which is its contribution of the system within which it operates. Research centres operate within innovation systems, and as such the strength of these systems are an important input and platform for centre's success. However, the system is not exogenous to the centre, as the strength of the system is influenced by the activities of the research centres within it. As such, regional-specific factors play an important role in determining research centre impact capacity when benchmarking research centre performance across regions.

This approach offers a unique perspective when analysing the economic impact of publicly funded research centres. The adoption of the systems-based approach allows for both the identification of the complex underlying dynamics and relationships inherent in the impact process while identifying the process by which these relationships contribute to the magnitude of economic impact. Therefore, the framework aims to juxtapose literatures focused solely on providing monetary estimates of research impact with frameworks focused on the mechanisms of research impact.

The IMPACTS framework provides the theoretical and conceptual foundation for the construction of a multidimensional index to benchmark the impacts generated by publicly funded research centres, Research Impact Index (RII).

### 8.8.3 Research Impact Index (RII)

The third research question is aimed at understanding how we measure research impact. The RII measures and compares the impacts generated by research centres through four composite indices:

i) The RII inputs sub-index is comprised of inputs across three different entities: research centre, industry partners and research system.
ii) The RII impact sub-index is composed of four dimensions and 16 indicators. The four dimensions of the RII Impacts sub-index are scientific impacts, technical impacts, human capital impacts and economic impacts.
iii) The Overall RII score is calculated as the average of research centre sub-index score and the industry partner sub-index score.
iv) The Impact Efficiency Ratio is calculated as the ratio of research centre inputs to research centre impacts. The assumption underlying the RII Efficiency Ratios is that research centres with higher RII input sub-index scores are expected to generate higher RII impacts sub-index scores

Section 3.3 highlights some well-known methodological issues that complicate research impact assessment exercises. The most common methodological issues are presented below alongside a discussion of how the RII aims to overcome them. Firstly, the burden of data collection is widely reported issue for RIA exercises (Guthrie et al. 2013, Barge-Gil and Modrego 2011). The generation of research impacts is a complex, nonlinear, highly uncertain process often involving multiple stakeholders. As such, efforts to demonstrate the impact of research centres requires data from multiple stakeholders. Data collection is often complicated by issues of confidentiality, subjectivity, the identification of a suitable contact person and lack of engagement from collaborative partners.

The issue of data collection led to the development, testing, and rolling out of two questionnaires to measure research centre impact, Research centre Impact Questionnaire and Industry Partner Impact Questionnaire. The Research centre Impact questionnaire contains 20 questions across four key areas – Research centre characteristics, Research centre objectives, research inputs, research outputs, and sources of collaboration. The Industry Partner Impact questionnaire contains 29 questions across five key areas – business characteristics, innovation capacity of business, sources of collaboration, and benefits of collaboration with the Research centre. The data collected though the two questionnaires is used to develop the RII.

The second key issue that is known as the 'attribution problem' (Guthrie et al. 2018). Attribution refers to the extent of changes in outcomes of interest can be attributed to an intervention e.g. the percentage of new product sales that can be attributed to the research centre. The generation of research impacts requires the combination of knowledge, skills and capabilities from multiple stakeholders and it is not always possible or desirable to attribute the contribution of a single intervention or stakeholder.

The contribution of this thesis to overcome the attribution problem' is twofold. Firstly, the two impact questionnaires contain several questions related to the criticality of the research centre for economic impacts generated by industry partners. These questions allow for the estimation of a crude quantitative measures of attribution. Secondly, much research has advocated for a shift in focus from attribution-based approaches towards contributions-based approaches (De Jong et al. 2014, Morton 2015, Ofir et al. 2016).

Contributions-based approaches do not require robust estimates of exactly how much difference a particular piece of work made, but rather to demonstrate a plausible pathway through which it supported or contributed to a particular benefit (Guthrie et al. 2018). Narratives or story-telling based approaches are often recommended to demonstrate how research 'contributes' to outcomes and impacts. As such, the findings of this thesis recommend combining the RII with research impact statements to capture a range of impacts generated by a research centre over a fixed time period.

Another key challenge faced by funding bodies and practitioners when measuring the impact generated by publicly funded research centres is time-lags. The impact of investments in research activities is uncertain, unequal and serendipitous, particularly for basic research, where projects may take much longer to achieve impact –

sometimes many decades (Mansfield 1991, Salter and Martin 2001, Toole 2012, Haskel and Wallis 2013). Therefore, funding bodies, research centres and evaluators must be cautious when adopting one-size-fits-all approaches to research impact assessment. Research centres operate under diverse missions, organisation, and structure. The ability of research centres to deliver impacts is dependent on several factors including the age of the centre, research mission, research discipline, life cycle of technology and Technological Readiness Levels (TRLs). As such, a flexible approach that takes into account these contextual factors is required to facilitate robust assessment exercises.

The RII is a flexible tool which allows research centres and funding bodies to adjust weightings based on the rationale for assessment. Guthrie et al. (2013) identify four rationales for conducting research impact assessment: accountability, analysis, advocacy, and allocation. As such, weightings may be adjusted for several factors including the mission of the research centre, objectives of funding body, research discipline, and importance of individual impact metrics. This allows for research impact assessment that is sufficiently robust to allow comparison across disciplines and structures, but yet sufficiently flexible to facilitate appropriate weightings for different elements of impact for centres at different Technological Readiness Levels (TRLs).

Guthrie et al. (2018) identify the absorptive capacity of collaborative partners as a key issue in RIA exercises. RII measures both potential and realised absorptive capacity of industry partners. Research centre collaborating with more innovative firms have higher impact capacity than research centres collaborating with firms of lower absorptive capacity. Research centres impact capacity is constrained if industry partner does not or cannot exploit knowledge or technology produced by research centre.

In forming their overall quality judgements, expert panels will combine the scores of assess three distinct elements of each submission. The RII Impact Score (60 per cent) and RII Efficiency Ratio (20 per cent) generated through the Research Impact Index will constitute 80 per cent of a research centres overall score. The remaining 20 per cent will be determined by the score of Research Impact Statements. The Research

Impact Statements provide rich and detailed information on specific topics or events, as well as related and contextual conditions. These statements will be reviewed by a panel of international experts based on a scoring criterion informed by international best practices. The weighting scheme for each element may be adapted based on feedback and experience gained during the initial roll-out of the tool.

## 8.3 Limitations of the Study

A key objective of this thesis was to develop and test the feasibility of a novel benchmarking tool to assess the economic impact of publicly funded research centres. Chapter 7 outlines the steps involved in constructing the Research Impact Index (RII). The purpose of this Chapter was to highlight key decisions made regarding data requirements, normalisation techniques, weighting methods and aggregation approaches adopted to construct the RII.

Chapter 7.5.2 and 7.5.3 discuss the selection and treatment of data included in the RII. The data required to populate the RII was gathered through two questionnaires, Research Centre Impact Questionnaire, and Industry Partner Questionnaire. These survey instruments were used to collect data for our test centre, thus demonstrating the feasibility of these tools to gather data across all research centres in Ireland. However, it was not feasible to collect data for all research centre comparators included in the study. Therefore, data for comparator centres were generated through two methods, secondary data, and simulation. As such, the results of the study do not allow for comparisons of economic impacts between research centres but rather demonstrate the feasibility of the tool to carry out such an analysis.

A second limitation of the study is the sample size used to test the feasibility of the RII. Initially, the test centre provided a list of twenty-eight industry partners that could potentially complete the Industry Partner Questionnaire. However, after initial contact three businesses were removed from study as one business had been taken over by another business, one contact point had left the business and one email address bounced back. The response rate for the remaining businesses was 48% (12/25).

Thirdly, the RII was primarily developed to measure and evaluate the economic impact of publicly funded research centre. However, research centres can contribute to a wide range of impact including but not limited to health impacts, societal impacts, policy impacts, cultural impacts, environmental impacts. However, the RII is a flexible approach to RIA that provides opportunity for future studies to incorporate more diverse dimensions of impact.

The next section presents the recommendations stemming from this thesis for policy and practice.

## 8.4 Recommendations for Policy and Practice

Research impact assessment (RIA) exercises need to be incorporated into a national research strategy. However, conceptual and methodological clarity related to what impact is, how it can be measured and how it can be maximised must firstly be addressed. The development of effective policies related to RIA requires buy-in from multiple stakeholders across the research sector including policymakers, funding bodies, research centres, universities, and the private sector. The Research Impact Index (RII) and the 'Impact Statements' developed in this thesis require detailed data from both research centres and their industry partners. As such, research centres and industry partners should be aware of and agree upon the collection of relevant metrics at the beginning and throughout the collaboration process.

The results of this thesis indicate that there is a lack of a systematic approach to RIA in Ireland including lack of standardised approach to defining and measuring impacts, lack of data collection systems to reduce burden on researchers and research centres, and lack of incentives to conduct blue-skies, fundamental research. This lack of a systematic approach to evaluation across the Irish research system has contributed to increased burden on researchers and research centres to demonstrate impacts.

As such, inefficiencies in the form of double reporting have been outlined as key problems with evaluation practices. Research centres receive project funding from multiple funding bodies, each with their own reporting standards and data collection methods. Furthermore, firms often collaborate with multiple research centres at the same time, thus requiring the completion of multiple questionnaires and testimonials for collaboration on a single project. Future research policy should move towards more systematic, integrated methods of data collection and evaluation. The use of online systems of data collection accessible by multiple funding bodies to evaluate research outputs, outcomes and impacts of publicly funded research centres would reduce the burden on research centres significantly.

The role of funding bodies in shaping the research sector in Ireland emerged as an important theme from the qualitative interviews with key stakeholders across the research system in Ireland. The key discussion that emerged under this theme is the opinion of stakeholders that Science Foundation Ireland (SFI), the main science funding body in Ireland have shifted focus from funding fundamental research towards more commercially-driven applied research. Several concerns were raised regarding this drive towards short-term, commercially-driven research. There are dangers associated with this narrow policy focus, particularly for a small open economy like Ireland, where an overemphasis by funding bodies on a particular policy may negatively skew the behaviour of actors within the system. The increased focus on delivering economic impacts has led to funding bodies targeting short-term, applied research projects at the expense of longer-term, blue-skies research. Donovan (2011) asserts that the impact agenda should produce no disincentive for conducting basic research. However, the emphasis on accountability and providing justification for public funding contributes to a natural shift towards emphasising economic impacts. Future research policy requires consideration of a more diverse range of research impacts, with less ‘bias’ towards rewarding economic impacts.

The lack of suitable measurement tools provides incentives for researchers and research centres to overstate, or at least overestimate, the magnitude of impacts generated through research activities. The RII coupled with the Impact Statements provides funding bodies, evaluators, and research centres with a robust tool to benchmark and analyse research centre impacts and performance. Therefore, the next steps are to implement these tools across the Irish research sector as they have been developed and tested and are robust. Therefore, a key policy goal is to develop a national benchmarking exercise to measure and evaluate the economic impact of publicly-funded research centres in Ireland.

## 8.5 Recommendations for Future Research

The findings of this research suggest that more work is required to offer conceptual and methodological clarity on the ‘research impact agenda’. The aim of this thesis was to develop frameworks and tools to measure and evaluate the economic impact of publicly funded research centres. This research took the first steps in developing a benchmarking tool that could be used measure the impacts of research centres operating across diverse missions, structures, governance, and research disciplines. This is not a straightforward task and requires careful consideration of several conceptual and methodological challenges.

Following the development and testing of the IMPACTS framework and the Research Impact Index (RII), a national assessment exercise aimed at benchmarking the performance and impacts of publicly funded research centres is required. Furthermore, the methodology developed in this thesis could also be applied to cross-national.

The IMPACTS framework and RII highlight potential metrics which may be used to measure and evaluate different stages of the research impact process, from initial investments through to long-term economic impacts. However, further work is required to develop and refine indicators and metrics used to measure research impact. Goodheart's Law states "when a measure becomes a target, it ceases to be a good measure" (Muller 2018). Therefore, research impact metrics require continuous revision and renewal. This process should include input from multiple stakeholders across the research sector. Furthermore, any potential metrics should be assessed in light of context-specific factors that influence the capacity and extent to which different types of impacts are generated by different research centres.

Following large scale roll out the RIA tools, the data collected through the Research Centre Impact Questionnaire and the Industry Partner Impact Questionnaire could be combined in several useful ways. Firstly, an empirical study analysing the impact of publicly funded research centres on firm competitiveness in Ireland. The two questionnaires provide data that allows researchers to determine the effect of publicly funded research centres on different categories of outcomes and impacts. (Barge-Gil and Modrego 2011) conducted a similar study across Spanish research and technological organisations (RTOs) with the findings suggesting that industry partners can identify the benefits of collaboration with RTOs across several impacts including technical, investment, economic, and intangible impacts.

Furthermore, the authors suggest several characteristics of these relationships affect the impact of RTOs. Therefore, a second study could be conducted analysing determining factors in the success of collaboration between businesses and research centres. The systems-based approach adopted in this thesis highlights the importance of interactions and collaboration between different actors within the innovation system to generate economic impacts. A research centre's impact capacity is influenced by the capacity of industry partners to absorb, assimilate, transform, and exploit knowledge produced by the centre into economically viable ends. Therefore, analysing the determining factors of successful collaborations across different contexts is an important future research area.

Thirdly, an analysis of the knowledge transfer channels between publicly funded research centres and industry partners would be useful. Knowledge transfer of publicly funded research into the commercial sphere has become an increasingly important part of the innovation ecosystem as it has been found to enhance the potential economic and social impact of publicly funded research. However, the relationship between knowledge, research, commercialisation, and economic development is a complex one, mediated by a complex set of overlapping interactions and institutions. The evaluation of knowledge transfer mechanisms is complicated by its dependence on the characteristics of knowledge, such as the degree of codification, the tacitness or expected breakthroughs. Therefore, an empirical study identifying the importance of knowledge transfer channels between publicly funded research centres and the private sector across different context would be very timely.

## 8.6 Summary

This thesis develops and tests robust tools and frameworks to measure and evaluate the economic impact of publicly funded research centres. The development of these tools and frameworks will result in a step change in the measurement and evaluation of publicly funded research centres, enabling centres to optimise structures and ways of working to maximise economic impact. These tools may be utilised to benchmark the performance of research centres support the decision-making processes of funding bodies and to identify best in-class performance to guide centre management teams in formulating and evaluating strategic objectives. In addition, it will help funding bodies select and oversee funded centres to increase the efficiency in transforming initial investments into economic and societal impacts for research centres, industry partners, and national and regional economies.

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## Appendix A1. Open Coding

| Name | Files | References |
|---|---|---|
| Access to academic research | 2 | 5 |
| Aligning stakeholder needs | 7 | 22 |
| Allocation | 5 | 5 |
| Barriers to collaboration | 3 | 3 |
| Industry buy-in | 5 | 20 |
| Trust | 6 | 14 |
| Basic vs applied research | 8 | 20 |
| Benefits to industry partners | 8 | 42 |
| Capacity building | 3 | 5 |
| Change in behaviour | 6 | 14 |
| Competition and co-operation | 6 | 16 |
| Conferences | 4 | 7 |
| Confidentiality | 1 | 1 |
| Contact point | 4 | 9 |
| Costs | 1 | 1 |
| Critical mass | 7 | 18 |
| Culture | 8 | 23 |
| Definition research impact | 13 | 28 |
| Degree of engagement | 7 | 19 |
| Dialogue between SFI and centres | 5 | 8 |
| Economic impacts | 10 | 42 |
| Education | 1 | 1 |
| Efficiency | 4 | 5 |
| Engagement with stakeholders | 7 | 13 |
| Equipment | 2 | 3 |
| Ex-ante and ex-post evaluation | 2 | 6 |
| Funding | 9 | 32 |
| Funding model | 9 | 30 |
| Future challenges | 13 | 47 |
| Future opportunities | 7 | 17 |
| Human capacity impact | 4 | 12 |
| Impact statement | 4 | 7 |
| Incentivise companies to provide data | 1 | 2 |
| Incentivising impact | 5 | 6 |
| Industry cash | 12 | 34 |
| Industry-led | 5 | 11 |
| Informal knowledge transfer | 1 | 1 |
| Informal transfer mechanisms | 3 | 3 |

| | | |
|---|---|---|
| In-kind funding | 2 | 2 |
| Institute for collaboration | 6 | 19 |
| Intellectual property | 4 | 7 |
| Internal vs external impacts | 1 | 1 |
| Interviews | 1 | 2 |
| Irish government | 6 | 17 |
| Justification of resources | 9 | 24 |
| Licensing | 6 | 8 |
| Losing funding | 3 | 6 |
| Mark Ferguson | 3 | 3 |
| Marketing tool | 9 | 14 |
| Measurement | 5 | 9 |
| Measurement issues | 10 | 30 |
| Attribution | 10 | 24 |
| Burden | 8 | 29 |
| Data collection | 12 | 70 |
| Gaming | 8 | 14 |
| Numbers skewed | 7 | 7 |
| One size fit all | 8 | 29 |
| Tracing impacts | 7 | 26 |
| Valuing outputs, outcomes and impacts | 8 | 17 |
| Measurement tools | 5 | 6 |
| Economic modelling | 2 | 8 |
| EI Method | 2 | 3 |
| Index | 4 | 5 |
| KPIs | 13 | 121 |
| SFI method | 6 | 45 |
| Mission of centre | 2 | 2 |
| Mobility to industry | 8 | 24 |
| Multiplier | 3 | 4 |
| Narratives | 8 | 34 |
| Negative impacts | 1 | 2 |
| Outputs, outcomes, impacts | 8 | 11 |
| Policy impacts | 5 | 12 |
| Portfolio of projects | 3 | 4 |
| Position | 12 | 14 |
| Process of impact generation | 7 | 8 |
| Qualitative measurement tools | 9 | 29 |
| Quantity vs quality | 4 | 12 |
| R&D | 5 | 9 |
| Rationale for setting up centre | 10 | 16 |

| | | |
|---|---|---|
| Recession | 2 | 2 |
| Recruiting or maintaining staff | 5 | 17 |
| Reputation | 2 | 3 |
| Research centre discipline | 2 | 2 |
| Research inputs | 2 | 2 |
| Research system in Ireland | 7 | 44 |
| Risk | 3 | 5 |
| Scientific impacts | 13 | 43 |
| SFI | 7 | 59 |
| SFI vs EI | 5 | 9 |
| Signal | 6 | 12 |
| SME vs MNC | 11 | 26 |
| Societal impacts | 2 | 4 |
| Spin offs | 2 | 7 |
| Surveys | 3 | 5 |
| Systematic approach | 5 | 21 |
| Technical impacts | 5 | 9 |
| Technological Readiness Levels (TRLs) | 8 | 24 |
| Technology centre model | 3 | 13 |
| Time scale | 7 | 20 |
| Training people | 10 | 26 |
| Transparency | 5 | 18 |

## Appendix A2. Axial Coding

| Name | Files | References |
|---|---|---|
| Funding Models | 9 | 32 |
| Funding model | 9 | 30 |
| Industry cash | 12 | 34 |
| In-kind funding | 2 | 2 |
| Technology centre model | 3 | 13 |
| Future Directions of Research Sector | 0 | 0 |
| Future challenges | 13 | 47 |
| Future opportunities | 7 | 17 |
| Systematic approach | 5 | 21 |
| Measuring Research Impact | 5 | 9 |
| Measurement issues | 10 | 30 |
| Attribution | 10 | 24 |
| Burden | 8 | 29 |
| Data collection | 12 | 70 |
| Incentivising impact | 5 | 6 |
| Numbers skewed | 7 | 7 |
| One size fit all | 8 | 29 |
| Basic vs applied research | 8 | 20 |
| Mission of centre | 2 | 2 |
| Research centre discipline | 2 | 2 |
| Technological Readiness Levels (TRLs) | 8 | 24 |
| Time scale | 7 | 20 |
| basic vs applied research | 8 | 20 |
| Technological Readiness Levels (TRLs) | 8 | 24 |
| Risk | 3 | 5 |
| Tracing impacts | 7 | 26 |
| Transparency | 5 | 18 |
| Valuing outputs, outcomes and impacts | 8 | 17 |
| Measurement tools | 5 | 6 |
| Economic modelling | 2 | 8 |
| EI Method | 2 | 3 |
| Impact statement | 4 | 7 |
| Index | 4 | 5 |
| Interviews | 1 | 2 |
| KPIs | 13 | 121 |
| quantity vs quality | 4 | 12 |
| signal | 6 | 12 |

| | | |
|---|---|---|
| Multiplier | 3 | 4 |
| Narratives | 8 | 34 |
| Qualitative measurement tools | 9 | 29 |
| SFI method | 6 | 45 |
| Surveys | 3 | 5 |
| Position of Responder | 12 | 14 |
| Rationale for RIA | 0 | 0 |
| Accountability | 9 | 24 |
| Advertising | 9 | 14 |
| Allocation | 5 | 5 |
| losing funding | 3 | 6 |
| Relationship between centre and industry partner | 6 | 19 |
| Barriers to collaboration | 3 | 3 |
| Confidentiality | 1 | 1 |
| Contact point | 4 | 9 |
| Culture | 8 | 23 |
| Industry buy-in | 5 | 20 |
| Trust | 6 | 14 |
| Benefits to industry partners | 8 | 42 |
| Access to academic research | 2 | 5 |
| Degree of engagement | 7 | 19 |
| Equipment | 2 | 3 |
| SME vs MNC | 11 | 26 |
| Competition and co-operation | 6 | 16 |
| Engagement with stakeholders | 7 | 13 |
| R&D | 5 | 9 |
| Research Impact | 13 | 28 |
| Change in behaviour | 6 | 14 |
| Critical mass | 7 | 18 |
| Dimensions of Impact | 0 | 0 |
| Capacity building | 3 | 5 |
| Economic impacts | 10 | 42 |
| Costs | 1 | 1 |
| Efficiency | 4 | 5 |
| Mobility to industry | 8 | 24 |
| Recruiting or maintaining staff | 5 | 17 |
| Spin offs | 2 | 7 |
| Human capacity impact | 4 | 12 |
| Training people | 10 | 26 |
| Industry cash | 12 | 34 |
| Policy impacts | 5 | 12 |

| | | |
|---|---|---|
| Scientific impacts | 13 | 43 |
| Conferences | 4 | 7 |
| Education | 1 | 1 |
| Reputation | 2 | 3 |
| Technical impacts | 5 | 9 |
| Intellectual property | 4 | 7 |
| Licensing | 6 | 8 |
| Internal vs external impacts | 1 | 1 |
| Justification of resources | 9 | 24 |
| Negative impacts | 1 | 2 |
| Process of impact generation | 7 | 8 |
| Outputs, outcomes, impacts | 8 | 11 |
| Research inputs | 2 | 2 |
| Research system in Ireland | 7 | 44 |
| Irish government | 6 | 17 |
| Rationale for setting up centre | 10 | 16 |
| Aligning stakeholder needs | 7 | 22 |
| Recession | 2 | 2 |
| SFI | 7 | 59 |
| Dialogue between SFI and research centres | 5 | 8 |
| Mark Ferguson | 3 | 3 |
| SFI vs EI | 5 | 9 |

## Appendix A3. Cover Letter to Industry Partners

Dear Responder,

My name is Stephen Brosnan and I am a PhD candidate at School of Economics, University College Cork. I am following up on a previous correspondence from Dr. Patrick Morrissey, Irish Photonic Integration Centre (IPIC) regarding my PhD which is focused on "Measuring and evaluating the economic and commercial impact of publicly funded Research Centres". The study is funded by Science Foundation Ireland and Irish Research Council but is conducted independently of them.

The objective of the study is to develop a tool to measure the economic and commercial impacts of Research Centres, such as IPIC, to help centres and funding bodies optimise engagement with industry, improve commercial impact and benchmark performance. As a result, the research could guide the future development of Research Centres and their partnerships with industry.

The development of an industry partner questionnaire will form the basis of the study and we were hoping that you could assist us with this endeavour. The questionnaire will require approximately 20 minutes to complete. We realise that some questions may request potentially sensitive information. All responses will be treated with absolute confidentiality and will be reported only in aggregate form. In order to ensure that all information will remain confidential, please *do not* include the name of your business.

If you agree to participate in this project, please note the questions on the questionnaire refer to your business unit only. If your business is a parent or a subsidiary business **<u>the questionnaire should be completed for the Irish-located business only, and not any related foreign parent company or foreign affiliates.</u>**

I would appreciate your assistance in shedding light on this very important issue by completing the questionnaire at your earliest convenience. The questionnaire can be accessed through the following link:

Thank you for your assistance in this important endeavour.

Kind regards,
Stephen Brosnan

## Appendix A4. Research Centre Impact Questionnaire

| | |
|---|---|
| **Respondent's Position:** | |
| **Research Centre Name:** | |
| **Research Centre Address:** | |
| | |
| | |
| | |
| **Telephone:** | |
| **Email Address:** | |

**PURPOSE AND INSTRUCTIONS**

Information obtained from this questionnaire will be used to help measure the economic and commercial impacts of Research Centres and identify ways the Centre can improve performance. The project is funded by Science Foundation Ireland but is independent of them.

Please answer all questions. For multiple choice questions, please TICK the number that corresponds to your response.

**Instructions**

The questionnaire refers to your Research Centre. If your Research Centre is operating with a larger research structure the questionnaire should be completed only for your Research Centre, and not for the Research Centre generally.

The questions refer to the innovative activity of your business for the three years from the start of 2015 to the end of 2017 unless otherwise stated.

We realise that some questions may request potentially sensitive information. All responses will be treated with absolute confidentiality.

Please answer each question. If you require clarification in relation to any question, please contact Stephen Brosnan on (021)4902577 or at stephen.brosnan@ucc.ie

## *1. Research Centre Characteristics*

**1.1)** During the past three years please indicate the <u>importance</u> of each research activity for your Research Centre operations (*Please tick all relevant boxes*).

| | | Not Important | | | | Very Important |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| TRL 1 | Basic research | | | | | |
| TRL 2 | Technology formulation | | | | | |
| TRL 3 | Applied research | | | | | |
| TRL 4 | Small scale prototype | | | | | |
| TRL 5 | Large scale prototype | | | | | |
| TRL 6 | Prototype system | | | | | |
| TRL 7 | Demonstration system | | | | | |
| TRL 8 | First of its kind commercialisation | | | | | |
| TRL 9 | Full commercial application | | | | | |

**1.2)** In what year did your Research Centre begin operations?

**1.3)** Please indicate the research prioritisation area which best aligns with your Research Centre operations. (Please tick one box)

| | | | |
|---|---|---|---|
| Future Networks & Communications | | Processing Technologies and Novel Materials | |
| Marine Renewable Energy | | Medical Devices | |
| Sustainable Food Production and Processing | | Innovation in Services and Business Processes | |
| Smart Grids & Smart Cities | | Diagnostics | |
| Digital Platforms, Content & Applications | | Therapeutics: Synthesis, Formulation, Processing and Drug Delivery | |
| Manufacturing Competitiveness | | Data Analytics, Management, Security & Privacy | |
| Connected Health and Independent Living | | Food for Health | |

**1.4)** Please indicate how many Research and Performing Organisations (RPOs) your Research Centre is based across.

| |
|---|
| |

## *2. Research Centre Objectives*

**2.1)** How important were the following strategic objectives for your Research Centre over the last three years? (*Please tick as appropriate*)

| | Not Important | | | | Very Important |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Income generation | | | | | |
| Generating potential academic collaborations | | | | | |
| Generating potential industrial collaborations | | | | | |
| Raising Research Centre's national profile | | | | | |
| Raising Research Centre's international profile | | | | | |
| Attracting and retaining staff | | | | | |
| Training PhDs | | | | | |
| Creating start-ups | | | | | |
| Promoting entrepreneurship | | | | | |
| Supporting private partners | | | | | |
| Contributing to economic growth | | | | | |
| Promoting knowledge and technology diffusion | | | | | |
| Meeting funding body requirements | | | | | |

# *3. Research Centre Inputs*

## *3.1 Sources of Funding*

**3.1)** Please indicate the average annual funding generated by your Research Centre from the following sources.

| | Average Annual Funding (€) |
|---|---|
| Science Foundation Ireland funding | |
| Enterprise Ireland funding | |
| International Competitive funding (e.g. EU Horizon2020) | |
| Industry funding | |
| -of which is industry cash | |
| Host university funding (if applicable) | |
| Other University funding | |

**3.2)** Please indicate the importance of each of the following types of research funding for your Research Centre operations.

| | Not Important 1 | 2 | 3 | 4 | Very Important 5 |
|---|---|---|---|---|---|
| Science Foundation Ireland funding | | | | | |
| Enterprise Ireland funding | | | | | |
| International Competitive funding (e.g. EU Horizon2020) | | | | | |
| Industry funding | | | | | |
| -of which is industry cash | | | | | |
| Host university funding (if applicable) | | | | | |
| Other University funding | | | | | |

### *3.2 Human Resources*

**3.3)** Please indicate the number of research and support staff in your Research Centre *(Please estimate in terms of full-time employment equivalent e.g. two half-time employees are equivalent to one full-time employee*)

| | 2015 | 2016 | 2017 (est.) |
|---|---|---|---|
| No. of researchers and support staff | | | |

**3.4)** Please indicate the percentage of your staff in each of the following categories *(please note answers should equal 100%)*

| | |
|---|---|
| Principal Investigators | % |
| Researchers | % |
| Postdoctoral researchers | % |
| PhD/ Masters students | % |
| Non-research staff (e.g. centre management and administrative staff) | % |

**3.5)** Please indicate the percentage of staff that are foreign nationals %

**3.6)** Please indicate the number of PhD graduates at your Research Centre during the last three years

| | 2015 | 2016 | 2017 (est.) |
|---|---|---|---|
| No. of PhD graduates | | | |

**3.7)** Please indicate the country of origin of PhD graduates from your Research Centre during last three years (Answers should equal 100%)

| | |
|---|---|
| Ireland | % |
| United Kingdom | % |
| Rest of Europe | % |
| North America | % |
| South America | % |
| China | % |
| India | % |
| Rest of World | % |

**3.8)** Please indicate the percentage of your Research Centres PhD graduates employed across each area (*please note answers should equal 100%)*

| | |
|---|---|
| IPIC | % |
| Other Research Centre | % |
| Academia | % |
| Industry | % |
| Government | % |
| Non-Profit | % |

## *4. Research Centre Outputs*

**4.1)** Please *estimate* the total number of research outputs produced by your Research Centre and the importance of each output for Research Centre

| | 2015 | 2016 | 2017 | Not Important 1 | 2 | 3 | 4 | Very Important 5 |
|---|---|---|---|---|---|---|---|---|
| Peer Reviewed Journal Publications | | | | | | | | |
| Public-private co-publications | | | | | | | | |
| Number of Citations | | | | | | | | |
| Other publications (e.g. policy documents etc.) | | | | | | | | |
| Conferences, workshops and seminars organised | | | | | | | | |
| European Council awards | | | | | | | | |
| Number of Spin-Offs | | | | | | | | |

**4.2)** Please indicate the total number of each of the following IP outputs produced by your Research Centre and the importance of each output to your Research Centre's operations? (*Please tick as appropriate*)?

| | 2015 | 2016 | 2017 | Not Important 1 | 2 | 3 | 4 | Very Important 5 |
|---|---|---|---|---|---|---|---|---|
| Number of patents filed | | | | | | | | |
| Licenses, options and Agreements | | | | | | | | |
| Trademarks filed | | | | | | | | |

## *5. Sources of Collaboration*

**5.1)** How important are the following sources of collaboration for your Research Centre the last three years? (*Please tick as appropriate*)?

| | Not Important | | | | Very Important |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Research Centres | | | | | |
| Host university, if applicable | | | | | |
| Universities | | | | | |
| Hospitals/ clinicians | | | | | |
| Research Performing Organisations (RPO) | | | | | |
| Irish Small and Medium Enterprises (SMEs) | | | | | |
| Foreign-Owned Multinationals (MNCs) | | | | | |
| Innovation support agencies (e.g. SFI, EI, IDA) | | | | | |

**5.2)** Please indicate the frequency of interaction with following sources of collaboration for your Research Centre activities during the last three years? (Please tick as appropriate)?

| | Never | | | | Continuous |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Research Centres | | | | | |
| Host university, if applicable | | | | | |
| Universities | | | | | |
| Hospitals/ clinicians | | | | | |
| Research Performing Organisations (RPO) | | | | | |
| Irish Small and Medium Enterprises (SMEs) | | | | | |
| Foreign-Owned Multinationals (MNCs) | | | | | |
| Innovation support agencies (e.g. SFI, EI, IDA) | | | | | |

**5.3)** Please indicate the percentage of collaborations involving international partners

| |
|---|
| % |

**5.4)** Please indicate the significance of the following barriers of knowledge transfer between your Research Centre and R&D partners (*Please tick as appropriate*)

| | Not Significant | | | | Very Significant |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Quality, relevance and usefulness of knowledge | | | | | |
| Lack of scientific knowledge base in partner | | | | | |
| No designated contact person | | | | | |
| Low quantity of interaction | | | | | |
| Poor quality of interaction | | | | | |
| Differences in culture | | | | | |
| Geographic distance between organisations | | | | | |

## Appendix A5. Industry Partner Impact Questionnaire

### 1. *Business Characteristics*

**1.1)** Please indicate whether this business is: *(Please tick relevant box)*

| | |
|---|---|
| A single-plant company | |
| A parent or group HQ | |
| A subsidiary plant in a group | |

**1.2)** In what year did your business begin operations in Ireland?

| |
|---|
| |

**1.3)** Is your business a spin-off from Irish Photonic Integration Centre (IPIC) or any other Research Centre?

| | |
|---|---|
| IPIC | |
| University | |
| Other Research Centre | |
| None of the above | |

**1.4)** Please indicate the number of employees employed in your business in Ireland *(Please estimate in terms of full-time employment equivalent e.g. two half-time employees are equivalent to one full-time employee*)

| | |
|---|---|
| (i) at the start of 2015 | |
| (ii) at the end of 2017 | |

**1.5)** Please <u>estimate</u> the total turnover for your business in 2017 *(Turnover is defined as the total amount of revenue generated by the business during the period*)

| | 2017(€) |
|---|---|
| Turnover | |

**1.6)** Please select the research prioritisation area which your business operates in. *(Please tick one box)*

| Research Prioritisation Area | | | |
|---|---|---|---|
| Future Networks & Communications | | Marine Renewable Energy | |
| Sustainable Food Production and Processing | | Smart Grids & Smart Cities | |
| Digital Platforms, Content & Applications | | Manufacturing Competitiveness | |
| Connected Health and Independent Living | | Processing Technologies and Novel Materials | |
| Medical Devices | | Innovation in Services and Business Processes | |
| Diagnostics | | | |
| Therapeutics: Synthesis, Formulation, Processing and Drug Delivery | | Data Analytics, Management, Security & Privacy | |
| Food for Health | | Other, please specify | |

## 2. *Innovation Capacity of Business*

### *2.1. R&D Activities of business*

| | Yes | No |
|---|---|---|
| **2.1)** Was any R&D undertaken in your business between 2015 and 2017? | | |
| **2.2)** Is there a formal R&D department in your business? | | |

**2.3)** Please indicate the number of employees engaged in R&D on FTE basis in 2017 *(Please estimate in terms of full-time employment equivalent e.g. two half-time employees are equivalent to one full-time employee*)

**2.4)** Please estimate R&D expenditure as a proportion of your business' turnover between 2015 and 2017. (*Please tick one box*)

| | | | |
|---|---|---|---|
| 0-5% | ☐ | 16-20% | ☐ |
| 6-10% | ☐ | 21-25% | ☐ |
| 11-15% | ☐ | More than 25% | ☐ |

**2.5)** Please estimate non-R&D expenditure as a proportion of business turnover during the last three years *(Please tick one box)*

| | | | |
|---|---|---|---|
| Less than 25% | ☐ | 46-55% | ☐ |
| 25-35% | ☐ | 56-65% | ☐ |
| 36-45% | ☐ | More than 65% | ☐ |

**2.6)** Please estimate the average annual expenditure for collaboration activities with IPIC between 2015 and 2017

| | € |
|---|---|
| Average annual expenditure | |
| -of which is industry cash | |

**2.7)** Please indicate the importance of each of the following activities between your business and IPIC during the last three years *(Please tick as appropriate).*

| | Not Important | | | | Very Important |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Peer-reviewed journal articles | | | | | |
| Co-publications with research centres | | | | | |
| Employment of research centre PhDs | | | | | |
| Attendance at conferences, workshops and seminars | | | | | |
| Financing PhD projects | | | | | |
| Informal meetings, talks and communications | | | | | |
| Personnel exchange between your business and research centres | | | | | |
| Collaborative research, joint research programmes | | | | | |
| Contract research | | | | | |
| Licensing of Research Centre IP | | | | | |
| Financing PhD projects | | | | | |

**2.8)** Please indicate the total number of each of the following measures of Intellectual Property (IP) produced by your business during the last three years

| | |
|---|---|
| Patents Filed | |
| Trademarks filed | |
| Licenses, options and agreements | |

**2.9)** Please indicate approximately the percentage of your employees with the following qualifications as their highest level of educational attainment (%)

| | % |
|---|---|
| Masters | |
| PhD | |

**2.10)** Please indicate the total number of IPIC postgraduates hired by your company during the last five years.

| |
|---|
| |

## *3. Sources of Collaboration*

**3.1)** How important are the following sources of collaboration for the R&D activities of your business over the last three years? (*Please tick as appropriate*)?

| | Not Importa | | | | Very Important |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| IPIC | | | | | |
| Research centres in Ireland | | | | | |
| Research centres outside Ireland | | | | | |
| Universities | | | | | |
| Research Performing Organisations (RPOs) | | | | | |
| Competitors | | | | | |
| Suppliers | | | | | |
| Innovation support agencies (e.g. Enterprise Irelar IDA Ireland etc.) | | | | | |

**3.2)** Please indicate the frequency of interaction between your business and its R&D partners *(tick as many as apply)*

| | Continu-ous | Very frequently (Several times a year) | Frequently (At least once per year) | Rarely (Less than once a year) | Never |
|---|---|---|---|---|---|
| IPIC | ☐ | ☐ | ☐ | ☐ | ☐ |
| Research centres in Ireland | ☐ | ☐ | ☐ | ☐ | ☐ |
| Research centres outside Ireland | ☐ | ☐ | ☐ | ☐ | ☐ |
| Universities | ☐ | ☐ | ☐ | ☐ | ☐ |
| Research Performing Organisations (RPOs) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Competitors | ☐ | ☐ | ☐ | ☐ | ☐ |
| Suppliers | ☐ | ☐ | ☐ | ☐ | ☐ |
| Innovation support agencies (e.g. Enterprise Ireland, IDA Ireland etc.) | ☐ | ☐ | ☐ | ☐ | ☐ |

## *4. Benefits of Collaboration with IPIC*

**4.1)** Please indicate the <u>importance</u> of each of the following objectives for your business when initially entering into collaboration with IPIC (*Please tick as appropriate*).

| | Not Important | | | | Very Important |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| To improve employee skills | | | | | |
| To increase profitability | | | | | |
| To capture a bigger market share | | | | | |
| To expand geographically | | | | | |
| To create new products | | | | | |
| To increase access to postgraduate level trainees | | | | | |
| To improve scientific capability of business | | | | | |
| To diversify / new products in new markets | | | | | |

**4.2)** To what extent would you agree with the following statements: During past three year's collaboration with IPIC has: (*Please tick as appropriate*).

| | Strongly Disagree 1 | 2 | 3 | 4 | Strongly Agree 5 |
|---|---|---|---|---|---|
| Improved my business' scientific capability | | | | | |
| Improved my business' ability to identify and recruit well-qualified graduate students | | | | | |
| Improved my business's ability to establish new strategic partnerships | | | | | |
| Improved the quality of strategic partners | | | | | |
| Helped accelerate the pace and/or completion of some R&D projects | | | | | |
| Helped the organisation to decide against starting one or more new R&D projects that otherwise would have been initiated. | | | | | |
| Contributed to development of new R&D projects at my organisation, or significantly redirected pending projects within my organisation. | | | | | |
| Significantly improved our business processes | | | | | |

**4.3)** Please indicate the importance of collaboration with IPIC on each of the following investments by your business *(Please tick as appropriate)*

| | Not Important 1 | 2 | 3 | 4 | Very Important 5 |
|---|---|---|---|---|---|
| R&D Team | | | | | |
| R&D facilities | | | | | |
| Advanced manufacturing activities | | | | | |
| Manufacturing facilities | | | | | |
| External R&D | | | | | |
| Acquisition of technology, patents and licenses | | | | | |

**4.4)** Has your business introduced ANY new or improved products during the last 3 years?

| | Yes | No |
|---|---|---|
| Product Changes over last 3 years | | |

**IF NO PLEASE SKIP TO QUESTION 5.6**

**4.5)** Please indicate approximately the percentage of turnover derived from new product sales during the last three years (%)

| |
|---|
| |

**4.6)** Please indicate approximately the percentage of exports derived from new product sales during the last three years (%)

| |
|---|
| |

**4.7)** Please describe the main type of product innovation facilitated by your business collaboration with IPIC between 2015 and 2017 (*Please tick as appropriate*)

| | |
|---|---|
| New to business product innovation | |
| New to industry product innovation (national) | |
| New to industry product innovation (international) | |
| Innovation which cannot be imitated | |
| None, but expected | |

**4.8)** Has your business introduced ANY new or improved processes innovations during the last three years?

| | Yes | No |
|---|---|---|
| Process Changes over last three years? | | |

**IF NO PLEASE SKIP TO QUESTION 5.8**

**4.9)** Please indicate the extent to which your business introduced new processes between 2015 and 2017. (Please tick one box)

| Continuous | Very frequently (Several times a year) | Frequently (At least once per year) | Rarely (Less than once a year) | Never |
|---|---|---|---|---|
| □ | □ | □ | □ | □ |

**4.10)** Please indicate the <u>importance</u> of collaboration with IPIC for the following indicators (*Please tick as appropriate*).

| | Not Important 1 | 2 | 3 | 4 | Very Important 5 |
|---|---|---|---|---|---|
| Turnover | | | | | |
| Employment | | | | | |
| Exports | | | | | |
| Profits | | | | | |
| R&D Investment | | | | | |
| Market Share | | | | | |

**4.11)** Please indicate <u>approximately</u> the average annual growth in each of the following indicators during the last three years (%)

| | |
|---|---|
| Turnover | |
| Employment | |
| Exports | |
| Profits | |
| R&D Investment | |
| Market Share | |

**4.12)** Please <u>estimate</u> what the average annual growth in each of the following indicators would have been **in the case that your business <u>HAD NOT</u> collaborated with IPIC (%)**

| | |
|---|---|
| Turnover | |
| Employment | |
| Exports | |
| Profits | |
| R&D Investment | |
| Market Share | |

We welcome your feedback. Please tell us what you think about this questionnaire and let us know what type of published data would be useful to your business.

Please add any comments that would help us interpret the data provided and avoid further

## Appendix A6. Contacting Interview Participants

Dear (Respondent)

As part of a research project funded by Science Foundation Ireland (SFI) and the Irish Research Council (IRC), we are developing robust tools and frameworks to measure and evaluate the economic impact of publicly funded research centres. The evaluation tool developed aims to optimise engagement between research centres and industry, increase economic impacts generated through research activities and benchmark research centre performance. The study is funded by Science Foundation Ireland and Irish Research Council but is conducted independently of them.

Qualitative interviews with key stakeholders in the Irish innovation system will form an important element of the study and we were hoping that you could assist us with this endeavour. The objective of the interview will be to shed light on key topics related to research impact, such as:

- Meanings and definitions of research impact
- The usefulness of impact to guide evaluation
- Impact measurement issues and strategies
- Impact management within organisations
- Research impact within the Irish innovation system

All responses to the questions will be treated with strict confidentially. Each interview will be assigned a number code to help ensure that personal identifiers are not revealed during the analysis and write up of findings and comments will not be attributable to any respondent.

We are hoping to conduct the interviews between December 2018 and February 2019. If you are willing to participate in the study please suggest a day and time that suits you, and I'll do my best to be available to travel to conduct the interview. The interviews will take approximately one hour to complete. If you have any questions, please do not hesitate to ask.

Kind regards,

Stephen Brosnan

**Stephen Brosnan**
**SFI Research Scholar**
Department of Economics
CORK UNIVERSITY BUSINESS SCHOOL
University College Cork, Ireland

stephen.brosnan@ucc.ie
cubs.ucc.com

## Appendix A7. Process of Contacting Potential Interviewees

| Position | Date Contacted | Follow up #1 | Follow up #2 | Follow up #3 | Interview Date |
|---|---|---|---|---|---|
| Head of Research Policy | 28/09/2018 | 21/11/2018 | 03/12/2018 | 17/01/2019 | 08/02/2019 |
| IP Manager | 28/09/2018 | 21/11/2018 | 03/12/2018 | 17/01/2018 | 30/01/2019 |
| Programme Manager - Technology Centres | 28/09/2018 | 21/11/2018 | 03/12/2018 | | 15/01/2019 |
| Director | 28/09/2018 | | | | 01/11/2018 |
| Head of Pre-Award & Grants | 28/09/2018 | | | | |
| Scientific Programme Manager | 28/09/2018 | | | | |
| Head of Enterprise Partnerships | 28/09/2018 | | | | |
| Associate Director | 28/09/2018 | | | | |
| General Manager | 28/09/2018 | | | | |
| Centre Manager | 28/09/2018 | | | | |
| Director | 08/10/2018 | 21/11/2018 | 03/12/2018 | 17/01/2018 | 21/01/2019 |
| Principal Investigator | 08/10/2018 | 21/11/2018 | 03/12/2018 | 17/01/2018 | |
| System Design Engineer | 08/10/2018 | | | | |
| Chief Executive Officer | 08/10/2018 | | | | |
| Innovation Unit Manager | 08/10/2018 | | | | |
| Co-founder & CEO | 08/10/2018 | | | | |
| Founder & CEO | 08/10/2018 | | | | |
| Principal Investigator | 16/10/2018 | | | | |
| Director | 16/10/2018 | | | | |
| Head of Business Strategy | 03/12/2018 | | | | 20/12/2018 |
| Head of Research | 03/12/2018 | | | | 18/12/2018 |

| | | | | | |
|---|---|---|---|---|---|
| Programme Manager | 03/12/2018 | | | | 11/12/2018 |
| Deputy Director and PI | 03/12/2018 | | | | |
| Commercial Manager | 03/12/2018 | | | | |
| Technology Gateway Manager | 03/12/2018 | | | | |
| Investigator | 22/01/2019 | | | | 18/02/2019 |
| Project Co-lead | 22/01/2019 | | | | 12/02/2019 |
| Director | 22/01/2019 | | | | 12/02/2019 |
| Director | 22/01/2019 | | | | 06/02/2019 |
| PI | 22/01/2019 | | | | |
| Director | 22/01/2019 | | | | |
| Director | 22/01/2019 | | | | |
| Funded Investigator | 22/01/2019 | | | | |
| Deputy Director and PI | 22/01/2019 | | | | 27/02/2019 |
| Project Manager | 22/01/2019 | | | | |
| Principal Investigator | 22/01/2019 | | | | |

**Appendix A8. Information Sheet and Consent Form**

# INFORMATION SHEET

**Purpose of the Study.** As part of the requirements for my doctoral thesis at UCC, I must carry out a research study. The aim of the study is to develop robust tools and frameworks to measure and evaluate the economic impact of publicly funded research centres.

**What will the study involve?** The study will involve the development of a robust framework, **I**mpact **M**easurement and **P**erformance **A**ssessment of **C**entres of **T**echnology and **S**cience (IMPACTS) framework, to measure economic impact of research Centres. The IMPACTS framework provides the theoretical foundation for the development of a novel measurement tool, Research Impacts Index (RII). The RII measures research centre performance across several dimensions including scientific, technological, investments and economic impacts. Thus, addressing the demands from policymakers, funding bodies and the public for greater justification for investments. Furthermore, qualitative interviews with key stakeholders in the Irish innovation system will form an important element of the study. The objective of the interviews will be to shed light on the meanings and conceptualisations of research impact.

**Why have you been asked to take part?** You have been asked to participate because you have been identified as a key stakeholder in the Irish research sector.

**Do you have to take part?** No – participation is voluntary. Each participant has the option of withdrawing before the study commences (even if they have agreed to participate) or discontinuing after data collection has started. A consent form is included which provides an explanation of the terms of agreement. Each participant does not have to sign the consent form. Participants will be allowed to keep the information sheet and a copy of the consent form. Participants may request to withdraw within two weeks of participation and ask to have their data destroyed.

**Will your participation in the study be kept confidential?** Yes. I will ensure that no clues to your identity appear in the thesis. Any extracts from what you say that are quoted in the thesis will be entirely anonymous.

**What will happen to the information which you give?** The data will be kept confidential for the duration of the study, available only to me and my research supervisor. It will be securely stored on an external hard drive with password protection on all interviews. On completion of the project, they will be retained for a further ten years and then destroyed.

**What will happen to the results?** The results will be presented in the thesis. They will be seen by my supervisors, a second marker and the external examiner. The results may be presented at SFI/IRC steering groups and committees. The study may be published in a peer-reviewed research journal.

**What are the possible disadvantages of taking part?** I don't envisage any negative consequences for you in taking part.

**What if there is a problem?** The interview may be paused or terminated at any time.

**Who has reviewed this study?** The study has been reviewed by the Social Research Ethics Committee of UCC.

**Any further queries?** If you need any further information, you can contact me: Stephen Brosnan, 0870968982, Stephen.brosnan@ucc.ie.

If you agree to take part in the study, please sign the consent form overleaf.

# CONSENT FORM

I……………………………………agree to participate in Stephen Brosnan's research study.

The purpose and nature of the study has been explained to me in writing.

I am participating voluntarily.

I give permission for my interview with Stephen Brosnan to be audio-recorded.

I understand that I can withdraw from the study, without repercussions, at any time, whether before it starts or while I am participating.

I understand that I can withdraw permission to use the data within two weeks of the interview, in which case the material will be deleted.

I understand that anonymity will be ensured in the write-up by disguising my identity.

I understand that disguised extracts from my interview may be quoted in the thesis and any subsequent publications if I give permission below:

(Please tick one box)

I agree to quotation/publication of extracts from my interview ☐

I do not agree to quotation/publication of extracts from my interview ☐

Signed: ………………………………….

Date: ………………….

PRINT NAME: …………………………………….