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Assessing the Economic and Commercial Impacts of Publicly Funded Research Centres: An endogenous systems framework

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Abstract

State-of the- Art: Publicly funded research has been identified as a key mechanism for enhancing economic growth, competiveness, and innovation at national, regional, and local levels. However, the relationship between research, commercialisation, and economic development is a complex one, mediated by a complex set of overlapping interactions and institutions. Suitable frameworks for assessing research impact should reflect this complex, dynamic, and nonlinear processes inherent in knowledge creation and commercialisation however current frameworks are underdeveloped and present an incomplete view of the research impact process. Research gap: This paper develops a novel framework to measure and evaluate the economic and commercial impacts of publicly funded research centres. An important new element in this framework is the inclusion of a research centre's contribution to the research system, in addition to more traditional direct contributions through bibliometrics, intellectual property, and industry engagements. The framework distinguishes between the potential and realised absorptive capacity of the system and the magnitude of its effect on a research centre's ability to provide economic and commercial impacts. Theoretical Considerations: Grounded in an evolutionary economics perspective, the framework views research centres as important cogs within an innovation system and emphasises that an important, and overlooked, element of the impact of such centres is their impact on the research system within which they operate. As such, this framework emphasises the importance of collaboration between research centres and other entities within the system for the enhancement of research centre impact. Methodology: A detailed literature review was conducted to assess current best practices associated with research centre impact assessment. This included identifying different indicators, metrics and categories used to measure research impact, various frameworks and methodologies used in impact assessment and limitations associated with current frameworks which the Research Centre Impact Framework attempts to overcome. Results: The result of the literature review has contributed to a working paper titled "Assessing the Economic and Commercial Impacts of Publicly Funded Research Centres: An endogenous systems framework". The paper presents a novel, flexible framework developed based on both best practices and inherent weaknesses of current frameworks identified in the research centre impact assessment literature.

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Ex Ante Evaluation Framework for the Economic and Commercial Impact of Publicly Funded Research Centres

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1. Introduction

Publicly funded research has been identified as a key mechanism for enhancing economic growth, competiveness, and innovation at national (Guellec and Potterie, 2000, Schildt et al., 2012), regional (Hewitt-Dundas and Roper, 2011), industry (Beise and Stahl, 1999, Arundel and Geuna, 2001), and firm (Roper et al., 2004) levels. However, governments are increasingly faced with difficult budgetary constraints, substantial competing demands and opportunity costs when making public investment decisions. As such, policymakers are increasingly stressing the importance of accountability and justification for the allocation of public funding for research activities.

Measuring the economic and commercial impacts of publicly funded research centres has generated an extensive and evolving literature, both in Europe (Buxton and Hanney, 1994, Salter and Martin, 2001, Grant, 2006, Spaapen and Van Drooge, 2011, Hughes and Martin, 2012) and the United States (Sarli et al., 2010, Lane and Schwarz, 2012). Frameworks developed to measure the impact of publicly funded research have been applied across a large variety of countries, sectors, and institutional settings. However, 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).

This paper provides an assessment of the range of potential economic and commercial impacts which may result from research centre activities. The indicators identified are based on an inventory suggested by ex post evaluations and related empirical and conceptual studies. These studies have been reviewed and analysed with the objective of identifying indicators used to capture the dynamics of the innovation process, best practices in regards to impact measurement, and key issues which need to be addressed when conducting research centre impact evaluation exercises. This analysis provides context and rationale for the development of a new robust framework and tools which move beyond standard measures of research impact to develop and test quantitative and qualitative indicators of impact.

In particular this paper 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 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. The impact assessment framework presented in this paper therefore includes the impact of a research centre on the innovation system.

The remainder of the paper is organised as follows. Section 2 presents the conceptual and contextual issues that must be considered in formulating a Research Centre Impact Framework (RCIF). Section 3 examines the factors which influence a research centre's ability to provide sustainable economic and commercial impacts. Section 4 focuses on the proposed implementation of the framework and the potential for future work in the area.

2. Why Invest in Publicly Funded Research Centres?

2.1 Neoclassical Perspective

The concept of market failure, drawn from neoclassical economic theory, provides the traditional justification for investment by government in publicly funded research. Nelson (1959) and Arrow (1962) provided the foundation for much of the economic analysis which considers knowledge a public or quasi-public good. Knowledge satisfies the criteria of public goods as it is considered non-rival and only partially excludable. The primary function of publicly funded research and research centres is to increase the stock of knowledge currently available in an economy. As such, investment in research centres is justified under the premise that these centres are producing public goods which would under-provided through market mechanisms, relative to the socially optimal level.

2.2.Evolutionary Perspective

An alternative approach to evaluating the impact of publicly funded research is the evolutionary perspective pioneered by Metcalfe (1995). From an 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, p.6). Two points are fundamental to the argument from 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 diffusion of knowledge should not be considered in isolation but rather in its interrelation to one another. 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 (Hughes and Martin, 2012).

The framework developed in this paper considers research centre impact from an evolutionary perspective. The evolutionary perspective provides a more satisfactory explanation of the processes through which publicly funded research centres contribute to increases in economic growth and development. Salter et al. (2000) highlight 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 the evolutionary perspective, the research centre is viewed as a vital cog within the innovation system, intrinsically linked to other entities within the system including firms, universities, and government agencies. Salter et al. (2000, p.29) assert "firms do not innovate in isolation". Additionally, research centres do not provide 'impacts' in isolation. The economic and commercial impacts of publicly funded research centres are dependent not only the quality of the research centre itself but also on the strength of the innovation system in which it is embedded. Gibbons et al. (1994) identified this important shift in the nature of knowledge production towards greater collaboration and trans-disciplinarity and research being conducted 'in the context of its application'. As such, research centre impact depends to a large extent on engagement and interaction of various actors within the innovation system contributing to the formation of a collective system of knowledge creation, assimilation and exploitation.

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 best use of available knowledge which provides unique opportunities to increase productivity and innovation capacity. The RCIF highlights the significance of specific researchers and collaborative networks at each stage of the research process.

The RCIF places significant importance on the absorptive capacity of firms and other elements of the innovation system. While the neoclassical perspective implies that knowledge is "on the shelf, costlessly available to all comers" (Rosenberg, 1990, p.165), 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.

Cohen and Levinthal (1990, p.129) define absorptive capacity as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends". However, the concept has been reconceptualised and reformulated by many authors citing the limitations of the original concept and ambiguity surrounding definitions and measurement of the term. Zahra and George (2002) provide a popular reconceptualisation of the concept suggesting that absorptive capacity exists as two subsets of potential and realised absorptive capacity. Potential absorptive capacity refers to a firm's capabilities in the acquisition and assimilation of knowledge while realised absorptive capacity refers to the transformation and exploitation of knowledge.

The RCIF considers the impact of publicly funded research centres in the context of its internal and external relationships which are essential for the development of absorptive capacity, both within the system and individually for each entity within the system. The framework adopts Zahra and George (2002) approach incorporating both potential and realised absorptive capacity into the framework. This allows for an investigation into the determinants of research centre impact and attempts to overcome the problem of attribution by identifying whether research impact is limited by weaknesses inherent in a particular centre, or whether firms have sufficient capacity to absorb and exploit knowledge.

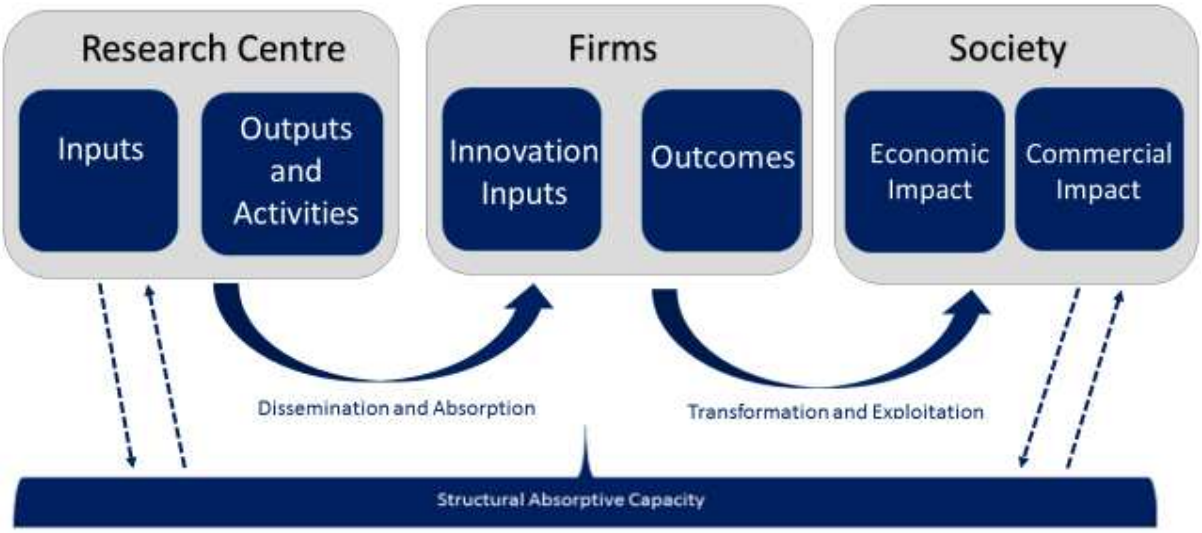
Finally, the influence of country specific factors, relating to the improvement of innovation capacity, are considered in the context of its effect on a research centres ability to generate economic and commercial impacts. These country specific factors are labelled structural absorptive capacity which relates to national system elements' ability to identify, assimilate, and exploit knowledge. Enhancing structural absorptive capacity is essential for driving innovation, economic growth and research centre's ability to provide economic and commercial impacts. However, research centres are not passive members of the system within which they operate. The activities of the research centre, including national and

international collaborations, hiring of researchers, and generation of research outputs, impact the effectiveness of the innovation system. As such, a bidirectional relationship exists between research centres and the system which they are embedded within. A research centres ability to provide economic and commercial impact is influenced by the system while the strength of the system is also influenced by research centres. Therefore, a comprehensive assessment of impact must move beyond bibliometric and industry-focussed indicators, to include the extent to which research centres contribute to the entire system.

3. Research Centre Impact Framework

The previous section highlighted the theoretical and conceptual basis for the development of a framework to measure and evaluate the economic and commercial impacts of publicly funded research centres. This section highlights the novel framework developed in this paper to measure these impacts. An extensive literature review was carried out in order to identify the frameworks currently available for the measurement of research centre impact. Figure 1 illustrates the RCIF developed in this paper to measure and evaluate the economic and commercial impact of publicly funded research centres.

Figure 1 Research Centre Impact Framework



The RCIF analyses the impact of publicly funded research centres by considering how each element of the innovation system and their interactions with one another contributes to

enhancing economic and commercial impacts. The first element of the system considered is the research centre itself. The framework identifies the inputs and outputs of the research centre.

3.1 Inputs

Inputs are defined as research centre resources required to achieve policy and strategic objectives and deliver economic and commercial impact. The framework developed in this paper categorises inputs into three categories:

- Financial resources, including the public funding received by the research centre, which can be leveraged with both cash and in-kind funding from industry.
- Human capital resources, including the characteristics of the personnel employed by the research centre, specifically relating to education, skills, and problem solving capabilities.
- Infrastructural resources, including fixed assets such as buildings and machinery, scientific equipment, databases and conceptual tools and models, often expensive and specialised, which are used in the innovation process.

Table 1 highlights the indicators and metrics of research centre inputs used in the framework.

Table 1 Research Centre Inputs

Input Category	Indicator(s)	Sample Metric(s)	Description
Financial Resources	Self-Generated Funding	Value in € of self-generated funding	Total value of funding generated by the research centre (€) as a result of sales IP, etc. (€, growth, expected, achieved)
		% of total funding from self-generated sources	Total value of funding generated by the research centre divided by total funding (%, growth, expected, achieved)
	Government Funding	Value in € of government funding	Total value of funding generated by the research centre from government sources (€, growth, expected, achieved)
		% of total funding from government sources	Total value of funding generated by the research centre from government sources divided by total funding (%, growth, expected, achieved)
	Competitive Funding	Value in € of industry funding	Total value of funding generated by the research centre from industry sources (€, growth, expected, achieved)
		% of total funding from industry sources	Total value of funding generated by the research centre from industry sources divided by total funding (%, growth, expected, achieved)
		Number of employees with PhDs	Total number of employees with PhDs (growth, expected, achieved)

Human Capital	**PHDs**	% of employees with PhDs	Total employees with PhDs divided by total employees (growth, expected, achieved)
	Internationalisation	% of employees from foreign countries	Total number of foreign employees divided by total employees (%, growth, expected, achieved)
Infrastructure	**Infrastructure Grants (€)**	Value in € of infrastructure grants	Total value of infrastructure grants in €
	Machinery	Value in € of machinery used by centre	Total value of machinery in €
	Scientific Equipment	Value in € of Scientific Equipment used by centre	Total value of scientific equipment in €
	Databases	Number of unique databases available the centre	Total number of unique databases available in the centre
	Instruments	Number of unique instruments available in the centre	Total number of unique instruments available in the centre
	Technological transfer support structures	Number and quality of technological transfer support structures	Total number and quality of technological transfer support structures
	Conceptual Tools	Number of new conceptual tools and models developed	Total number of new conceptual tools and models developed

Under the RCIF, financial resources are comprised of various sources of funding including public funding (from national and international sources) which is leveraged with c funding to finance activities within the research centre. The objectives of research centres concerning the composition of research funding vary from centre to centre. For example, the Fraunhofer Centres in Germany adopt a model which aims to generate a third of its funding from public sources, a third from industry sources, and a third of self-generated funding. The generation of industry and international funding is considered a key indicator of research centre quality with only the most prestigious centres are likely to have the ability and reputation to attract sufficient investment.

Human capital resources provide key inputs into the process of research centre impacts. 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, and society. The level of education is the most common indicator of human capital and as such, the framework includes sample measures of human capital based on educational attainment

and research intensity of work, such as the percentage of staff with PhDs and the percentage of staff working in R&D.

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, 2015). 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".

3.2 Outputs and Activities

Research outputs are produced as a result of research centre inputs and research activities undertaken. Outputs such as patents, publications, and citations are used extensively in studies measuring the impact of publicly funded research. Studies present contrasting evidence with some suggesting that codified outputs, such as patents and publications, are the most important transfer mechanisms (Arundel and Geuna, 2001, Cohen et al., 2002) while others highlight the importance of tacit outputs such as conferences, networking, and informal contacts, to knowledge transfer activities (Meyer-Krahmer and Schmoch, 1998, Bekkers and Freitas, 2008, Perkmann et al., 2013). As such, the RCIF identifies a combination of both codified and tacit measures of research centre output.

However, caution should be taken when interpreting outputs as impacts in themselves. For example, while patents are considered an important output of research centre activities, the value and impact of the patent itself is often uncertain. The volume of patenting tends to be industry specific with patenting highly valued in certain industries such as ICT, biotech and pharmaceuticals while less so in other industries. Additionally, Nelson (2009) finds direct patent citations dramatically understate the extent of technology diffusion compared to other outputs such as licenses and publications. As such, a patent represents only a potential impact which must be exploited before providing economic and commercial impacts.

The RCIF categorises outputs and activities into five different categories including:

- Scientific quality,
- Collaboration and Mobility,
- Intellectual Property,

- Methodologies and Instrumentalities, and
- Spin-Offs.

Table 2 shows the potential research output indicators and metrics included in the RCIF.

Table 2 Research Output Indicators

Output Category	Indicator(s)	Sample Metric(s)	Description
Scientific Excellence	**Publications**	Number of peer reviewed publications	Total number of peer reviewed publications
		Publications per researcher	Total number of publications/ total number of researchers
		Publications downloaded	Average number of downloads per publication
	Citations	Average Relative Citation	Average number of citations per publication
		Citations in high impact journals	% of citations in high impact journals
		Media citations	Number of media citations including international seminar presentations, interviews and newspaper articles
		% of international citations	Total number of international publications / total number of publications
		% of industry citations	Number of industry citations / total number of citations
Collaboration and Mobility	**Collaborations**	Number of collaborations	Total number of collaboration between research centre and partners
		Type of collaboration	Types of collaboration between research centre and partners
		Average Duration of collaborations	Average length of collaboration between research centre and partners
		Number of Institutions engaged in Collaboration	Average number of Institutions engaged in Collaboration
		% of international collaborations	Total number of international collaborations/ total collaborations.
		New Strategic Partners	New strategic partnerships created through funding
	Staff Mobility	Number of researchers leaving to work in industry	Total number of researchers leaving to work in industry
	Patents	Number of patent applications	Total number of patent applications
		Number of patents granted	Total number of patents granted
		Patents per € of funding	Total number of patents/ total funding
		Number of licenced patents	Total number of licenced patents

Intellectual Property	**Licensing**	Number of patents licenced per € of funding	Total number of licences divided by total funding (€)
	Trademarks	Number of trademarks, copyrights, etc. received	Total number of trademarks, copyrights, etc. received
		Number of trademarks, copyrights, etc. per € of funding	Total number of trademarks divided by total funding (€)
	Prototypes	Prototypes developed	Total number of prototypes developed
		Prototypes developed per € of funding	Total number of prototypes divided by total funding (€)
	Products	Creation of new products	Total number of new products
		New products per € of funding	Total number of new products created / total funding
		Improvements to existing products	Total number of improvements to existing products
Methodologies and Instrumentalities	**Datasets**	New databases created	Total number of databases created
		New databases created per € of funding	Total number of databases created divided by total funding (€)
	New conceptual tools and models for decision making	Number of models developed to inform decision making	Total number of models developed to inform decision making
		Number of models developed to inform decision making per € of funding	Total number of models developed to inform decision divided by total funding (€)
	Creation of new novel research methodologies	Number of new novel research methodologies	Total number of new novel research methodologies
	New instruments and tools developed	Total number of new instruments and tools developed	New tools, techniques, models, simulations, prototypes, demonstration activities, pilots, living labs, competence platforms
		Total number of new instruments and tools developed per € funding	New tools, techniques, models, simulations, prototypes, demonstration activities, pilots, living labs, competence platforms per € of funding
Spin Offs	**Number of new spin-offs**	Total number of new spin-offs	Total number of new spin-offs
	Spin-offs per € of funding	Number of spin-offs per € of funding	Total number of spin-offs divided by funding (€)
	Survival rates of spin-offs	Survival rates of new spin-offs	% of spin-offs still active after a specific period of time
	Average number of employees at spin-offs	Average number of former researchers in employment in spin-offs	Average number of former researchers employed in spin-offs and details surrounding nature of the work, R&D intensity of jobs and whether full time or part time.

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 citations are considered important indicators of scientific quality. These outputs facilitate knowledge transfer which may be used by individuals and businesses to increase competitiveness whilst informing decision-making for policymakers. Cohen et al. (2002) found that nearly 30% of R&D managers in industry cited publications from public research as a useful input into their projects within the past three years, in industries as varied as petroleum, pharmaceuticals, aerospace, communication, and semiconductor industries (ibid, p.11-12). Similarly, Arundel and Geuna (2001) found that publications are the methods to obtain the results of public research most frequently cited as important.

Collaboration refers to the process of two or more individuals or organisations working together to achieve a shared goal. Collaboration between research centres and other entities within the innovation system is important for the generation of new ideas, facilitation of knowledge transfer and leveraging of new funding. The importance of collaboration in the generation of research centre impact and thus, the strengthening of the innovation system cannot be understated. Collaboration facilitates the transfer, absorption, assimilation, transformation and exploitation of knowledge within an innovation system. However, the qualitative nature of collaboration has made measurement more difficult and time consuming than quantitative measures such as R&D proxies. Innovation surveys provide the main source of information regarding collaboration activities between firms and between firms and research centres. Under the RCIF, collaboration is measured through surveys conducted with researchers and firms. The type, frequency and intensity of collaboration are identified as key indicators of knowledge transfer which improves the potential absorptive capacity, both for firms and within the system generally.

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. 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. McMillan et al. (2000) studied the biopharmaceutical sector and found that biotechnology firms cite public research in 83% of their patents, compared to 79% of pharmaceutical firms.

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 consider instrumentation because of the limited ability of industrial R&D managers to recognise the contribution made by earlier government-funded research. deS Price (1984) argues that systematic interaction between science and technology will largely be based on improvements to existing methods and techniques, rather than arising from the application of relevant results.

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 et al. (2004) note spin-offs represent one of the major routes through which publicly supported R&D activity - particularly that undertaken by universities - is commercialised. New spin-offs are measured using indicators of absolute numbers of spin-offs and start-ups, size of spin-offs and start-ups, in terms of both employment and monetary value and the survival rates of the spin-off companies. These indicators should provide an extensive picture of the scale and potential impact of the spin-off and start-up companies identified.

3.3 Firm Level Inputs: Potential Absorptive Capacity

Under the RCIF, the process of converting new knowledge and outputs into economic and commercial outcomes and impacts is dependent firstly on the ability of research centres to create and transfer new knowledge and outputs, and secondly on the ability of businesses to absorb, assimilate, transform, and exploit this knowledge into economic and commercial impacts. 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 et al., 2008, Finne et al., 2011, 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.

Hughes and Martin (2012) assert that when attempting to assess the impact of publicly funded research, one needs to bear in mind that the exploitation of publicly funded research often depends on private sector capacities and investments, factors outside the control of the publicly funded researchers. Consequently, the task is less about assessing the impact of

publicly funded research per se, and more about understanding and managing connections between public and private sector in a system of knowledge production and innovation.

Potential absorptive capacity is measured using indicators of firm level inputs into the innovation process. Firm level characteristics have been identified as an important prerequisite for developing absorptive capacity (Dyer and Singh, 1998, Schildt et al., 2012). The inclusion of a firm's potential and realised absorptive capacity allows us assess whether research centre impacts are strengthened or limited institutionally, within the centre, or systematically, outside of the centre. For example, benchmarking research centres may show particular centres produce knowledge and outputs more efficiently and effectively than competitors, however if partners, such as firms, do not possess the capacity to absorb, transform, and exploit the knowledge into commercially viable ends then the impact of the centre is reduced as a result of external factors outside of its control.

Most studies measure absorptive capacity using indicators of R&D intensity and levels of R&D investment. These measures appear overly simplified to capture the multidimensional concept. Under the RCIF, potential absorptive capacity is captured using a combination of indicators categorised into five categories:

- R&D resources,
- Human capital resources,
- Scientific Excellence resources,
- Collaboration resources, and
- Infrastructural resources.

Table 3 below shows the firm level inputs into the innovation process and outlines sample indicators used to measure these inputs.

Table 3 Firm Level inputs into the Innovation Process: Potential Absorptive Capacity

Firm level Inputs	Indicator(s)	Metric(s)	Description
R&D expenditure	**Total expenditure on R&D**	Total expenditure on R&D (€, growth, expected, achieved)	Total expenditure on R&D (€, growth, expected, achieved)
	R&D Intensity	R&D as a % of Sales	Total expenditure on R&D divided by Sales
Research Collaborations	**Number of collaborations**	Total number of collaborations	Total number of collaboration between research centre and partners
	Types of Collaborations	Type of collaboration	Types of collaboration between research centre and partners
	Length of collaboration	Average Duration of collaborations	Average length of collaboration between research centre and partners
	Number of Institutions represented	Average Institutions represented during Collaboration	Average number of Institutions represented during Collaboration
	International Collaborations	% of international collaborations to total collaborations	Total number of international collaborations divided by total collaborations.
	New Strategic Partners	New Strategic Partners	New strategic partnerships created through funding
Scientific Excellence	**Publications**	Number of peer reviewed publications	Total number of peer reviewed publications
		% of publications in highly ranked journals	% of publications in highly ranked journals
		Publications per researcher	Total number of publications divided by total number of researchers
		Publications generated by research is downloaded	Average number of downloads per publication
	Citations	Average Relative Citation	Average number of citations per publication
		Citations in high impact journals	% of citations in high impact journals
		Co-citations	Number of citations with public institutions
		% of international citations	total number of international publications divided by total number of publications
	Patents	Number of patent applications	Total number of patent applications
		Number of patents granted	Total number of patents granted
		Patents per € of investment	Total number of patents divided by total investment (€)
		Total expenditure on infrastructure	Total expenditure on infrastructure

Investments in infrastructure	**Expenditure on Infrastructure**	Total expenditure on infrastructure as % total expenditure	Total expenditure on infrastructure as % total expenditure (%, growth, expected, achieved)
Human Capital	**Employees in R&D**	Total number of employees working in R&D	Total number of employees working in R&D (growth, expected, achieved)
		Employees working in R&D as % of total employees	Employees working in R&D divided by total employees (growth, expected, achieved)
	Employees with PHDs	% of employees with PhDs	Total number of employees with PhDs divided by total number of employees

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 et al., 2001, Muscio, 2007, Vega Jurado et al., 2008). The justification for these measures is based on the assumption 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 measures 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 et al., 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). 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 et al. (2012) emphasise the significance of both firm level processes and collaboration processes in building absorptive capacity while Knudsen et

al. (2001) find that that active participation in strategic alliances along with high R&D intensities are important as preconditions 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.

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 et al., 2001, van der Heiden et al., 2015) and the research intensity of firm i.e. researchers as a percentage of total employees (Gao et al., 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.

3.4 Outcomes: Realised Absorptive Capacity

Realised absorptive capacity is defined as a firm's ability to transform and exploit knowledge into commercial ends. Under the RCIF, the transformation and exploitation of knowledge and outputs into commercial ends is labelled 'outcomes'. Outcomes may be shorter-term and/ intermediate effects, with 'impact' associated with longer term and/or ultimate effects. Hughes and Martin (2012) note that 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.

Under the RCIF, realised absorptive capacity is captured using a combination of indicators including:

- Sales,
- Profitability,

- Spin-Offs and Start-Ups,
- Cost Savings, and
- Processes.

Table 4 below highlights the research outcome indicators included in this study.

Table 4 Outcome Indicators: Realised Absorptive Capacity

Outcome Category	Indicator(s)	Sample Metric(s)	Description
Sales	**Total Sales**	Total revenue from product sales (€)	Total revenue from product sales (€)
	Sales as result of funding	Estimated additional turnover resulting from funding	Estimated additional turnover resulting from funding (achieved, expected within 2 years)
	New product Sales	Total revenue from new product sales	Total revenue in € from new product sales
	New Product Sales as result of funding	Estimated additional new product sales resulting from funding	Estimated additional new product sales resulting from funding (achieved, expected within 2 years)
	Growth in New product Sales	Average Annual Growth in revenue from new product sales	Average Annual Growth in revenue from new product sales (%)
	Sales per Employee	Total sales per employee (€)	Total sales per employee in €
Profitability	**Total Profitability**	Total profitability in €	Total value of profitability in €
	Profitability Growth	Growth in profitability (%)	Average annual growth in profitability (%)
	Profitability as result of funding	Estimated additional profit resulting from funding (€)	Estimated additional profit resulting from funding (achieved, expected within 2 years) (€)
Spin-Offs/ Start-Ups	**Sales in Spin-Offs**	Revenue from product sales in spin-offs	Total revenue of product sales in spin off companies (€)
	Sales Growth in Spin Off	Revenue growth from product sales in spin offs	Average Annual Growth in revenue from product sales in spin-offs (%)
	Sales in Spin-Offs as result of funding	Estimated additional spin-offs resulting from funding	Estimated additional spin-offs resulting from funding (achieved, expected within 2 years)
	Profitability in Spin-Offs	Profitability in spin-offs	Total profitability spin- off companies (€)
	Profitability Growth in Spin-Offs	Profitability growth from product sales in spin-offs	Average Annual Growth in revenue from product sales in spin-offs (%)
	Profitability as result of funding	Estimated additional profit resulting from funding	Estimated additional profit resulting from funding (achieved, expected within 2 years)
	Total cost savings	Total cost savings in €	Total cost savings (€, achieved, expected within 2 years)

Cost Saving	**Cost savings as a result of research funding**	Estimated additional profit resulting from funding	Estimated additional cost savings resulting from funding (achieved, expected within 2 years)
Processes	**New Processes**	New processes (achieved, expected, time to market)	New processes (achieved, expected, time to market)
	Improvements to existing Processes	Improvements to existing processes (achieved, expected, time to market)	Improvements to existing processes (achieved, expected, time to market)

Research centre outcomes relate to internal 'impacts' to the firm as a result of the commercialisation of research outputs. These indicators are primarily focused on financial outcomes as a result of research activities, i.e. increases in sales, turnover, and profitability. While these outcomes may provide marginal impacts to the wider economy, the majority of the benefits are accrued internally within the firm.

The impact of publicly funded research on sales has been widely studied. Mansfield (1991) shows that 10% of appraised innovations in the United States would not have been possible without recent academic research. Beise and Stahl (1999) confirm these results in a study on the effects of publicly funded research at universities, polytechnics and federal research labs on industrial innovations in Germany. 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 et al. (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) examines 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 research and development (R&D) expenses while having higher levels of innovative output. However, the results do not support the proposition that companies with these linkages achieve higher financial performance than similar firms without such linkages.

Spin offs have been identified as an important mechanism for the commercialisation of technical knowledge. Spinoffs are closely aligned with labour mobility and knowledge

spillovers. The creation of a spinoff is 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, spinoffs may facilitate the transfer of knowledge considered 'tacit' in nature i.e. embodied within people. Several studies have estimated the potential spillover of knowledge through entrepreneurship and spinoff companies (Møen, 2002, Audretsch and Lehmann, 2005, Audretsch et al., 2006, Acs et al., 2009). However, the results of these studies tend to be mixed.

3.5 Impacts

Research Impact is defined as a broader, wider, and longer term impact compared to a research outcome. While research outcomes are considered 'narrow impacts' at a firm level, research impacts are 'wider impacts' at an economy level. Table 5 highlights the impact indicators identified in the RCIF.

The Research Impacts Framework categorises research impacts into six impact categories:

- Job Creation,
- Job Retention,
- Economic Growth,
- Foreign direct Investment, and
- Exports.

Table 5 Impact Indicators

Impact Category	Indicator(s)	Metric(s)	Description
Job Creation	**Total number of new jobs created**	Total number of jobs created	Total number of jobs created(FTE, growth, achieved/ expected)
	Growth in Job Creation	Growth in number of jobs created	Growth in number of jobs created (FTE, growth, achieved/ expected)
	Number of new jobs created as a result of funding	Total number of jobs attributed to research funding	Total number of jobs attributed to research funding (FTE, growth, achieved/ expected)
	Number of high tech jobs created as a result of funding	Total number of high tech jobs created	Total number of high tech jobs created (FTE, growth, achieved/ expected)
	Number of jobs created based on commercialisation of technologies	Total number of jobs created based on commercialisation of technologies	Total number of jobs created based on commercialisation of technologies (FTE, growth, achieved/ expected)
Job Retention	**Number of jobs saved as result of research funding**	Total number of jobs saved as a result of research funding	Total number of jobs saved as a result of research funding (FTE, growth, achieved/ expected)

Economic Growth	**GDP contribution of research**	Total contribution of research funding to GDP	Total contribution of research funding to GDP (€, growth, expected, achieved)
Foreign Direct Investment	**Increases in FDI as a result of research funding**	Increase in FDI as a result of research centre funding	Increase in FDI as a result of research centre funding (€, growth, expected, achieved)
Exports	**Total Value of exports from firms**	Total value of exports from firms (€, expected, achieved)	Total value of exports from firms (€, expected, achieved)
	Growth in exports of firms	Increase in export value from firms involved with research centre	Increase in export value from firms involved with research centre (growth, expected, achieved)
	Exports as a result of research funding	Value of exports resulting from research funding	Value of exports resulting from research funding (€, growth, expected, achieved)

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 national, regional and local level. Few academic studies have examined the impact of publicly funded research centres on economic growth, employment, FDI and exports. Guellec and Van Pottelsberghe de la Potterie (2004) estimates of the long-term impact of various sources of knowledge (R&D performed by the business sector, the public sector and foreign firms) on multifactor productivity growth of 16 countries from 1980 to 1998. The main results show that the three sources of knowledge are significant determinants of long term productivity growth. Carr et al. (2013) provided the first empirical estimate of the economic contribution of publically funded research in the Yukon, Nunavut, and Northwest Territories of Canada between 2000 and 2009. The findings suggest public investment in research has grown considerably and is estimated to have increased the territorial GDP by 0.04%, income by 0.09%, and employment by 0.11%.

3.6 Structural Absorptive Capacity

Structural Absorptive Capacity refers to the country's ability to absorb, assimilate, transform and exploit knowledge. Investments in a country's structural absorptive capacity increases 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".

Structural absorptive capacity is measured to assess the strength of the national innovation system which the centre is embedded which may enhance the research centres ability to provide economic and commercial impacts while also measuring the impact the research centre has on strengthening the national innovation system. Structural absorptive capacity is measured across five categories:

- R&D and Innovation Expenditure
- Scientific Excellence
- Intellectual Property
- Human Capital
- Infrastructure

These categories are composed of potential indicators which can be used measure the direct impact of the research centre on the structural absorptive capacity. Research centre inputs and outputs strengthen the structural absorptive capacity of a country.

Table 6 Strengthening Structural Absorptive Capacity – Direct Impact of Research Centre

Input Category	Indicator(s)	Sample Metric(s)	Description
R&D and Innovation Expenditure	**Gross Expenditure on R&D**	Gross expenditure on R&D (€ millions, growth)	Gross expenditure on R&D by research centre to conduct research activities (as % national)
	Government Funding	Value of government funding (as % national)	Total value of funding generated by the research centre from government sources (as % national)
	Business Funding	Value of business funding (as % national)	Total value of funding generated by the research centre from government sources (as % national)
	International Funding	Value of international funding (as % national)	Total value of funding generated by the research centre from government sources (as % national)
	Publications	Number of peer reviewed publications (as % national)	Total number of peer reviewed publications (as % national)
		% of publications in highly ranked journals (as % national)	% of publications in highly ranked journals (as % national)
		Publications per researcher (as % national)	Total number of publications divided by total number of researchers (as % national)
		Publications downloaded (as % national)	Average number of downloads per publication (as % national)

Scientific Excellence	**Citations**	Average Relative Citation (as % national)	Average number of citations per publication (as % national)
		Citations in high impact journals (as % national)	% of citations in high impact journals (as % national)
		% of international citations (as % national)	total number of international publications divided by total number of publications (as % national)
		% of industry citations (as % national)	Number of industry citations divided by total number of citations (as % national)
Intellectual Property	**Patents**	Number of patent applications (as % national)	Total number of patent applications (as % national)
		Number of patents granted (as % national)	Total number of patents granted (as % national)
	Licensing	Number of Patents licenced	Total number of licenced patents (as % national)
	Trademarks	Number of trademarks, copyrights, etc. received (as % national)	Total number of trademarks (as % national)
	Prototypes	Prototypes and testing activities (as % national)	Total number of prototypes developed (as % national)
Human Capital	**PHDs**	Number of employees with PhDs (as % national)	Total number of employees with PhDs (as % national)
	Post-Doctoral researchers	Number of Post-doctoral researchers (as % national)	Total number of employees with Post-doctoral researchers (as % national)
	Internationalisation	% of employees from foreign countries (as % national)	Total number of foreign employees divided by total employees (as % national)
Infrastructure	**Infrastructure Grants (€)**	Value of infrastructure grants (as % national)	Total value of infrastructure grants (as % national)
	Machinery	Value of machinery used by centre (as % national)	Total value of machinery (as % national)
	Scientific Equipment	Value of Scientific Equipment used by centre (as % national)	Total value of scientific equipment (as % national)
	Databases	Number of databases compiled by the centre (as % national)	Total number of databases compiled by the centre (as % national)
	Technological transfer support structure	Number and quality of technological transfer support structures (as % national)	Total number and quality of technological transfer support structures(as % national)

4. Implementation

The project will generate quantitative and qualitative indicators and measures of economic impact of research centres. These will be based on a combination of secondary data (e.g. bibliometrics, number of industry partners and licensing), and primary data (from original surveys, interviews and stakeholder focus groups). The project will survey industry collaborators to explore the nature of the collaboration, its contribution to their business productivity and performance, and the criticality of the centre for their operations (both R&D and advanced manufacturing).

The indicators identified from the literature review and structured interviews with staff from research centres, firms and funding agencies will be combined to develop a Research Impact Index (RII). The Research Impact Index 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 agencies. Practitioners must exercise caution when measuring and evaluating research centre outcomes and impacts. The attribution issue must be considered when measuring outcomes and impacts. Attribution issues relate to determining the proportion of total outcomes and impacts attributable to the research activities conducted by the research centre. The use of surveys, questionnaires and willingness to pay techniques will be conducted in order to estimate the percentage of firm outcomes and impacts that result directly from research centre outputs and activities.

Economic and commercial impact assessment frameworks and methods will differ according to: the level of analysis of a funded project (scholarship, centre, programme, etc.); the level of maturity of a funded project (application stage, mid-term, completion); and the TRL of a funded project. As such, the assessment frameworks and methods need to be consistent, but sufficiently flexible, so they can be applied at different stages of a research centre's life cycle, and to centres with different TRLs and to centres in different sectors. Weightings will be assigned to different aspects of the economic and commercial impacts of the Research Centre and, following sensitivity analysis, may be adjusted according to the TRLs of each research centre, since centres at different TRLs may be expected to have different levels or compositions of economic impact. Centres operate along a range of TRLs and it may be appropriate for measures of impact to reflect different objectives within a centre.

An example of a commercial impact indicator will be the calculation of jobs created and/or sustained by a research centre. This will be developed by surveying a centre's industry partners on the criticality of the centre for their operations, in particular their specific business unit, on a likert scale from 1 to10 and multiplying this by the number of jobs in that business unit. This is one indicator among several that attaches a more sophisticated measure of the relative importance of a research centre for sustaining high value jobs. This research will control for the size of the research centre and the scale of investment.

5. Conclusion

The objective of this paper was to develop an ex-ante framework to measure and evaluate the economic and commercial impact of publicly funded research centres. This paper develops a novel framework to measure and evaluate the economic and commercial impacts of publicly funded research centres. The study identifies a range of potential economic and commercial impacts resulting from research centre activities. The indicators identified are based on an inventory suggested by ex post evaluations and related empirical and conceptual studies. This analysis provides context and rationale for the development of a new robust framework and tools which move beyond standard measures of research impact to develop and test quantitative and qualitative indicators of impact.

Grounded in an evolutionary economics perspective, the framework views research centres as important cogs within an innovation system. In particular this paper sets out an important, and to date underappreciated, element of the impact of research centres, which is the bidirectional relationship between research centres and the system within which it is embedded. Research centres operate within an innovation system, and 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. The impact assessment framework presented in this paper therefore includes the impact of a research centre on the innovation system.

To date, the framework developed remain experimental in nature at the early stages of application. However, early indications are that this has been found to be a useful tool in assisting research centre, firms and policy-makers in ex ante impact evaluation. The next stage of development is the implementation of the RCIF will be tested and implemented at the Science Foundation Ireland-funded Irish Photonic Integration Centre (IPIC), hosted by Tyndall National Institute, University College Cork, and used to benchmark IPIC against

national and international comparators. Future developments may see the implementation of the RCIF across a wide range of research centres at different stages of a research centre's life cycle, to centres with different TRLs, centres in different sectors and the potential impact of different regional innovation systems on the economic and commercial impact of research centres.

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