Overcoming barriers to research and innovation in firms: A study of financial and non-financial constraints

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Overcoming barriers to research and innovation in firms: A study of financial and non-financial constraints

By

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Abstract: Firm-level Research and Innovation (R&I) are vital for firm competitiveness, and for the development of economies and societies. Yet, firms' engagement in R&I remains low, especially in the European Union (EU) when compared to other advanced economies. A dominant view in academic and policy spaces is that this is mainly due to market failures and financial constraints hindering firms' R&I activities. Governments in many countries thus, provide firms with public financial support for R&I to address such issues. Firms, however, typically experience other non-financial constraints affecting their R&I activities. Most notably, firms may suffer from a lack of human capital, and/or a lack of partners with whom to engage in collaborative R&I. Firms may also experience a lack of demand for R&I. While the literature has identified the importance of non-financial constraints, our understanding of how firms can overcome them, and the types of policy interventions that may help firms to do so, remains very limited. This is a major limitation that prevails in the literature, as non-financial constraints can negate existing policy efforts to drive R&I in firms.

My PhD research addresses the above knowledge gaps, by critically analysing the nature of firms' financial and non-financial constraints, and how public financial support for R&I can help firms to overcome them. The focus on public financial support for R&I as a means to address financial and non-financial constraints, builds on a growing literature which highlights such support as having important behavioural and learning effects in firms. The impacts of public financial support for R&I on firms' non-financial constraints, however, have not, heretofore, been critically examined. To address these issues, the research builds a novel and highly detailed dataset comprising information on firms' R&I activities and their constraints. These firm-level data are merged with administrative data on public financial support for R&I available to firms in Ireland obtained from Ireland's three main funding agencies: (a) Enterprise Ireland (EI); (b) the Industrial Development Agency (IDA) Ireland; and (c) Science Foundation Ireland (SFI). Data on R&D tax credits from Ireland's Revenue Commissioners are also merged. The analysis uses econometric techniques, such as instrumental variables (IV) and propensity score matching, to mitigate potential endogeneity and self-selection biases associated with the receipt of public funding, and firms' perceptions of constraints.

The research finds that firms' financial and non-financial constraints are endogenous and dynamic, in the sense that they arise as firms engage in more knowledge and resource intensive R&I activities. Furthermore, as firms gain deeper R&I capabilities, they are more equipped to overcome their constraints. In this context, the research finds that, by encouraging more R&I in firms, public financial support for R&I can indeed help firms to overcome their financial and non-financial constraints. These insights are critical, as they advance an understanding of a topic which, hitherto, remains largely unexplored. They are also highly policy-relevant, as they could potentially inform how policymakers can use existing policy instruments in new ways, such as using public financial support for R&I to address firms' non-financial constraints.

Declaration of originality

I, the undersigned, hereby declare that this submission is entirely my own work, in my own words, and that all sources used in researching it are fully acknowledged and all quotations properly identified. It has not been submitted, in whole or in part, by me or another person, for the purpose of obtaining any other credit / grade. I understand the ethical implications of my research, and this work meets the requirements of the Kemmy Business School Research Ethics Committee.

Signed: Mauricio Perez-Alaniz

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This PhD research is the product of a process of self-development and (a lot of) hard work. However, this could have not been possible without the guidance, support, and expertise, of my supervisors, Professor Helena Lenihan (UL) and Professor Justin Doran (UCC). I am forever grateful for the opportunity to learn from, and work with, both of you.

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I am grateful to Science Foundation Ireland (SFI), for the financial support that made this PhD research possible. My research emanates from a Science Foundation Ireland (SFI) funded research project entitled "*Evaluating the impact of science policy on the economy and society: A national evaluation and international benchmarking of science policy in Ireland*" (Grant number 17/SPR/5328). The project is funded under Science Foundation Ireland's Science Policy Research Programme. I am also grateful to the Department of Economics at the KBS, University of Limerick, the Higher Education Authority, and the Department of

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Finally, I would like to especially thank my wife, Rozi Perez-Goodbody, for being a daily source of inspiration, love, support, and admiration. I could not have done this without you. To my two children, Rio Perez-Goodbody and Eva Perez-Goodbody, thank you for your unconditional love and support. This is for you (even if you think that my work is boring). Los amo! (I love you guys!).

Publications

Following Annex 2 (Chapters 3.1 and 3.2) of the University of Limerick's Handbook of Academic Regulations and Procedures (version updated on September 1st, 2021), this PhD research is submitted as a monograph, but in a publication-style format.

The research comprises one journal article published in the peer-reviewed international academic journal *Industry and Innovation* (Scimago Ranking Quartile 1 [Q1], Chartered Association of Business Schools [ABS] 3 stars/rate):

- Perez-Alaniz, M., Lenihan, H., Doran, J., and Hewitt-Dundas, N. (2022) 'Financial resources for research and innovation in small and larger firms: Is it a case of the more you have, the more you do?', *Industry and Innovation,* DOI: https://doi.org/10.1080/13662716.2022.2036597.

Moreover, the research includes two unpublished manuscripts, which are in the process of being submitted to high impact peer-reviewed international academic journals in economics/innovation studies:

- Perez-Alaniz, M., Lenihan, H., Doran, J., and Roper, S. (2022) 'Can public financial support help firms overcome non-financial constraints to research and innovation?'

- Perez-Alaniz, M., Lenihan, H., Doran, J., and Rammer, C. (2022) 'Subsidising research and innovation in knowledge constrained firms: A policy failure or a key to higher additionality?'

The above academic publications comprise Chapter 3, Chapter 4, and Chapter 5, of this PhD thesis. In all papers, I have conducted the literature reviews, constructed the datasets, cleaned and organised the data, performed the empirical analyses, and written the papers. This has been conducted under the supervision of, and in consultation with, my supervisors. I am the first author on all the above papers, the remaining authors are listed in order of contribution.

Furthermore, my PhD research emanates from a Science Foundation Ireland (SFI) funded research project entitled "*Evaluating the impact of science policy on the economy and society: A national evaluation and international benchmarking of science policy in Ireland*" (Grant number 17/SPR/5328). The project is led by the Principal Investigator (PI), and my PhD supervisor, Professor Helena Lenihan. The project benefits from ongoing collaborations with international and national experts in the field, some of whom have co-authored to the academic publications comprising this PhD research.

Conference Proceedings

Earlier versions of the academic papers comprising my PhD research have been featured as Refereed Conference Proceedings at three academic conferences:

- Perez-Alaniz, M. Lenihan, H., Doran, J., and Roper, S. (2021) 'Old policies for new problems: Can public financial support help firms overcome non-financial constraints to research and innovation?', presented at the *Eu-SPRI 2021 International conference*, Oslo, Norway, 9-11 June (virtual conference).
- Perez-Alaniz, M., Lenihan, H., Doran, J., and Hewitt-Dundas, N., (2019) 'Financial resources and firm engagement in scientific and innovative activity: does firm size matter?', presented at the *Danish Research Unit for Industrial Dynamics* (DRUID) *International conference*, Copenhagen, Denmark, 19-21 June.
- *Perez-Alaniz, M., Lenihan, H., Doran, J., and Hewitt-Dundas, N., (2018) 'Understanding constraints to science and innovation in SMEs: a necessary first step for science and innovation policy.', presented at the *Institute for Small Business and Entrepreneurship (ISBE) 41st Annual Conference*, Birmingham, UK, 7-8 November.

*Nominated for Best Paper Award in the SME Growth & Performance: Quantitative Perspectives track.

Presentations

I have presented some insights of my PhD research at the following events:

- Perez-Alaniz, M. (2019), ‘Grants for science and innovation: encouraging innovation or a hole in the public purse?’, [Presentation], presented at the *Thesis in Three Final*, University of Limerick, Limerick, Ireland, June 22nd, 2019.

- Perez-Alaniz, M. (2019). ‘Understanding the Nature and Impact of Financial and Capability Constraints on SME Scientific and Innovative Activity’, [Presentation], presented at the *Public Policy, Enterprise, Governance and Sustainability (PPEGS) Seminar Series*, University of Limerick, Limerick, Ireland, October 10th, 2019.

Funding

- 2021-Awarded a 4-months funding extension from the Higher Education Authority’s COVID-Research Disruption Fund.

- 2018- Selected for the PhD Student position for a Science Foundation Ireland (SFI) funded project- entitled “*Evaluating the impact of science policy on the economy and society: A national evaluation and international benchmarking of science policy in Ireland*" (Grant Number: 17/SPR/5328), led by Prof. Helena Lenihan.

- 2017- Awarded (as part of a competitive process) the Department of Economics PhD Scholarship at the Kemmy Business School, University of Limerick.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1: Introduction

The objective of this chapter is to introduce the research topic and set out the structure of the PhD thesis. Specifically, the chapter summarises the motivation driving my research, the research questions, and the structure of the PhD thesis.

1.1 Focus of the research

Research and Innovation (R&I) are key drivers of the development of economies and societies (Edler and Fagerberg 2017; Borrás and Edler 2020). By translating knowledge into economic value, firms are largely responsible for realising the economic and societal benefits of R&I (Dedrick and Kraemer 2015; Cassiman *et al.* 2018). As noted by Teece (2017, p. 1693), "the health and dynamism of national economies are inseparable from the health of the firms that operate there". Firms' R&I activities, however, are bound with high uncertainty and appropriability concerns, which result in firms having limited access to external finance for these activities (Himmelberg and Petersen 1994; Hall 2002; Hall *et al.* 2016). Firms, therefore, primarily finance their R&I activities internally (Himmelberg and Petersen 1994; González-Bravo *et al.* 2021). Limited levels of financial resources can thus lead to firms refraining from engaging in R&I activities due to financial constraints (Hottenrott *et al.* 2016; Giebel and Kraft 2019).

Governments in many countries design and implement science, technology, and innovation (STI) policy interventions to encourage R&I in firms (Wanzenböck *et al.* 2013; European Comission 2017; Borrás and Edler 2020). Public financial support for R&I, in particular, is widely recognised as a key STI policy intervention to address firms' financial constraints, and encourage R&I activity in firms (see, for recent reviews, Zúñiga-Vicente *et al.* 2014; Becker 2015; Jugend *et al.* 2020). Increasing pressure on public resources, however, has reinvigorated debates in academic and policy spaces regarding how to ensure that public financial support for R&I represents value for money (Lenihan and Hart 2004; Czarnitzki and Lopes-Bento 2013; Haapanen *et al.* 2014; Vanino *et al.* 2020; Petelsky *et al.* 2020; Laplane and Mazzucato 2020). This is especially true with regard to the types of firms (i.e. firms of different sizes and sectors), and R&I activities (i.e. explorative versus exploitative research activities, incremental versus radical forms of innovation), that such support should prioritise (Autio and Rannikko 2016; Mazzucato and Semieniuk 2017; Hottenrott *et al.* 2018; Laplane and Mazzucato 2020; Gao *et al.* 2021). Such debates have been recently exacerbated due to the Covid-19 pandemic. This is because the pandemic has negatively affected firms' financial resources, while firms are under increasing pressure to adjust to a new economic environment (Brown *et al.* 2020). As a result, public financial support for R&I may be needed now more than ever (Roper and Turner 2020; Morgan *et al.* 2020; Paunov and Planes-Satorra 2021). However, the pandemic has also negatively impacted the public purse, and increased demand on already limited public financial resources (European Commission 2020a, OECD 2021a).

Furthermore, firms typically face other non-financial constraints to R&I (Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020; Radicic 2021). Most notably, firms may face knowledge constraints, associated with a lack of qualified employees to perform R&I activities (D'Este *et al.* 2014), and encounter difficulties in identifying suitable R&I collaboration partners, such as other firms and universities, with whom to engage in collaborative R&I (Antonioli *et al.* 2017; Radicic 2021). Firms may also face market constraints arising from a lack of demand for their R&I activities (García-Quevedo *et al.* 2017; Szambelan *et al.* 2020). Several studies have demonstrated that such non-financial constraints can hinder firms' R&I activities (Blanchard *et al.* 2013; Pellegrino and Savona 2017; Pellegrino 2018; Radicic 2021; Zahler *et al.* 2022). However, how firms overcome non-financial constraints, and the specific STI policy interventions that can support firms to do so, remain contested topics of academic debate (see, for example, D'Este *et al.* 2014; Antonioli *et al.* 2017; Szambelan *et al.* 2020).

For example, some previous studies, such as D'Este *et al.* (2014), Antonioli *et al.* (2017), and Pellegrino (2018), have highlighted the need for STI policy interventions that address 'systemic failures' underpinning firms' non-financial constraints. This is because, unlike financial constraints, which arise due to failures in financial markets, non-financial constraints are associated with failures in the 'systems', or 'environments', in which firms locate (Pellegrino and Savona 2017). Specifically, they noted that STI policies should focus on: (a) improving the level of human capital available to firms (D'Este *et al.* 2012; Pellegrino 2018); (b) removing obstacles impeding collaborations between firms, and between firms and knowledge providers (i.e. universities and research centres) (Antonioli *et al.* 2017; De Moraes Silva *et al.* 2020); and (c) generating demand for R&I, for example, through public procurement (García-Quevedo *et al.* 2017; Pellegrino and Savona 2017). As Wanzenböck *et al.* (2013) and De Moraes Silva *et al.* (2020) note, however, such systemic policy interventions may be difficult to design and implement. In addition, as Borras and Edquist (2015) have outlined, STI policies that focus on addressing the above systemic failures (and build capability at the firm level), may take time to have an impact on firms' R&I activities.

Considering the above, several studies, such as those of Antonioli *et al.* (2017), Pellegrino and Savona (2017), Pellegrino (2018), and Szambelan *et al.* (2020), have emphasised the need for future research to enhance an understanding of how firms overcome non-financial constraints and the STI policies that can accelerate such processes. As an illustrative example, Antonioli *et al.* (2017, p. 861) called for future research to "investigate more directly the real effectiveness of system-oriented policies to mitigate the barriers to innovation for firms". Pellegrino and Savona (2017, p. 511), in turn, stated that non-financial constraints may lead to persistent systemic failure, and thus "it is more important for policy to extend analysis to non-financial obstacles". More recently, Szambelan *et al.* (2020, p. 425) noted that "while the types of innovation barrier[s] have already been identified, we know relatively little about how firms can overcome these barriers". At the policy level, addressing this imbalance is paramount, given that supporting firms to overcome their non-financial constraints is at the centre of innovation policy in many country settings (see, for example, Skilnet Ireland 2016; Federal Ministry for Economic Affairs and Energy of Germany 2019; Nepelski and Van Roy 2021; DBEI 2020; HM Government 2021).

This PhD research makes a distinct contribution to the above debates, by advancing an understanding of the financial and non-financial constraints that firms face when engaging in R&I activities. Moreover, the research provides novel evidence regarding how public financial support for R&I, as a key STI policy intervention, can support firms to overcome their financial and non-financial constraints to R&I. Collectively, the research advances an understanding of three key intricacies that remain contested topics of research in the prevailing literature. The next section explains the rationale for the focus on public financial support for

R&I in the context of firms' financial *and* non-financial constraints, and the specific three intricacies addressed by the research.

1.2 Motivations and contributions to the literature

My PhD research provides a more in-depth understanding of the role of financial and non-financial constraints on firms' Research and Innovation (R&I) activities. In addition, the research provides novel insights regarding how public financial support for R&I can help firms overcome such constraints. This is achieved by performing a deep-dive examination of three inter-related, and crucial, current academic and policy debates. This section provides a summary of these three academic and policy debates, and the resulting contributions of my research, while a more detailed discussion is provided in Chapter 2.

Chapter 3 provides new detailed evidence on how firms' levels of internal financial resources impact their engagement in R&I activities. The key research questions driving this chapter are:

- How do firms' levels of internal financial resources impact their engagement in R&I activities?
- Is the relationship between firms' internal financial resources and their R&I activities similar for different R&I activities (i.e. explorative versus exploitative research activities; incremental versus radical forms of innovation; innovations that entail the development of processes and products, and innovations that require organisational changes)?

- Is the relationship between firms' internal financial resources and their R&I activities similar for firms of different sizes (i.e. small-sized and larger-sized firms)?

This chapter is motivated by behavioural and resource-based theories of innovation that highlight the importance of firms' financial resources for driving their engagement in R&I (Cyert and March 1963; Jissink *et al.* 2019; González-Bravo *et al.* 2021). The research is also motivated by the financial literature on innovation, which proposes that firms with limited financial resources may be constrained at the time of engaging in R&I activities (Himmelberg and Petersen 1994; Bond *et al.* 2005; Hall *et al.* 2016). However, Weiss *et al.* (2017, p. 842) highlight that despite numerous studies addressing this topic, the extent to which firms' financial resources translate into more R&I remains "unclear". A similar observation has been more recently noted by Teirlinck (2020, p. 181) in the context of the relationship between slack resources, which the author defined as uncommitted financial resources, and innovation. In his view, this relationship remains "unclear since the behavioural literature puts forward arguments in favour of innovation, whereas agency theorists point to potential inefficient use of slack resources for innovation".

Therefore, Chapter 3 posits, and empirically demonstrates, that the extent to which firms' levels of financial resources lead to more R&I depends on: (a) the type of R&I activity in question (i.e. explorative research versus exploitative research, process innovation, product innovation, service innovation and organisational innovation); and (b) firms' sizes (i.e. small-sized versus larger-sized firms). Chapter 3 thus contributes novel insights that can inform the formulation of a more refined theory of the role of financial resources for firms' R&I activities, which, according to Hoegl *et al*. (2008, p. 1389), remains “much-needed”. Such insights may also be very useful for policymakers designing, implementing and/or improving targeted science and innovation policy interventions to help firms to innovate. This Chapter has been published in the Scimago Quartile 1 (Q1), Chartered Association of Business Schools (ABS) 3-stars, peer-reviewed international academic journal *Industry and Innovation*.

In Chapter 4, novel insights are provided regarding how public financial support for R&I can enable firms to overcome their financial and non-financial constraints to R&I. The research questions driving this chapter are:

- Can public financial support for R&I enable firms to overcome the financial and non-financial constraints affecting their R&I activities?
- How does the impact of public financial support for R&I on firms’ financial and non-financial constraints persist over time?
- Are there any differences across different types of public financial support instruments?

As discussed in Section 1.1 above, and in more detail in Chapter 4, addressing firms’ non-financial constraints may require Science, Technology and Innovation (STI) policy interventions that address systemic failures underpinning such constraints (D’Este *et al.* 2014; Antonioli *et al.* 2017). However, as noted in Section 1.1, such STI policies may be difficult to design and implement (Wanzenböck *et al.* 2013; De Moraes Silva *et al.* 2020), while they may take time to have an effect on firms’ R&I activities (Borrás and Edquist 2015). The chapter is thus motivated by an established body of literature, which proposes that public financial support for R&I can be a vital STI policy intervention for addressing firms' financial constraints, and encouraging R&I in firms (see, for recent reviews, Zúñiga-Vicente *et al.* 2014; Becker 2015; Jugend *et al.* 2020). Furthermore, the research is grounded in organisational learning theories of innovation, which highlight how firms can develop capabilities for R&I by enaging more in these activities (Montalvo 2006; Clarysse *et al.* 2009; Bourke and Roper 2017).

In light of the above, Chapter 4 posits, and empirically demonstrates, that public financal support for R&I can indirectly enable firms to overcome their non-financial constraints to R&I. That is, while public financial support for R&I is primarily designed for to address market failures and financial constraints, by driving more R&I in firms, the support can also enable firms to overcome their non-financial constraints. Chapter 4 offers new insights for understanding the nature of firms' constraints to R&I. Moreover, it provides novel evidence which may encourage debate and consideration amongst academics and policymakers, regarding the use of public financial support for R&I to address firms' non-financial constraints (Clarysse *et al.* 2009; Wanzenböck *et al.* 2013).

Chapter 5 extends the insights arising from the previous chapter (i.e. Chapter 4). The chapter is motivated by the insights of Chapter 4. Moreover, the chapter is motivated by existing debates in the literature regarding whether providing public financial support for R&I to firms that lack sufficient R&I skills represents an efficient allocation of public financial resources (Haapanen *et al.* 2014; Mazzucato and Semieniuk 2017). This is important, because, as noted above, the insights of Chapter 4 indicate that such support can be an effective STI policy tool to help firms overcome their non-financial constraints. In this context, however, it is important to ascertain whether allocating public financial support for R&I to non-financially constrained firms, also represents value for money.

Chapter 5 thus evaluates how knowledge constraints, as key non-financial constraints, moderate the impact of public financial support for R&I on firms' engagement in R&I. This pertains specifically to radical innovation activities, which refer to the development of products and services that are new to the market (Percival and Cozzarin 2008; Hewitt-Dundas *et al.* 2019). The focus on radical innovation is important because this form of innovation is widely recognised in the literature as having significant economic and social returns (Beck *et. Al.* 2016; Hewitt-Dundas *et al.* 2019). However, as D' Este *et al.* (2016) have noted, our understanding of the factors that result in radical innovation success (and failure) remains limited. In addition, as proposed by Keupp and Gassmann (2013), and more recently Radicic (2021), the impact of constraints to R&I on firms' radical innovation activities continues to be an under-studied topic of research. The research questions driving this chapter are:

- How do non-financial constraints moderate the impact of public financial support for R&I on firms' R&I activities?
- Can providing public financial support for R&I to non-financially constrained firms be justified given the associated impacts?

The insights arising from Chapter 5 enhance an understanding of whether using public financial support for R&I to enable firms to overcome their non-financial constraint represents an effective way to use such support. This is potentially very insightful, as it can inform the design and implementation of more effective and impactful allocation policies for public financial support for R&I.

1.3 Structure of the PhD thesis

This PhD thesis is submitted as a monograph, but it is presented in a publication-style format. Chapter 2 provides an overview of the literature driving the rationale of the research. The core empirical analysis is included in Chapter 3, Chapter 4, and Chapter 5. Each of these chapters (Chapter 3 to Chapter 5) contains an introduction, literature review, methodology, results and discussion, and a conclusion. Finally, Chapter 6 provides in-depth discussions of: (a) the contributions of the research to the literature; and (b) the associated implications of the research for the design and implementation of public financial support for R&I allocation policies. This is specifically in the context of using public financial support for R&I to help firms to overcome their financial and non-financial constraints to R&I.

Chapter 2: Rationale and background of the research

The purpose of this chapter is to discuss the rationale and background of my PhD research. The chapter also discusses the key contributions of the research, and provides an overview of the data used in the empirical analysis, in Chapters 3 to 5. As the empirical analysis focuses on firms in Ireland, the rationale for the focus on firms in Ireland is also discussed. Considering the format of the PhD thesis (i.e. publication-style format), all of the above issues are addressed in greater detail in Chapter 3, Chapter 4, and Chapter 5.

2.1 Research and innovation

In the context of this PhD research, firm-level research refers to scientific and technological research. These research activities are defined as the generation of logical explanations about physical, biological and social phenomena, by the application of scientific and/or technical methods (Stokes 1997; Borrás and Edquist 2014). Scientific and technical methods, in turn, are methods of logical reasoning that enable the derivation of deductively and inductively valid arguments (Rosenberg 2005).

In this research, innovation is defined as initially coined by Schumpeter (1934), as the combination of new and/or old knowledge for the creation of new value, by means of new processes, products, and forms of firm organisation. Schumpeter's initial definition of innovation was mainly conceived in the context of manufactured products (i.e. commodities), which reflected the emergence of technological innovations at the time. In this context, innovation in processes, primarily entailed the development of new manufacturing processes. New forms of firm organisation pertained to changes in the structure of organisations which enabled them to develop and commercialise innovations more efficiently (e.g. mergers). In his subsequent work, Schumpeter defined innovation more broadly, as "setting up of a new production function" (Schumpeter 1939, p. 84). This broader definition of innovation also included innovation in services, or any other activities that enabled firms to open new markets. Yet, the focus remained on technological products, while services were rendered to activities which applied new technology. For example, as Schumpeter discussed in 'Business Cycles' (1939), the development of transport and electricity distribution systems were examples of innovation in services.

Innovation as known today, also pertains to other forms of innovation activities, such as innovation in marketing (OECD 2015). In addition, existing definitions of innovations in products, services and processes, more accurately reflect the types of innovations taking place in current times (e.g. radical technological and service innovations, different forms of process innovations such as logistics, digitalisation, and the increasing importance of service innovation in the online marketplace and complex distribution systems) (OECD 2015). As a result, Borras and Edquist (2014, p. 361) define innovation more broadly, as "new creations of economic and societal significance". Despite this, Schumpeter's definition of innovation remains widely used in the literature, whilst acknowledging the different types of innovation occurring in current times (Fagerberg *et al.* 2008). The same approach is adopted in my research.

My focus on research and innovation (R&I) encapsulates research and development (R&D), which is recognised in the literature as firms' innovative inputs and/or efforts (Lahr and Mina 2021). It also encapsulates innovative outcomes, which may result as the output of firms' R&D efforts. However, as I discuss throughout this thesis, my focus on R&I (as opposed to R&D) stems from a view of innovation as the result of non-linear, and developmental processes (Pavitt 1984; Kline and Rosenberg 1986; Roper *et al.* 2008; Cassiman *et al.* 2018). This contrasts with earlier linear models of innovation, which conceptualise innovation as mainly the product of R&D (Crepon *et al.* 1998). My rationale here rests on the understanding that while some firms may innovate by engaging in R&D, other firms may innovate without performing such activities (Rammer *et al.* 2009; Hervas-Oliver *et al.* 2011; Lee and Walsh 2016). Moreover, as demonstrated by Klingebiel and Rammer (2014), and Hullova *et al.* (2019), firms may typically engage in several R&D and innovation activities at the same time. By engaging in a portfolio of R&I activities, firms may hedge against the risks associated with failure of innovative projects, and benefit from complementarities between different R&I activities (Percival and Cozzarin 2008; Rammer *et al.* 2009; Hullova *et al.* 2019).

R&I are regarded, by academics and policymakers alike, as key drivers of firm competitiveness (Atkinson 2013; Krammer 2017). This is because innovation can result in more efficient production processes, that can reduce cost and increase quality, while new products and services can enable firms to enter new markets and increase sales (Lang 2009; Roper and Arvanitis 2012; Uhlaner *et al.* 2013; Coad *et al.* 2016; Wojan *et al.* 2018). Research can act as a roadmap to innovation, by enabling firms to identify and organise commercially valuable knowledge (Kim 1998; Fleming and Sorenson 2004; Arora *et al*. 2018). Reikard (2011), for example, attributes approximately 40 percent of the productivity growth experienced by firms in the US during the second half of the 20th century to investments in research activities. Furthermore, as the European Commission (2020, p.1) has recently argued, in the context of the Covid-19 pandemic, "R&I are critical levers to ensure a sustainable and inclusive recovery, while boosting the resilience of our production sectors, the competitiveness of our economies and the transformation of our socio-economic systems". Firms that engage in R&I typically tend to be more productive, and grow more (and faster), than firms that do not engage in these activities (Cardinal *et al.* 2001; Griffith, *et al.* 2006; Heshmati and Loof 2006; Reikard 2011; Roper and Arvanitis 2012; Duch-Brown *et al.* 2018; Piekkola and Rahko 2020).

Firm-level R&I is also vital for wider economic development (Borrás and Edquist 2014). The importance of innovation for economic development has evolved, from an initial focus on science and technology in universities and specialised research centres in the 1960s and 1970s (Bush 1945; OECD 1971), to innovation in firms, from the 1980s to date (OECD 2000; Lundvall and Borrás 2005; Borrás and Edquist 2016). Since the 1980s, the focus on innovation has also expanded from innovation at the firm-level, to a more comprehensive conceptualisation of innovation as a product of 'system of innovation' at different geographical scales (i.e. local, regional, and national) (Dosi *et al.* 1988; Freeman 1995; Acs *et al.* 2017; Edquist 2018). Nevertheless, innovation at the level of the firm continues to be considered, in academic and policy perspectives, as a key driver of societal and economic development to this day. This is because firms are the engine of growth, innovation, and wealth creation (Protogerou *et al.* 2017; Zahler *et al.* 2022). According to Rosenberg and Birdzell (1990), advances in scientific and technological knowledge have been a major contributor to the unprecedented levels of prosperity experienced by advanced market economies during the previous century. Yet, it is through the work of firms that the benefits of scientific and technological knowledge can be realised (Pavitt 1984; Dedrick *et* *al.* 2015; Cassiman *et al.* 2018). R&I by firms is thus a crucial driver of development in modern economies (Kline and Rosenberg 1986; Dedrick *et al.* 2015; Cassiman *et al.* 2018; Fagerberg 2018; Holl 2021).

More recently, the focus on R&I has been extended by also considering societal perspectives (Edquist and Zabala-Iturriagagoitia 2012; Borrás and Edquist 2013; Fagerberg 2018). To a large extent, this resulted from new challenges arising from the process of technological change, such as the need to promote the upskilling of the workforce, and stimulate more knowledge-driven economic growth (Lundvall and Borrás 2005; de Jesus *et al.* 2019; Grashof 2021). According to Borrás and Edquist (2015, p. 215), a crucial element which translates knowledge into innovation is "the way in which skills and expertise are developed and used by individuals and organizations". McGuirk *et al.* (2015), and Lenihan *et al.* (2019), have also highlighted that, in addition to skills and expertise, attitudinal elements of employee managers, such as their willingness to change, are pivotal for driving R&I in firms. The engagement in R&I activities, in turn, can contribute to developing such attitudes, skills, and expertise (Antonioli *et al.* 2011, 2014; Szambelan *et al.* 2020). This is vital, given that countries in the European Union (EU), and elsewhere, increasingly focus on transitioning towards smarter, and more knowledge-intensive economic systems (European Commission 2010; Mazzucato 2016; Moreau *et al.* 2017; Laplane and Mazzucato 2020).

Despite the importance of R&I in firms, the level of firms' engagement in R&I activities remains low. In the EU, for example, the 2021 Innovation Scoreboard (European Commission 2021a) indicates that only around a third (i.e. 34%) of all firms in the EU innovated in processes, products, or services, during the period from 2020 to 2021. The European Commission (2021) notes that this is believed to be higher in comparison to less advanced global competitors such as China (no precise data), Brazil (33%), South Africa (no precise data), Russia (~ 5 to 10%), and India (no precise data). However, it is lower when compared to other advanced economies such as South Korea (37%), Canada (65%), Australia (52%), the United States (50.9), and Japan (39.7). Moreover, the intensity of business research and development (R&D) remains low, at below two percent of Gross Domestic Product (GDP) on average, while firms' investments in non-R&D innovation continue to be below one percent of firms' total turnover (European Commission 2021a). The EU Horizon Europe Strategic Plan 2021-2024 (European Commission 2021b), highlights the need for public investments in R&I to encourage economic and social development, especially following the Covid-19 pandemic. However, as stated in the Horizon 2020 Research and Innovation Programme (the previous EU STI policy initiative), "public funding alone is not enough: the EU needs to encourage businesses to invest more in research, and target areas where they can work with the public sector to boost innovation" (European Commission 2014, p. 9).

Furthermore, as I outline in this PhD thesis, an understanding of how to encourage firms to engage in more R&I remains limited. For example, as noted by Hall *et al.* (2016, p. 193), "there is relatively little knowledge about what makes an organisation innovate, which conditions favour the rise of such organisations and whether certain socio-economic environments and policies can support their development in both manufacturing and service industries". In a similar vein, Holl (2021) notes that it is widely accepted in academic and policy perspectives that STI policies should focus on the development of favourable business environments for R&I to flourish. However, "there exists still relatively little knowledge on how

[the] firms' external environment affects commitment to innovation" (Holl 2021, p. 565). In this context, my research offers deeper insights on the constraints that hinder firms' R&I activities, and how public financial support for R&I can enable firms to overcome such constraints.

2.2 Constraints to research and innovation

Understanding the drivers of firm-level Research and Innovation (R&I) remains a fruitful and highly contested topic of research. A vast number of studies have focused on the drivers of R&I activities in firms at different levels of analysis. These include studies focused at the level of the firm (Roper and Hewitt-Dundas 2008; Roper *et al.* 2008; Amore 2015), at the level of teams within firms (Hoegl *et al.* 2008; Weiss *et al.* 2017), and at the level of the ecosystem in which firms locate (Moulaert and Sekia 2003; Gomes *et al.* 2015; Oh *et al.* 2016). Such studies have enabled a deep understanding of the motivations and factors, that enable firms to innovate. However, our understanding of the mechanisms that hinder firms' R&I activities remains limited (D'Este *et al.* 2012; Pellegrino and Savona 2017; Pellegrino 2018; Bodlaj *et al.* 2020; Radicic, 2021; Zahler *et al.* 2022). This is a major limitation that prevails in the literature, as understanding the constraints affecting firms' R&I is paramount for gaining a deeper knowledge of the process of innovation in firms (D'Este *et al.* 2014; Pellegrino and Savona 2017) .

This PhD research builds on, and contributes to, a growing literature that strives to understand the constraints that deter firms from engaging in R&I. Most of the prevailing studies in this vein have mainly focused on firms' financial constraints. Yet, as I discuss in Section 2.2.1 (below), our understanding of the nature and impact of financial constraints remains incomplete. The section also outlines how this research contributes to advancing an understanding of the nature of firms' financial constraints. Furthermore, firms may also face other critical non-financial constraints to R&I, which are related to a lack of knowledge and demand for R&I (D'Este *et al.* 2012; Pellegrino and Savona 2017; Radicic, 2021). In Section 2.2.2, I discuss how the literature regarding non-financial constraints remains scarce, and outline the key areas that remain largely unexplored by prevailing studies. Moreover, I explain how the research provides novel insights regarding how firms may overcome financial and non-financial constraints, and how public financial support for R&I can accelerate such processes.

2.2.1 Financial constraints

The concept of financial constraints emerged from the seminal work of Fazzari *et al.* (1988), when analysing the relationship between firms' cash-flows and their investments in Research and Innovation (R&I) activities. In this context, financial constraints refer to firms sustaining sub-optimal levels of investments in R&I due to a lack of financing, or because the high cost of external financing (Hall 2002; Hottenrott *et al.* 2016). They arise from the high level of uncertainty, and concerns about appropriability, associated with private R&I (Nelson 1959; Arrow 1962; Hall 2002; Carboni 2017; Mina *et al.* 2021).

R&I activities, particularly the research component (i.e. the 'R'), produces knowledge, which is largely non-rival and non-excludable. This means that the use of knowledge by one firm does not preclude other firms from using the same knowledge (Arrow, 1962; Hall, 2002). As a result, R&I activities are a form of public good (Stiglitz 1999; Cowling 2016; Florio and Sirtori 2016; Klímová *et al.* 2020). Therefore, firms may 'free-ride' on the R&I investments made by other firms (Stiglitz 1999; Kaul *et al.* 1999; Strandholm *et al.* 2018). Furthermore, a significant share of the costs of R&I is in the form of salaries of R&D workers, and the loss of these workers means that investments in R&I can be lost and/or transferred to other firms (Hall 2002; Brown and Petersen 2011; Hall *et al.* 2016). R&I investments are thus bound with uncertainty and issues of appropriability, which reduce their value (e.g. through discounting) (Czarnitzki and Kraft 2004; Czarnitzki and Delanote 2017). Such issues can also hinder firms' access to external finance for R&I, by encouraging information asymmetries between firms and lenders (Hall 2002; Hottenrott and Peters 2012; Hall *et al.* 2016). This occurs when firms do not disclose information on innovation projects to protect proprietary knowledge, and lenders are not able to assess the viability and value of R&I investments (and/or of the firm). As a result, lenders could refrain from lending for R&I activity and/or ask for higher premiums (Akerlof 1970; Hall 2002; Czarnitzki *et al.* 2011).

Because of the above, firms tend mainly to rely on internal funding for R&I before exploring more expensive options externally (Myers and Majluf 1984; Himmelberg and Petersen 1994; Fazzari *et al.* 1988; Hall *et al.* 2016). However, factors such as moral hazard (e.g. principal-agent problems), tax issues (e.g. taxes on retained earnings), and shareholders' pressure for dividends, can influence the liquidity that firms hold at any given time (see, for a discussion, Hall *et al.* 2016). For private firms managed by the owner(s), investment in R&I will influence the income that the owner(s) can withdraw from the firm. The available cash reserves for R&I are, therefore, likely to be limited. This, in turn, hinders firms' R&I investments (Hottenrott and Peters 2012; Schäfer *et al.* 2017).

Numerous studies have shown that firms facing financial constraints are less likely to engage in R&I, and invest less in such activities (e.g. Himmelberg and Petersen 1994; Bond *et al.* 2005; Savignac 2008; Hall *et al.* 2016; Pellegrino and Savona 2017). However, a growing number of studies also demonstrate that firms may continue to engage in R&I, despite (or because of) financial constraints (e.g. Katila and Shane 2005; Hoegl *et al.* 2008; Gibbert and Scranton 2009; Keupp and Gassmann 2013; Weiss *et al.* 2017). This has led to new questions regarding the importance of financial constraints for R&I, with several authors highlighting the need for more research to deepen our understanding on this topic (Keupp and Gassmann 2013; Berends *et al.* 2014; Teirlinck 2020).

In this PhD thesis, I posit that a limitation affecting prevailing studies in this vein, is that they have mainly focused on the impact of financial constraints on firms' engagement in R&D, or product and process innovation. However, firms may typically engage in several other R&I activities, which may not necessitate high levels of financial resources, such as organisational innovation and incremental service innovation (Percival and Cozzarin 2008; Tavassoli and Karlsson 2015; Hullova *et al.* 2019). Furthermore, I propose that existing studies typically ignore potential heterogeneities between firms of different sizes, which may affect the extent to which firms are able (and willing) to use their limited financial resources to engage in different types of R&I activities (Berends *et al.* 2014). In Chapter 4, I also argue that financial constraints may not necessarily relate to firms having limited financial resources. That is, they may also arise as firms engage in more resource intensive projects (Savignac 2008; Pellegrino and Savona 2017; Hottenrott *et al.* 2018; Lahr and Mina 2021).

My PhD research addresses the above limitations that prevail in the literature in two main ways. The first way, as discussed in Chapter 3, is by examining how levels of internal financial resources impact firms' engagement in a comprehensive set of R&I activities of firms of different sizes. My focus on firms' levels of internal financial resources is critical, as it permits an understanding of the extent to which firms' R&I activities are constrained, when faced with limited financial resources. As I discussed earlier in this section, this is a key theoretical proposition in the literature of financial constraints, but one that continues to be highly contested in the literature. I specifically show that firms may require high levels of financial resources in the context of R&I activities that are distant to market (e.g. research activities). Firms may also need high levels of financial resources for more resource intensive R&I activities (e.g. innovation in products and processes, more radical forms of product and service innovation). However, firms may not need to have high levels of financial resources for innovations that mainly arise from changes in the way they manage innovation, and how they engage with their existing clients (e.g. organisational and incremental service innovation).

Moreover, my analysis considers the importance of internal financial resources for R&I in the context of small-sized (10 to 49 employees) and *medium and large-sized* firms (i.e. hereafter referred to as larger-sized firms; 50+ employees), separately.[1]. My findings indicate that financial resources may not be a key driver of R&I in the context of small-sized firms. I discuss these findings by

[1] The European Union recommendation 2003/361 defines small-sized firms as firms with less than 50 employees, medium-sized firms as firms between 50 and 249 employees, and large-sized firms as firms with 250 employees or more. The recommendation also classifies firms according to their turnover or balance sheet (see http://data.europa.eu/eli/reco/2003/361/oj), but the number of employees is the most commonly used classification (Eurostat 2019). Data for firms with fewer than 10 employees were not available to my PhD research study.

highlighting that such firms may also experience other constraints associated with resources and capabilities for R&I. As a result, such firms may continue to refrain from engaging in R&I despite having high levels of financial resources. These insights are critical as they contribute to the development of a more comprehensive theory of the importance of financial resources for R&I. In addition, they are helpful for explaining the existing mixed results which are typically found in earlier studies in this vein. Ultimately, they are potentially highly policy relevant, as they may signal the key R&I activities for which firms are more likely to need public policy support.

In Chapter 4, I advance the insights arising from Chapter 3, by exploring the nature of firms' perceived financial constraints, and how firms overcome such constraints. Switching the focus from internal financial resources to perceived financial constraints is important. This is because firms may only perceive such constraints as they engage in more resource demanding R&I activities (D'Este *et al.* 2012; Lahr and Mina 2021). My research demonstrates that perceived financial constraints are endogenous to firms R&I activities. That is, firms are more likely to perceive such constraints as they engage in more, and more distant, R&I activities. In addition, while firms may overcome their perceived financial constraints, they are likely to perceive such constraints when engaging in new R&I projects. This takes place in a dynamic and evolutionary process, as firms gain deeper R&I capabilities, and perform more resource-demanding R&I projects. Moreover, my research indicates that perceived financial constraints may result in firms performing fewer R&I projects, but with higher commercial value, as measured by firms' turnover generated from innovation. These insights are crucial for understanding how firms perceive financial constraints. In addition, they highlight that while financial constraints may hinder firms R&I activities, they may also result in firms being more selective of the types of R&I projects they engage with. That is, firms may decide to invest their limited financial resources in R&I projects that maximise their returns.

2.2.2 Non-financial constraints

In addition to financial constraints, firms typically face other critical non-financial constraints to Research and Innovation (R&I) (García-Quevedo *et al.* 2017; Pellegrino and Savona 2017). Non-financial constraints mostly relate to a lack of knowledge for R&I (D'Este *et al.* 2014), a lack of suitable partners with whom to engage in collaborative R&I efforts (Antonioli *et al.* 2017), and a lack of demand for their R&I activities (García-Quevedo *et al.* 2017; Szambelan *et al.* 2020).[2] The literature on non-financial constraints to R&I emerges mainly from theories of innovation concerned with resources and capabilities for R&I. Chapter 4 and Chapter 5 provide a detailed discussion of such constraints. Here, I provide a summary.

The generation of scientific and technological knowledge, and the development of new processes and products, can have deep implications for the structure and performance of industries and markets (Dosi 1988). As a result, the technological frontier, and the market in which firms operate, are in continuous flux, meaning that firms' competitive advantages are continuously being challenged (Teece 2007; Roper and Hewitt-Dundas 2017). In this context, established firms

[2] As Chapter 4 outlines, firms may also perceive regulation constraints, which refer to firms perceiving difficulties to innovate due to a confusing or restrictive regulatory environment (D'Este et al. 2012). However, as explained by Mohnen *et al.* (2008), addressing these constraints may entail shaping the regulatory environment, rather than firm-level interventions. Regulatory constraints thus extend beyond the scope of this research.

may experience knowledge constraints due to organisational inertia and rigid structural routines. Such knowledge constraints can impede firms' abilities to adapt and evolve in line with changing business environments, especially with regards to R&I (Nelson and Winter 1982; Dougherty and Hardy 1996; Assink 2006).

New and young firms may suffer from other types of knowledge constraints, which result from a lack of resources and/or experience for R&I (Gort and Klepper 1982; D'Este *et al.* 2012; Pellegrino and Savona 2017). Innovation is a cumulative process, which requires knowledge-creating resources (e.g. capital equipment, knowledge-creating routines) for developing R&I capabilities (D'Este *et al.* 2016). New and young firms may lack the required knowledge creating resources for R&I because such resources may take time to develop. Firms may also face financial constraints hindering their ability to carry out the necessary investment obtain and develop such resources (Hall 2002; Colombo *et al.* 2006; Gomez and Vargas 2009).

Furthermore, R&I are increasingly recognised as the product of collaborations between different actors embedded in innovation ecosystems (Mitra and Formica 1997; van de Vrande *et al.* 2009; Colombo *et al.* 2014; Love *et al.* 2014; de Faria *et al.* 2020). Firms may engage in collaborative R&I projects for several reasons, including risk-sharing (e.g. sharing the cost of innovation), accessing external resources (e.g. expertise, physical resources), and exploiting technology complementarities (Serrano-Bedia *et al.* 2010; Antonioli *et al.* 2017; Meulman *et al.* 2018). However, managing external relationships within collaborative R&I projects can be resource-intensive, as it requires managers to gain competencies and skills that are specific to this task (Love *et al.* 2011; Laursen and Salter 2014; Wang 2016; Roper *et al.* 2017). Therefore, firms may experience difficulties in identifying partners for collaborative R&I projects (Roper *et al.* 2008), and/or may have insufficient managerial skills and experience to engage in R&I collaborations (Lhuillery and Pfister 2009; Hewitt-Dundas *et al.* 2019).

Finally, as firms engage in R&I, the resulting innovative processes, products, and services, can enhance their competitive advantages, at least temporarily (Roper *et al.* 2008). This is because innovation can enable firms to increase their sales, enter new markets, and generate new demand (Lee 2011). However, as initially highlighted by Schumpeter (1934) and Arrow (1962), competition and market structure, combined with appropriability concerns, can deter firms from engaging in R&I activities. According to D' Este *et al.* (2012), such market constraints can be particularly binding in less competitive markets, where dominance by established firms can represent an important barrier to entry for some firms, especially small-sized firms.

Empirical evidence regarding the impact of non-financial constraints is scarce, and typically emerges from studies focused on firms' perceived constraints, including financial constraints (see, Galia and Legros 2004; D'Este *et al.* 2012; Blanchard *et al.* 2013; Antonioli *et al.* 2017; Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020). The limited available evidence indicates that perceived non-financial constraints harm firms' likelihood to engage in R&I activities, and increase firms' likelihood to delay and/or discontinue existing ones (Galia and Legros 2004; Blanchard *et al.* 2013; Antonioli *et al.* 2017). Such non-financial constraints can be particularly binding in the context of more radical forms of innovation (Woschke *et al.* 2017; Pellegrino 2018; Radicic 2021).

As I discuss in Chapter 4 and Chapter 5 in greater detail, I propose that our understanding of how firms overcome their non-financial constraints, and the policy interventions that may accelerate such processes, remains very limited (Pellegrino and Savona 2017; Antonioli *et al.* 2017; Szambelan *et al.* 2020; Zahler *et al.* 2022). I also highlight that this is a limitation affecting existing studies in this vein. For example, in Chapter 4, I specificallly discuss that existing studies have proposed that helping firms to overcome their perceived non-financial constraints may require policy interventions that address 'systemic failures' (D'Este *et al.* 2012; Pellegrino and Savona 2017; Antonioli *et al.* 2017). However, as several authors, such as Wanzenböck *et al.* (2013), Borrás and Edquist (2015), and Uyarra *et al.* (2020), have outlined, designing and implementing such forms of systemic policy interventions may be a challenge (and opportunity) for policymakers. Furthermore, such policies may take time to have an impact on firms' R&I activities (Borras and Edquist 2015).

A key contribution of my PhD research is that it explores whether public financial support for R&I could also enable firms to overcome their perceived knowledge and market constraints.[3] As Section 2.3 (below) discusses in more detail, public financial support for R&I support was initially designed to address

[3] Borras and Edquist (2015) note that many countries (more specifically, OECD countries) have public financial policy instruments to improve firms' managerial and R&I capabilities (e.g. mentoring programs and vocational training for firms' employees). Such policy instruments primarily focus on increasing firm-level capacity, and thus may be discussed as financial policy instruments to specifically target firms' non-financial constraints. However, as Borras and Edquist (2015) highlight, firms face several challenges when availing of such forms of financial support. Specifically in the context of SMEs, this is because firms often lack capacity to organise and co-finance encompassing training programmes that ensure quality training and certification. Moreover, SMEs may encounter challenges in finding suitable trainers, and for designing the adequate educational frameworks. As a result, such forms of public financial support are very different to the public financial support instruments considered in this PhD research, which specifically aim to increase R&I activities in firms (i.e. R&D subsidies, R&D tax credits, and R&D subsidies that require collaboration between firms and universities and research centres).

market failures, and firms' financial constraints. However, by encouraging more R&I in firms, in Chapter 4, my research also shows that public financial support for R&I can indeed help firms to overcome their financial and non-financial constraints. This takes place through a developmental process, in which, by investing more in R&D, firms are able to develop R&I capabilities and absorptive capacity (Clarysse *et al.* 2009; Radas *et al.* 2015; Hullova *et al.* 2019). More innovation, in turn, can improve firms' positions in the market, and help firms to overcome their market constraints (Hewitt-Dundas and Roper 2010; Hottenrott and Lopes-Bento 2014).

However, if public financial support were to be used to enable firms to overcome their non-financial constraints, we need to ensure that this represents an efficient allocation of public money. As a result, in Chapter 5, I critically evaluate the impact of public financial support for R&I on the radical innovation activities of firms that perceived knowledge-related constraints. The insights arising from this PhD research contribute to generating a deeper understanding regarding the nature of non-financial constraints. In addition, they are potentially very policy relevant, as they can inform a more effective allocation of public financial support for R&I.

2.3 Public financial support for research and innovation

Governments in many countries provide public financial support to encourage firms to engage in research and innovation (R&I) activities (Zúñiga-Vicente *et al.* 2014; Becker *et al.* 2017). As Nelson (1959) and Arrow (1962) have posited, the rationale for such support has initially focussed on addressing market failures affecting the rate and direction of firms' investments in R&I activities. In line with the literature on financial constraints previously discussed in Section 2.2.1, investments in R&I are bound with high uncertainty and issues of appropriability. This, in turn, reduces the value of R&I investments through discounting, and increases the risk-reward ratio of such investments. As a result, firms may resort to carrying out sub-optimal levels of investments in R&I (Nelson 1959; Arrow 1962; Hall 2002; Busom and Vélez-Ospina 2020). The provision of public financial support for R&I is expected to address the above discounting effects, and encourage R&I activities in firms (Kleer 2010; Becker 2015; Barbosa and Silva 2018). Public financial support for R&I is, therefore, increasingly recognised as a key policy intervention to address firms' financial constraints (Busom *et al.* 2014; Carboni 2017; Mina *et al.* 2021).

To be effective, however, public financial support for R&I should complement, rather than substitute, private R&I investments (Lenihan and Hart 2004; Wanzenböck *et al.* 2013; Czarnitzki and Delanote 2015). The pertaining available evidence tends to indicate that such support can lead to additional R&I inputs and outputs by firms (see, for reviews, Zúñiga-Vicente *et al.* 2014; Becker 2015; Jugend *et al.* 2020). More recently, some evidence also indicates that public financial support for R&I can induce long-term behavioural changes in the way that firms carry out R&I activities, specifically with regard to their engagement in riskier R&I activities (Falk 2007; Gök and Edler 2012; Chapman and Hewitt-Dundas 2018). Public financial support may also encourage learning effects in recipient firms, which can lead to long-term improvements in their R&I capabilities (Clarysse *et al.* 2009; Radas *et al.* 2015; Jugend *et al.* 2020). As I discussed in Section 2.2.2, and explore in greater detail in Chapter 4, this is a key issue in the context of the current research.

Despite the above, several firm characteristics have been found to moderate the impact of public financial support for R&I on firms' R&I activities. For example, such support has been found to have greater input additionality effects on smaller firms, than on larger firms (see, for a review, Becker 2015). Public financial support may also primarily impact R&I activities that are more distant to the market, such as research activities (Hottenrott and Lopes-Bento 2014; Beck *et al.* 2016; Hottenrott *et al.* 2017; Fudickar and Hottenrott 2019). Evidence also indicates that the support is most effective when allocated to firms for the first time, but that the impact of such support can decline when allocated to firms that have already received the support in previous years (Takalo and Tanayama 2010; Huergo and Moreno 2017; Nilsen *et al.* 2020). Huergo and Moreno (2017) and Nilsen *et al.* (2020), therefore, propose that public financial support for R&I can be more effective at the extensive margin (i.e. increasing the pool of innovators), rather than at the intensive margin (i.e. make firms innovate more).

The heterogeneity of the available evidence highlighted above has led to new questions regarding how to ensure that public financial support for R&I represents value for money (Mazzucato and Semieniuk 2017; Mina *et al.* 2021). Such questions primarily pertain to the types of firms and R&I activities that the support should prioritise (see, for example, Autio and Rannikko 2016; Mazzucato and Semieniuk 2017). Chapter 3 and Chapter 5 of this PhD thesis explore these arguments in more detail. A key issue in the context of this PhD research pertains to how such support can lead to potential unexplored impacts in firms, such as firms changing their R&I behaviour in response to this support (Beck *et al.* 2016; Chapman and Hewitt-Dundas 2018). My PhD research advances an understanding in this regard. This is achieved by exploring whether public financial support for

R&I can address firms' financial constraints, and indirectly help firms to overcome non-financial constraints to R&I. This is an important issue, which, to the best of my knowledge, has not been addressed by previous studies.

2.4 Data

Addressing the research questions driving this PhD research, as presented in Section 1, requires detailed firm-level data. Specifically, the data need to include in-depth information on: (a) firms' resources for Research and Innovation (R&I); (b) the different types of R&I activities that firms may engage in; (c) the constraints that firms face when carrying out R&I activities; and (d) the receipt of public financial support for R&I by firms. Such information is obtained by constructing a novel and detailed dataset, which merges different sources of data from the Irish Central Statistics Office (CSO), with detailed administrative data regarding public financial support instruments for R&I available to firms in Ireland. The administrative data available to this research comprise information data on the full spectrum of public financial support for R&I from Ireland's three main funding agencies (i.e. Enterprise Ireland [EI], Industrial Development Agency [IDA] Ireland, and Science Foundation Ireland [SFI]). Moreover, the data include information on R&D tax credits from the Irish Revenue Commissioners.[4]

[4] Enterprise Ireland provides a range of policy support instruments for Irish-owned firms from start-up to maturity, with a particular focus on innovation and exporting activities (Enterprise Ireland, 2019). For more information see https://www.enterprise-ireland.com/en/.IDA Ireland mainly focuses on attracting and supporting investments into Ireland by foreign-owned multinational corporations (IDA, 2020). For more information see https://www.idaireland.com/. SFI primarily funds scientific research in higher education institutions, but SFI funded institutions can also provide cutting edge knowledge to firms through co-funded collaborative research projects (SFI, 2018). For more information see https://www.sfi.ie/. Ireland's Revenue Commissioners oversees all tax-related matters in Ireland. For more information see https://www.revenue.ie/en/Home.aspx. Chapters 4 and 5 provide more details into the specific instruments provided by each agency for supporting R&I activities in firms.

The data used in this PhD research allow me to build on, and advance, previous studies on this topic, in three key ways. Firstly, the data permit a comprehensive understanding of firms' internal resources, especially their financial resources, and a comprehensive set of R&I activities performed by firms. As discussed in Section 2.2.1, and as I explore in Chapter 3 in greater detail, this enables an analysis of the relationship between firms' levels of financial resources and their engagement in a comprehensive set of R&I activities. Specifically, the data permit extending the focus to explorative and exploitative research activities, and to five types of innovation activities (i.e. [a] process innovation; [b] product innovation; [c] service innovation; [d] radical product and services innovation; and [e] organisational innovation). This is a major advantage of the data because previous studies in this vein have typically focussed on firms' financial resources in the context of R&D, process, and product innovation (see Chapter 3 for a detailed discussion on this issue).

Secondly, the data enable an in-depth understanding of the types of public financial support for R&I available to firms. As I discuss in more detail in Chapter 4 and Chapter 5, this enables my analysis to assess whether public financial support can help firms to overcome their financial and non-financial constraints. Crucially, it also enables my research to identify the different types of public financial support instruments that may be most effective to achieve these goals. To the best of my knowledge, this PhD research is the first to carry out such forms of analyses.

Thirdly, the data enable this research to construct robust data structures, which permit controlling for important sources of bias that may affect the findings of the research. As I explain in Chapter 4 and Chapter 5, this permits establishing cause-effect relationships, rather than simply correlations, as is typically the case in the literature pertaining to firms' constraints to R&I.

Sections 2.5.1 to 2.5.2, describe the data sources, while the processes used to merge the data are discussed in Chapter 3, Chapter 4, and Chapter 5.

2.4.1 Data from the Irish Central Statistics Office:

This PhD research benefits from access to five different sources of data from the Irish Central Statistics Office (CSO):

- **Innovation in Irish Enterprises Survey (IIE):** The IIE survey was formerly known as the Community Innovation Survey (CIS). This is a biennial survey, with information on the internal characteristics, innovation activities, and the constraints that firms face when engaging in R&I, for firms with at least 10 employees in selected sectors of the economy (CSO, 2018). Specifically, the sample frame of the IIE survey is a stratified sample of enterprises with at least 10 and a maximum of 49 persons engaged, and a census of all firms with 50 persons engaged or more, in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73 (CSO 2018).[5] Data from the surveys waves from 2008 to 2016 were available to this PhD research. Response rates to the IIE survey were 72% in the 2008-2010 wave

[5] NACE codes refer to Nomenclature of Economic Activities. The Nace Rev. 2 Sectors from 05- to 39, as included in the IIE survey, pertain to industrial firms (i.e. Mining and quarrying, Manufacturing, Electricity, gas, Steam and air conditioning supply, Water supply; sewerage, Waste management and remediation activities). The Nace Rev. 2 Sectors from 46- to 73, in turn, pertain to firms in selective services (i.e. Wholesale trade, except of motor vehicles and motorcycles, Transportation and Storage, Information and communication, Financial and insurance activities, and Architectural and engineering activities; technical testing and analysis; scientific research and development; advertising and market research. For additional information on the IIE survey see https://www.cso.ie/en/methods/scienceandtechnology/innovationinirishenterprisesformerlyknownascommunityinnovationsurvey.

(CSO 2012), 73% in the 2010-2012 wave (CSO 2014), 69% in the 2012-2014 wave (CSO 2016a), and 66% in the 2014-2016 wave (CSO 2018a).[6]

- **Business Expenditure on Research and Development Survey (BERD):** The BERD survey is a biennial survey containing detailed information on R&D expenditure incurred by firms across all business sectors of the economy. The BERD survey is "designed to be a census of all enterprises that are believed to be engaged in research and development activities in all business sectors of the economy" (CSO 2017, p. 4). Such enterprises are identified from: (a) previous BERD surveys data; (b) other CSO data, such as the IIE survey; and (c) administrative data sources, such as Balance of Payments data. However, only around 45 percent of firms featured in the BERD survey dataset typically engage in R&D across the different survey waves (e.g. 1,900 firms out of a sample of 4,200 firms performed R&D in the 2016 wave).[7] The available BERD data thus include information on R&D-active firms, and on firms that do not engage in these activities. Data from the 2008 to 2016 BERD survey waves were available to this PhD research. The response rates for the BERD survey waves used are 77% for the 2011-2012 wave (CSO 2013), 70% for the 2013-2014 wave (CSO 2015), and 68% for the 2015-2016 wave (CSO 2017).[8]

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[6] The 'Quality Reports' for the IIE survey waves used in the current research can be accessed online at: https://www.cso.ie/en/methods/qualityreports/innovationinirishenterprises/.

[7] This issue is addressed in more detail in Chapter 3. For additional statistical description of the data see: https://www.cso.ie/en/media/csoie/methods/businessexpenditureonresearchdevelopment/Standard_Report_on_Methods_&_Quality_BERD_2015-2016.pdf.

[8] The BERD survey 'Quality Reports', published by the Irish CSO, can be accessed online at: https://www.cso.ie/en/methods/qualityreports/businessexpenditureonresearchdevelopment/.

- **Census of Industrial Production (CIP):** The CIP is a yearly census of all enterprises registered in Ireland, which are wholly or principally involved in industrial production (i.e. NACE Sections B to E) (CSO 2018b). The CIP includes information on firms' trading dimensions, such as turnover, purchases of materials and services and labour costs during the year (CSO 2018). The CIP data available to this PhD research spans from 2005 to 2016. Response rates to the CIP survey during the period covered in this research ranged between 55% and 68%, with the lowest response rate occurring in 2010, and the highest in 2016 (CSO 2018b).[9]

- **Annual Services Inquiry (ASI):** The ASI is a yearly survey with information on all enterprises in the retail, wholesale, transportation and storage, accommodation and food, information and communication, real estate, professional, scientific, technical, administrative, and other selected services sectors (CSO 2019). The ASI is a census of enterprises with 50 or more persons engaged in the above sectors. Enterprises with fewer than 50 persons engaged are included as part of a stratified random sample, with decreasing sampling proportions taken from those enterprises in the lower persons engaged ranges (CSO 2019). Moreover, while all enterprises with one or more persons engaged are included in the survey frame, data for enterprises with fewer than 2 persons engaged are obtained directly from administrative data sources (i.e. tax information from the Irish Revenue Commissioners). The information included in the ASI survey is similar to that included in the CIP survey (i.e. turnover, purchases of materials and

[9] The CIP 'Quality Reports', published by the Irish CSO, can be accessed online at: https://www.cso.ie/en/methods/qualityreports/censusofindustrialproductionenterprises/.

services and labour costs during the year). As explained below, the ASI data are merged with the IIE and BERD data (see Chapter 3 for details), and thus only firms with 10 or more persons engaged are considered in this research. ASI data available to this PhD research spans from 2004 to 2016. Response rates to the ASI survey during the period covered in this research ranged between 45% and 55%, with the highest response rate occurring in 2010, and the lowest response occurring in 2016 (CSO 2018c).[10]

- **Business Register:** This is a register of all firms registered in Ireland. The Business Register is generated by the Companies Registration Office (CRO) and updated by the CSO on a yearly basis. The Business Register provides additional information on NACE sectors (i.e. three-digit NACE sector codes), firms' locations (i.e. Irish Country Codes), and firms' registration year, from which firms' ages can be calculated (i.e. by subtracting the year of registration from the current date). The Business Register data available to this PhD research consist of historical summaries generated by the CSO, that span the period from 2004 to 2016.

2.4.2 Administrative data on public financial support for research and innovation

My PhD research benefits from unique administrative data on public financial support for Research and Innovation (R&I) instruments available to firms

[10] The response rates of the ASI survey for the period prior 2016 are obtained from communications with the Irish CSO, given that the ASI 'Quality Reports' published by the Irish CSO only pertain to the period from 2016 onwards. The reports for the ASI survey from 2016 to 2021 can be accessed online at: https://www.cso.ie/en/methods/qualityreports/annualservicesinquiry/.

in Ireland. The administrative data used comprise of the full range of public support for R&I available to firms in Ireland from Ireland's three main funding agencies, and the Irish Revenue Commissioners. These agencies are Enterprise Ireland (EI), IDA Ireland (IDA), and Science Foundation Ireland (SFI). A summary of the administrative data used is provided below, while a more detailed discussion of the administrative data is provided in Chapter 4 and Chapter 5 (an in-depth review of the R&D support instruments described below is provided by Lenihan *et al.* [2020]):

- **Public financial support for R&I from Enterprise Ireland (EI):** EI is a government organisation responsible for the development and growth of Irish enterprises in world markets (Enterprise Ireland 2021).[11] EI provides a comprehensive suite of supports for Irish-owned firms, from start-up to maturity, with a particular focus on innovation and exporting (Enterprise Ireland 2021). Only public financial support instruments to promote R&I at the firm level are considered in this PhD research. As proposed by Zúñiga-Vicente *et al.* (2014), Rogge and Reichardt (2016), and Vanino *et al.* (2019), public financial support instruments for R&I can be categorised in many ways. As they note, one common categorisation in the literature is to differentiate between direct and collaborative public financial support instruments. Direct instruments consist of direct cash transfers to firms, to perform R&I activities internally. Collaborative instruments, in turn, focus on supporting collaborations between firms and public knowledge providers (i.e. universities and research centres), and are typically paid to the

[11] For information on EI's objectives and activities see https://www.enterprise-ireland.com/en/.

knowledge provider. Based on this, the public financial instrument for R&I provided by EI can be divided into two groups.

The first group of public financial instruments for R&I provided by EI comprises direct types of support for R&D. As noted above, these public financial instruments support firms when carrying out R&I activities internally (Zúñiga-Vicente *et al.* 2014). Public financial instruments in this group include: (i) Business Innovation Initiative; (ii) Company expansion including R&D, (iii) Innovative High-growth potential start-ups (HPSUs) fund; (iv) Strategic R&D fund; (v) The Intellectual Property (IP) Strategy Scheme, and (vi) Technical Feasibility Grant. Such direct forms of R&D subsidies aim to encourage firms to engage in the development of new or substantially improved products, services or processes which will have a competitive advantage in firms' target markets (Enterprise Ireland 2019). Firms can avail of these forms of direct R&D support instruments through a competitive application process, which assesses the importance of the proposed project for the overall business strategy of the firms, in addition to firms' ability to deliver on the outputs proposed (Enterprise Ireland 2021).

The second group of public financial instruments for R&I provided by EI consists of public funding to encourage firms to collaborate with local knowledge providers, such as universities and research centres (Zúñiga-Vicente *et al.* 2014; Vanino *et al.* 2020). Within this group of instruments, the data available to this PhD research specifically include the following public financial support for R&I instruments: (i) Innovation Vouchers; (ii), funding Technological Centres and/or Technological Gateways to collaborate with firms; and (iii) Innovation Partnerships. Innovation

Vouchers consist of vouchers worth €5,000 to enable firms explore business opportunities, and/or solve specific R&I problems, in collaboration with local knowledge providers (Enterprise Ireland 2019). To obtain such vouchers, firms are required to collaborate with registered public local knowledge providers (Enterprise Ireland 2020a).

Technological Centres and Technological Gateways are industry-focused hubs, which are based across 16 Irish Institutes of Technology and Technological Universities (Enterprise Ireland 2020b). These research centres focus on delivering technology solutions for industry through collaborative industrial projects (Enterprise Ireland 2020b). Firms can avail of these forms of R&I support instruments through a competitive application process, which is made by the public knowledge provider (i.e. firms cannot access these R&I support instruments on their own). The funding is also allocated to the knowledge provider, as opposed to firms (Enterprise Ireland 2020b).

Finally, Innovation Partnerships provide up to 80 percent of the cost of research work towards the development of new and improved products, processes, or services, or the generation of new knowledge and know-how (Enterprise Ireland 2020c). This form of public R&I support requires firms to form partnerships with local knowledge providers, as described above. Funding is made available through a competitive process, and is awarded to the public knowledge provider. A key feature of R&I projects funded by the Innovation Partnership scheme is that these projects should not duplicate work already known to be in progress in Ireland, or already performed in other countries (Enterprise Ireland 2020c). Data from EI available to this research spans from 2006 to 2017.[12]

- **Public financial support for R&I from Industrial Development Agency (IDA) Ireland:** IDA Ireland focuses on attracting and supporting investments into Ireland by foreign-owned companies (IDA, 2021).[13] The administrative data includes three distinct types of public financial support instruments from IDA Ireland, which can also be discussed in terms of being direct (i.e. paid directly to firms) or collaborative (i.e. paid to public knowledge providers to enable collaborations with firms).

  Two of the types of support provided by IDA Ireland are direct: (a) RD&I Feasibility Study Grant; and (b) R&D Capability Grant. As outlined by IDA Ireland (2018), the RD&I Feasibility Study Grant provides up to a maximum of €250,000 or 50 percent of eligible expenditure, to firms that seek to have the feasibility of a potential project evaluated or analysed (IDA Ireland 2018). The R&D Capability Grant, in turn, covers a percentage of the overall eligible costs (determined on a case-by-case basis) of projects in foreign-owned firms that are planning an expansion of their existing R&D activity in Ireland (IDA Ireland 2020). Funding is made available through a competitive process.

  The remaining type of public support for R&I provided by IDA Ireland is collaborative, and pertains to Innovation Partnerships, as already discussed

[12] It is important to note that the public financial instruments for enhancing R&I activities in firms from EI have evolved, meaning that they may have undergone changes, during the period covered by this PhD research. For a detailed account on this issue see Lenihan *et al.* (2020).
[13] For information on IDA Ireland's objectives and activities see https://www.idaireland.com/.

in the context of EI. A key difference here, in comparison to EI, is that in the case of IDA Ireland, the support only funds collaboration between local knowledge providers and foreign-owned firms (i.e. no domestic firms, as these need to apply for the funding directly to EI). Moreover, the funded projects tend typically to be much larger than those projects funded by EI involving domestic firms. On average, the available administrative data indicates that Innovation Partnerships funded under the auspices of IDA Ireland, are approximately three times larger than Innovation Partnerships funded by EI to domestic firms.

In addition to the above three key instruments, IDA Ireland client firms can also avail of the same public financial instruments offered by EI. This is because the R&D support programmes provided by IDA Ireland are carried out in partnership with EI, but are targeted at foreign-owned companies (IDA Ireland, 2021). Data from IDA Ireland available to this research spans from 2006 to 2016.

- **Data on firms that collaborate with Research Centres from Science Foundation Ireland (SFI):** SFI primarily funds scientific research in higher-education institutions. This is a vital pillar of the innovation policy system in Ireland, as SFI funded institutions can provide cutting edge knowledge to firms through co-funded collaborative research projects (SFI 2018). The available data for this PhD research includes information on the firms that took part in the following schemes (i) SFI Centres for Science Engineering and Technology (CSETs); (ii) Strategic Research Clusters (SRCs); and (iii) Research Centre Awards (RCA). As outlined by SFI (2007), the CSETs and SRCs programme was created in the year 2000 to help link scientists and engineers in partnerships across academia and industry. Firms participating with CSETs and SRCs were required to co-share (up to 20 percent) the costs associated with industry-relevant scientific and technological research projects. In a similar vein, the Research Centre Award was launched in 2012, by creating new Research Centres and building on large-scale investments, such as those pertaining to the establishments of CSETs and SRCs. Under the new Research Centre Awards scheme, SFI is responsible for funding up to 70 percent of the overall Research Centre budget, while a minimum of 30 percent must be secured from industry (SFI 2016). Data from SFI available to this research spans from 2007 to 2016.

- **R&D tax credits from Ireland's Revenue Commissioners:** The Irish Revenue Commissioners oversees all tax-related matters in Ireland (Revenue 2021).[14] Firms can avail of R&D tax credits to reduce their corporation tax. In its current form (i.e. 2021-2022), R&D tax credits are calculated at 25 percent of qualifying expenditure for large-sized firms, while micro, small, and medium-sized firms can avail of up to 30 percent of qualifying expenditure (Revenue 2020; OECD 2021b).[15] To qualify for R&D tax credits, firms must be liable for corporation tax in Ireland, and must undertake R&D activities involving: (i) systemic, investigative, or experimental activities; (ii) be in the field of science or technology; and (iii)

[14] See https://www.revenue.ie/en/Home.aspx.

[15] As detailed by Acheson and Malone (2020), the maximum percentage of eligible R&D expenditure that firms can claim as tax credits has increased from an initial maximum of 20 percent in 1994 (when the scheme was introduced), to 25 percent in 2009. Furthermore, as highlighted by the OECD (2020), this percentage was adjusted to 30 percent for micro, small, and medium-sized firms in 2020.

involve specific R&D activities such as explorative and exploitative research, seek to make scientific and/or technological advances, and/or focus on resolving scientific or technological uncertainty (Revenue 2020). All firms can apply for R&D tax credits, in a non-competitive basis. Firms can use R&D tax credits to offset corporation tax liabilities (Revenue 2021). The R&D tax credit data available to this research covers the full populations of firms that obtained R&D tax credits from 2005 to 2017.

2.5 Operationalising measures of financial and non-financial constraints

This PhD research builds on, and extends, a small group of studies which have specifically focused on the constraints that firms perceive to hinder their Research and Innovation (R&I) activities. Table 2-1 summarises these previous studies. Chapter 4 and Chapter 5 of the current research measure firms' financial and non-financial constraints by using measures of firms' perceived constraints. As the table shows, the measures of perceived financial and non-financial constraints used in this research have been widely used by previous studies in this literature.[16]

[16] Moreover, as I outline in Section 2.5, measures of firms' perceived constraints are obtained from the Innovation in Irish Enterprises (IIE) Survey, which is the Irish equivalent of the Community Innovation Survey (CIS) in other European countries. Appendix 4-A (Panel B) includes the specific question in the IIE survey used to derive the financial and non-financial constraints variables.

Table 2-1: Summary of previous studies focused on firms' perceived constraints to Research and Innovation (R&I)

Author(s)	Sample	Type of Constraint	Key Findings
Baldwin and Lin 2002	Manufacturing firms in Canada	Financial and non-financial	Technology adopters are more likely to perceive constraints to R&I than non-technology adopters.
Tourigny and Le 2004	Manufacturing SMEs in Canada	Financial and non-financial	Large firms are more likely perceive high cost of developing innovation and organizational rigidities than SMEs. Financial constraints more important for SMEs.
Galia and Legros 2004	Manufacturing firms in France	Financial and non-financial	Firms postponing R&I projects are more prone to perceive financial and non-financial constraints. Firms that abandoned projects are more prone to perceive financial constraints.
Hewitt-Dundas 2006	Large and Small Manufacturing plants in Ireland	Financial and non-financial	Lack of external partners negative effects R&I activities in small-sized plants. High risk of R&I and a lack of internal expertise hinder R&I in larger plants.
Mohnen *et al* 2008	Firms in Netherland	Financial and non-financial	The constraints perceived by innovative firms have a major negative impact on their innovative activities.
Tiwari *et al*. 2008	Firms in Netherland	Financial	Financial constraints hamper firms' innovation propensity, but less so for old firm and firms that belong to a group.
Segarra-Blasco *et al.* 2008	Manufacturing and Knowledge-Intensive services firms in Catalonia	Financial and non-financial	Financial and knowledge barriers negatively impact firms' decision to innovate and their ability to complete R&I projects.
Savignac 2008	Established firms in France	Financial	Financial constraints reduce firms' likelihood to innovate.
Iammarino *et al.* 2009	Multinational Enterprises and Domestic firms in Italy	Financial and non-financial	Perception of constraints is influenced by the environment where firms locate
D'Este *et al.* 2012	Firms in UK	Financial and non-financial	Financial and non-financial constraints have a deterrent and a revealed effect.
Blanchard *et al.* 2013	Firms in France	Financial and non-financial	Non-financial barriers equally important as financial barriers in lowering firms' propensity to innovate.
Amara *et al.* 2016	Knowledge-intensive business services (KIBS) in Canada	Financial and non-financial	Market constraints as important as financial constraints in lowering firms' likelihood to innovate.
Pellegrino and Savona 2017	Firms in UK	Financial and non-financial	Market constraints as important as financial constraints in lowering firms' propensity to innovate.
Pellegrino 2018	Firms in Spain	Financial and non-financial	Young firms are less sensitive to knowledge constraints when initiating an innovative project than when they are already engaged in such activities. Mature firms' R&I activities are negatively affected by knowledge constraints
Radicic 2021	Firms in Germany	Financial and non-financial	Knowledge and market constraints are an impediment to radical innovation. Financial and knowledge barriers reduce firms' probability of incremental innovation.
Arza and López 2021	Firms in Argentina	Financial and non-financial	Market and knowledge constraints lower intensity of firms' R&I investment. SMEs are more deterred from innovation than big firms due to perceived obstacles.

Source: Author's own elaboration. The terminology and definitions used in the Column 'Key Findings' is consistent with the terminology and definitions used by the studies summarised in the table.

As Chapter 3 discusses in more detail, specifically in the context of financial constraints, several previous studies have used the sensitivity of firms' R&I investments to their cash-flows as a proxy for financial constraints (Fazzari *et al.* 1988; Bond *et al.* 2003; Colombo *et al.* 2013; Guariglia and Liu 2014; Howell 2016). The rationale for this type of 'indirect' approach rests on the assumption that, if firms' R&I investments are sensitive to their cash-flow levels, it can indicate that firms may not have sufficient levels of financial resources to finance all their desired R&I activities (i.e. firms had R&I projects waiting for finance). This is because firms may only be able to invest in R&I when they have high levels of internal financial resources to do so. As a result, firms may perform sub-optimal levels of R&I investments (i.e. they are financially constrained) (Fazzari *et al.* 1988; Hall *et al.* 2016).

However, some studies such as Kaplan and Zingales (1997) and Cleary (1999), have demonstrated that the cash-flow sensitivity of R&I investments can also relate to other factors unrelated to financial constraints. As an illustrative example, firms may decide to invest additional financial resources in R&I as a response to market dynamics, such as increasing product demand, or new market opportunities (Cleary 1999). Because of this, indirect measures of firms' constraints, which are based on their levels of resources, such as their financial resources, may be subject to interpretation problems (Savignac 2008; Hall *et al.* 2015; Pellegrino and Savona 2017). That is, one can never ascertain that low levels of financial resources indeed constitute a 'constraint'. Furthermore, such an indirect approach may only be suitable for measuring firms' constraints to R&I which relate to financial resources (as is the case in Chapter 3 of this PhD research). They may not be suitable in the context of other intangible resources, such as expertise, know-how, and human capital (D'Este *et al.* 2014; Pellegrino and Savona 2017). This is because these types of resources and capabilities are specific to each firm and may not be comparable (Dosi *et al.* 2021).

In light of the above, Savignac (2008) has argued that using indicators of perceived obstacles to R&I as a measure of financial constraints is desirable. This is because indicators of perceived constraints represent more direct measures of the obstacles affecting firms' R&I activities, as they avoid the above issues of interpretation. Furthermore, an important advantage of using measures of perceived constraints in the context of this PhD research, is that they permit extending the focus beyond financial constraints, and to also consider non-financial constraints (Pellegrino and Savona 2017). Chapters 4 and 5 of this PhD thesis discuss this issue in more detail.

However, operationalising measures of perceived financial and non-financial constraints to R&I requires addressing some conceptual and methodological challenges. Such challenges mainly relate to endogeneity due to reverse causality between firms' decisions to innovate, and their probability of perceiving constraints. In addition, it requires considering a potential survey bias arising from the questions pertaining to firms' obstacles to R&I in innovation surveys, such as the Community Innovation (CIS) survey. These issues are discussed as follows.

Regarding issues of reverse causality, some studies have found that more innovative firms tend to typically be more likely to perceive constraints to R&I than less innovative firms. Baldwin and Lin (2002) and Tourigny and Le (2004), for example, studied the relationship between firms' levels of technology adoption and

R&I activities, and their likelihood to perceive obstacles to R&I, in the context of firms in Canada. They found that more innovative firms, and firms that adopted new technologies, were more likely to perceive obstacles to innovation. This is in comparison to less innovative firms, and non-technology adopters. The authors thus concluded that the variables of obstacles to R&I in innovation surveys, such as the CIS, should not be interpreted as insurmountable constraints that deter firms' R&I activities. Instead, such variables may signal key areas where firms have encountered difficulties and/or challenges, when adopting new technologies and/or performing R&I activities.

Subsequent studies, such as Galia and Legros (2005), Mohnen and Röller (2005); Mohnen *et al.* (2008), Savignac (2008), and Iammarino *et al.* (2009), have provided a more complete explanation of the results reported by Baldwin and Lin (2002) and Tourigny and Le (2004). Galia and Legros (2005) and Mohnen *et al.* (2008), for example, demonstrated that financial and non-financial constraints are positively associated with firms' likelihood to delay and/or abandon R&I projects. In their view, therefore, a positive relationship between firms' levels of R&I activities and their likelihood to perceive obstacles to innovation demonstrates that more innovative firms typically face more obstacles (Blanchard *et al.* 2013). Moreover, firms may become aware of financial and non-financial constraints to R&I as they begin to face them. That is, innovation may require firms to match their resources and expertise to specific R&I activities, and some obstacles may only come to light once firms engage in these activities (Galia and Legros 2004).

Based on the above, D'Este *et al.* (2012) made a seminal contribution to our current understanding of the nature of perceived constraints to R&I. Specifically, they posited that firms may perceive financial and non-financial constraints at different junctions of their innovation paths. By building on the above studies, they proposed that firms that are new to the innovation contest (i.e. firms that aim innovate for the first time), may perceive constraints as insurmountable obstacles. As a result, such firms may forego R&I activities due to their constraints. The authors labelled these types of perceived constraints as 'deterring' constraints. In addition, firms may also perceive constraints as they perform R&I activities. Such constraints are inherently different to the 'deterrent' constraints. This is because they constitute "firm's awareness of the difficulties involved as a result of engagement in innovation activities—pointing to a "disclosing" or "learning" outcome based on direct experience" (D'Este *et al.* 2012, p. 482). In their view, such constraints may not completely deter firms from engaging in R&I activities, but they may negatively impact their ability to successfully complete these activities. They thus labelled these constraints as 'revealed' constraints.

Furthermore, by using data on firms in the UK, D'Este *et al*. (2012) demonstrated that firms are more likely to perceive obstacles as highly important constraints at the two extremes of their innovative paths. That is, firms that had low levels of innovativeness, as measured by the number of R&I activities that they engaged in, perceived financial and non-financial to have a highly important negative effect on their R&I activities. In their view, this demonstrates the deterring nature of perceived constraints. Those firms that engaged in a larger number of R&I activities no longer regarded their constraints as highly important obstacles. In their view, this demonstrates that once firms learn how to innovate, the importance of their constraints may attenuate. However, more innovative firms, which engaged in R&I more intensively and in a greater array of resource- and knowledge-intensive R&I activities, were more likely to perceive financial and non-financial constraints as highly important obstacles. The authors interpreted these findings as evidence of the constraints having a ‘revealed’ effect’. That is, firms that focused on more knowledge- and resource-demanding R&I activities, encountered more constraints.

At the empirical level, the distinction between deterring and revealed constraints highlights that constraints to R&I are endogenously determined (i.e. innovation causing more constraints). As a result, subsequent studies, such as Blanchard *et al.* (2013); D’Este *et al.* (2014) D’Este *et al.* (2016); Pellegrino and Savona (2017), Pellegrino (2018), and more recently Radicic (2021), used econometric techniques to control for endogeneity due to reverse causality (e.g. selection models, bivariate probit models). In addition, they performed their analysis by distinguishing between firms that were considered as ‘potential innovators’ (i.e. firms that want to innovate but have not yet engaged in R&I), and ‘innovative’ firms (i.e. firms that engage in R&I).

Regarding endogeneity due to survey bias, Savignac (2008) has noted that the CIS survey requires all firms to answer the questions on obstacles to R&I. This is regardless of whether firms engaged or did not engage in R&I. Given that firms that do not engage in R&I do not experience obstacles, including such firms in the analysis can result in spurious correlations between firms’ perceived constraints and their ability to successfully innovate. Based on this, studies that focused on the impact of perceived financial and non-financial constraints on firms’ R&I activities typically excluded ‘non-innovators’ from their effective sample (Savignac 2008; Blanchard *et al.* 2013; Pellegrino and Savona 2017; Zahler *et al.* 2022). As proposed by Pellegrino and Savona (2017, p. 511), performing the analysis on the relevant sample of potential innovators "should represent the working sample of any CIS-based empirical contributions to the literature on barriers to innovation".

My research builds on the above methodological discussions in two main ways. Firstly, the research constructs specific data structures which permit the analysis to address issues of endogeneity due to reverse causality and survey bias, by means of semi-parametric matching approaches (i.e. Propensity Score Matching). As Silva and Carreira (2012) and Pellegrino (2018) have highlighted, these matching approaches can provide a more precise understanding of the impact of financial and non-financial constraints, and how firms overcome them. Specifically, the approach used here, as discussed in Chapters 4 and 5, permits comparing 'like-with-like', which is possible due to the construction of hypothetical counterfactual scenarios. That is, the approach permits comparing the innovative performance of firms that perceive financial and non-financial constraints and receive public financial support for R&I, with a hypothetical counterfactual scenario in which: (a) the same group of firms does not perceive financial and non-financial constraints; and (b) the same group of firms does not receive public financial support for R&I. Moreover, as the analysis focuses on firms that receive public financial support for R&I, for which firms need to apply and demonstrate their innovative intentions, the research primarily considers firms that engage, or that intend to engage, in R&I activities (i.e. potential innovators and innovators). This overcomes issues related to finding the 'relevant' sample as proposed by Pellegrino and Savona (2017).

From a conceptual perspective, the current research treats constraints to R&I to take place in a continuous and developmental process. In this way, the research permits understanding how firms overcome their perceived financial and non-financial constraints, and a result, how they may perceive new constraints. Therefore, the research extends the conceptual framework as proposed by D'Este *et al.* (2012), by identifying how firms can move from perceiving 'deterring' constraints, towards perceiving 'revealed' constraints, as they become more innovative. In doing so, the research permits a more in-depth understanding of the nature of firms' financial and non-financial constraints to R&I, than the previous studies discussed above. The research thus, unravels the dynamic nature of firms' constraints to R&I, as firms move towards more intensive and distant R&I activities.

Finally, it is important to note that previous studies in this vein have referred to financial and non-financial constraints as 'constraints', 'obstacles', 'barriers' and/or 'challenges' (See Table 3-2). This PhD research primarily uses the word 'constraint' to refer to firms' obstacles to R&I, which is in line with studies studying this topic from financial (Savignac, 2008; Blanchard *et al.* 2013; Busom *et al.* 2015; Mateut, 2018) and resource-based (Hewitt-Dundas 2006; Hoegl *et al.* 2008; Weiss *et al.* 2017) theoretical lenses. This is because these literatures provide the conceptual foundations of the current research.

2.6 Focus on firms in Ireland

My PhD research extends our knowledge of the financial and non-financial constraints affecting firms' Research and Innovation (R&I) activities. Furthermore, the research provides novel insights regarding the extent to which public financial support for R&I can enable firms to overcome their constraints. This is only possible due to the research having access to highly detailed firm-level data on the R&I activities and constraints faced by firms in Ireland. This firm-level data is merged with a novel administrative dataset which comprises the full set of public financial support instruments for R&I available to such firms. The focus on firms in Ireland thus represents a unique opportunity to critically address key research questions which have not been addressed before. This is key for advancing an understanding of a topic that, as Pellegrino (2018, p. 200) puts it, suffers from a "paucity of contributions", despite a "growing interest among policy makers".

Furthermore, the insights emanating from this PhD research have the potential to provide crucial implications for R&I policy beyond the Irish case. This is because, as a small open economy with limited natural resources, Irish development efforts are primarily focus on building a smart economy, based on R&I (Roper and Arvanitis 2012). This is reflected in the current National Consultation document to inform the Economic Recovery Plan 2021 (DFHERIS 2021, p. 2), which specifically states Ireland's "dual ambition of placing research, development and innovation at the heart of addressing Ireland's economic and societal challenges, and building capacity and capability across the research and innovation system to move R&I up the value chain." This is also the case in other countries in the European Union (e.g. Germany, Norway, and Sweden, amongst many others), which are currently seeking to transition towards smarter economic systems based on R&I (European Commission 2021).

Moreover, most firms in Ireland are small and medium-sized enterprises (i.e. 99.8 percent of all firms are SMEs) (CSO 2020). Previous research has demonstrated that SMEs in Ireland typically experience financial and non-financial constraints to their R&I activities (Hewitt-Dundas 2006; Roper and Arvanitis 2012). For example, the Irish Government identifies that supporting firms, especially SMEs, to overcome challenges related to resources and capabilities for R&I is a key innovation policy priority (Skillnet Ireland 2020; DEBEI 2020). The latter is also the case beyond Ireland, as evidenced in innovation policy documents in other countries, including the UK, Germany, Norway and Sweden, amongst many others (HM Government 2021; Federal Ministry for Economic Affairs and Energy of Germany 2019; Innovation Policy Platform 2016; The Swedish Ministry of Enterprise, Energy and Communications 2020; OECD 2021b). Therefore, the insights of this PhD research are highly relevant in the context of Governments in many countries which intend to help firms to overcome their financial and non-financial constraints to R&I.

2.7 Conclusion

This chapter provided the rationale and background of this PhD research. In doing so, the chapter outlined existing knowledge gaps in two interrelated literature strands: (i) the literature concerned with firms' constraints to Research and Innovation (R&I); and (ii) the literature focused on the impact of public financial support for R&I. Such knowledge gaps are addressed empirically in the subsequent chapters, by drawing on novel and highly detailed data regarding firms in Ireland. This is achieved by merging several data sources held at the Irish Central Statistics Office (CSO), with administrative data on the provision of public financial support for R&I from several sources. As Chapters 3 to 6 discus in more detail, by addressing the above knowledge gaps, this PhD research makes a distinct contribution to our understanding of the nature and impact of firms' financial and non-financial constraints. Furthermore, the research generates robust new evidence, which indicates that public financial support for R&I, could represent an effective policy intervention to help firms overcome their financial and non-financial constraints to R&I.

The remainder of the PhD thesis presents the three chapters, which include the main empirical analysis comprising this research (Chapters 3 to 5). These chapters are presented in publication-style, stand-alone, format. This means that each chapter includes a specific introduction, literature review, discussions on the data and methodology used, and a discussion of the main empirical findings and potential implications for policy. Finally, Chapter 6 brings together the main insights arising from the preceding chapters, in a coherent discussion *vis-à-vis* the prevailing literature. As Chapter 6 discusses, this PhD research, collectively, makes a distinct and significant contribution to our understanding of the nature and impact of firms' financial and non-financial constraints to R&I, and how public financial support for R&I can enable firms to overcome such constraints. Crucially, the research offers important insights that can be very useful for the design and implementation of more effective Science, Technology, and Innovation (STI) policy interventions, to support firms to overcome their constraints to R&I. Therefore, Chapter 6 also provides a detailed discussion of the implications for policy arising from the research.

Chapter 3: Financial resources for research and innovation in small and larger firms: Is it a case of the more you have, the more you do?

This chapter has been published in the peer-reviewed international academic journal *Industry and Innovation* (Scimago Ranking Quartile 1 [Q1], Chartered Association of Business Schools [ABS] 3 stars/rate), with details as follows:

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Authors' Contributions:

I, Mauricio Perez-Alaniz, am the first author of the academic paper. The remaining authors are listed in order of contribution. I was responsible for: (1) the conceptual development of the paper; (2) choosing and refining the methodology; (3) preparing the empirical setting; (4) carrying out the empirical analysis; (5) writing the original draft paper; (6) incorporating the co-authors' suggestions and comments into the final paper; and (7) incorporating the suggestions and comments from the anonymous reviewers during the peer-review process. Helena Lenihan provided expert advice and guidance on all of the above listed activities (1-7), as well as reviewing and editing the paper. She also enabled the research to access the necessary data and resources (i.e. in her role as Principal Investigator [PI] of the Science Foundation Ireland funded project funding this research). Justin Doran provided expert advice on all of the above listed activities (1-7), as well as reviewing and editing the paper. Nola Hewitt-Dundas provided expert advice on the initial conceptualisation of the paper, and in reviewing and refining the paper before submitting it for publication.

Abstract:

Our study analyses how firms' internal financial resources impact their engagement in scientific research, development, and five innovation activities. Furthermore, we investigate how firm-size moderates the impact of firms' internal financial resources on scientific research, development, and innovation. Our detailed approach provides novel insights regarding whether more money leads to more research and innovation, a topic that remains highly contested in the literature. Our analysis uses a novel unbalanced panel dataset of 1,446 firms in Ireland, over the period 2008-2016. Levels of internal financial resources are found to positively impact larger-sized firms' (50+ employees) engagement in scientific research, process innovation and product innovation. However, such resources tend to hinder small-sized firms' (less than 50 employees) engagement in service and organisational innovation. Our research refines innovation theory by reconciling contrasting views regarding the importance of financial resources for research and innovation, and offers novel insights for informing related public policy interventions.

3. 1 Introduction

Behavioural and resource-based theories of innovation highlight the importance of firms' levels of internal financial resources for their engagement in research and innovation (R&I) (Cyert and March 1963; Jissink *et al.* 2019; González-Bravo *et al.* 2021). The financial literature on innovation also proposes that financial constraints hinder firms' engagement in R&I (Himmelberg and Petersen 1994; Bond *et al.* 2005; Hall *et al.* 2016). However, a growing number of studies, such as those of Berends *et al.* (2014), Bicen and Johnson (2014) and De Massis *et al.* (2018), demonstrate that some firms, especially small-sized firms, engage in R&I, despite having limited financial resources. Gibbert and Scranton (2009) and Keupp and Gassmann (2013), in particular, propose that financial resource constraints can encourage firm-level R&I. Therefore, as Weiss *et al.* (2017, p. 842) note, despite a large number of studies addressing this topic, the extent to which more money leads to more R&I remains "unclear". Hoegl *et al*. (2008, p. 1389) have particularly emphasised that more research is needed to formulate a "much-needed unifying theory of the role of financial resources in innovation management at large". Keupp and Gassmann (2013) have also highlighted the specific need for a better understanding of innovation with limited financial resources. Developing a better understanding of this topic is more crucial now than ever (as we emerge from the Covid-19 pandemic), because it can inform the design and implementation of policies that support firms to innovate their way out of the current crisis (Roper 2020; Morgan *et al.* 2020).

Our paper responds to the above call for further research by addressing the following main research question: *Is the relationship between firms' internal financial resources and their engagement in R&I similar for different R&I activities* *(i.e. explorative versus exploitative research activities; incremental versus radical forms of innovation; innovations that entail the development of processes and products, and innovations that require organisational changes)?* Moreover, the paper addresses the following ancillary research question: *Is the relationship between firms' internal financial resources and their R&I activities similar for firms of different sizes (i.e. small-sized and larger-sized firms)?* By addressing the above research questions, our paper provides a more in-depth understanding of how firms' levels of internal financial resources impact firms' engagement in a comprehensive set of R&I activities. In addition, it permits identifying cross-cutting effects between: (a) firms' levels of financial resources; (b) specific R&I activities; and (c) firms' sizes. In doing so, the paper addresses three critical intricacies regarding the impact of firms' levels of internal financial resources on their engagement in R&I, that have not heretofore, been fully explored in the literature, as follows.

Our first contribution is to analyse how firms' internal financial resources impact their engagement in (i) scientific research and (ii) development. Arora *et al.* (2018) highlight that firms increasingly focus on exploiting existing knowledge, while their investments in new knowledge decline (i.e. explorative versus explorative research). They call for future research to address the "underlying drivers" of such trends (Arora *et al.* 2018, p. 29). Studies up to now, have focused on financial resources as drivers of R&D investments (see, for example, Himmelberg and Petersen 1994; González-Bravo *et al.* 2021), but do not consider different types of research activities (Choi *et al.* 2019). Addressing this imbalance is important, as explorative research can enable firms to develop and sustain competitive advantage (Czarnitzki *et al.* 2012; Añón Higón 2016), and is also vital for addressing current social, environmental, and economic societal challenges

(Borrás and Edler 2020). Our study makes a distinct contribution to the prevailing literature, by analysing how firms' levels of internal financial resources impact their engagement in scientific research (explorative) *and* development (exploitative).[17] From a policy perspective, our analysis is also important because it can usefully identify key entry points for innovation policy interventions to encourage more explorative research by firms (Czarnitzki *et al.* 2011).

Our second contribution is to unravel novel intricacies regarding firms' levels of internal financial resources impacting their engagement in five innovation activities: (i) process innovation; (ii) product innovation; (iii) service innovation; (iv) radical product and services innovation; and (v) organisational innovation.[18] Percival and Cozzarin (2008, p. 371) note that the prevailing literature on the drivers of innovation rarely considers the "significance of the innovation under study". Studies concerning the importance of financial resources for innovation, in particular, mainly focus on process and product innovation (Greve 2003; Keupp and Gassmann 2013; Pellegrino and Savona 2017; Giebel and Kraft 2019). This is a limitation that prevails in the literature, as firms may engage in different types of innovation activities depending on their levels of resources, including internal financial resources (Klingebiel and Rammer 2014).

Our paper extends the focus to innovation in services, which is an increasingly important innovation activity for service and manufacturing firms

[17] Scientific research generates logical explanations about physical, biological and social phenomena through means of basic and applied research, and is explorative in nature (i.e. the 'R' of R&D) (Borrás and Edquist 2014). Development mainly focuses on exploitation, as it is the application of knowledge to, for instance, the development of innovations (i.e. the 'D' of R&D) (OECD 2015).

[18] In line with Hewitt-Dundas *et al.* (2019), radical innovations refer to products and services that are new to the market.

(Witell *et al.* 2017). As Mennens *et al.* (2018, p. 502) highlight, "successful product and service innovation have different antecedents", such as their financial resource needs. We also consider organisational innovation, where "R&D Sunk Cost" arguments of innovation may not apply (Tavassoli and Karlsson 2015, p. 1891). Furthermore, we distinguish between incremental and radical innovation activities, with the latter defined as products and services that are new to the market (Hewitt-Dundas *et al.* 2019). This is important, as the extent to which more financial resources lead to more radical forms of innovation remains a contested topic of research (see, for example, Weiss *et al.* 2017; Giebel and Kraft 2019). To the best of our knowledge, our study is the first to analyse the importance of internal financial resources for such a comprehensive set of innovation activities. Our analysis contributes to debates regarding the importance of financial resources for innovation, by going beyond whether more (less) money leads to more (less) innovation, and considering how firms' internal financial resources impact their probability of engaging in different forms of innovation. From a theoretical perspective, the insights of our study are vital for developing a more complete understanding of the importance of firms' financial resources for different forms of innovation.

Our third contribution is to unravel how firm size moderates the impact of firms' internal financial resources regarding their engagement in the seven R&I activities considered in this paper. We explore this by analysing the importance of internal financial resources for the R&I activities of *small* (10 to 49 employees) and *medium and large-sized* firms (i.e. hereafter referred to as larger-sized firms; 50+

employees), separately.[19] Focussing on *small* and *larger-sized* firms is a commonly adopted approach in the Irish context (See Hewitt-Dundas 2006; Vahter *et al.* 2014; McGuirk *et al.* 2015, for examples), as most firms in Ireland are *small-sized* (98.9 percent), with *larger-sized* firms representing only 1.1 percent of firms (CSO 2020). The focus on *small-sized* firms is vital in the context of the prevailing literature concerning the impact of financial resources for R&I. This is because the available evidence points to a specific need to reconsider the conventional wisdom regarding the importance of financial resources for R&I in this firm-size group (Berends *et al.* 2014; Bicen and Johnson 2014; Colclough *et al.* 2019). Furthermore, the insights of our study provide new evidence that can be considered by policymakers, as they aim to encourage more R&I amongst firms of different sizes. The latter policy focus is seen in recent policy documents in varying country contexts (see, for example, Herr and Nettekoven 2018; OECD 2019; HM Treasury, 2021).

In our study, to operationalise our analysis, we measure firms' internal financial resources as the ratio of Net Operating Surplus to turnover. This is similar to the measures of internal financial resources used by Czarnitzki *et al.* (2011), Hottenrott and Peters (2012) and González-Bravo *et al.* (2021).[20] Information on firms' R&I activities, and financial information, were obtained by merging a number of separate business surveys conducted by the Irish Central Statistics Office (CSO). Four waves of the Innovation in Irish Enterprises survey (IIE, formerly known as the Community Innovation Survey) were merged with four waves of the

[19] The European Union recommendation 2003/361 defines small-sized firms as firms with less than 50 employees, medium-sized firms as firms between 50 and 249 employees, and large-sized firms as firms with 250 employees or more. The recommendation also classifies firms according to their turnover or balance sheet (see http://data.europa.eu/eli/reco/2003/361/oj), but the number of employees is the most commonly used classification (Eurostat 2019). Data for firms with fewer than 10 employees were not available to my PhD research study.

[20] Section 3-3 describes the process used to combine these datasets and the variables used.

Business Expenditure on Research and Development (BERD) survey. The IIE dataset contains data on firms' engagement in innovation activities, while the BERD contains information on firms' engagement in scientific research and development. The Census of Industrial Production (CIP) and Annual Service Inquiry (ASI) surveys were also merged to obtain in-depth details of firms' internal resources, specifically their internal financial resources. This resulted in a novel unbalanced panel dataset of 2,531 observations from 1,446 firms in Ireland for the period 2008 to 2016.

Ireland represents an interesting locale for this study. Previous research has identified the availability of financial resources as an important determinant of the engagement in R&I activities by firms in Ireland (Roper and Arvanitis 2012), especially for *small-sized* firms (Hewitt-Dundas 2006). The period covered in this study also corresponds to the period following the 2008 Global Financial Crisis (GFC), when commercial lending significantly decreased, and firms' profits were the main source of funding for R&I by firms in Ireland (Central Bank of Ireland 2019). Recent data regarding the impact of the Covid-19 crisis show important similarities with the 2008 GFC (CSO 2020).[21] As these business conditions are being experienced globally, the insights of our paper are particularly relevant in the current economic climate.

The remainder of the paper is organised as follows. Section 3.2 reviews the literature on the importance of firms' financial resources for their R&I activities and formulates hypotheses. Section 3.3 describes the data, the construction of the

[21] Data from the Central Statistics Office (CSO) show that by April 2020, around 23% of firms in Ireland were temporarily or permanently closed (compared to 15% of total business closing permanently after 2008). From the remaining firms that continued trading, around 70% of businesses experienced a slight (16%) or a significant (54%) decline in turnover.

variables, and the empirical approach. Section 3.4 presents the empirical findings, which are then discussed in the context of the prevailing literature. Section 3.5 concludes by suggesting implications for the design and implementation of science and innovation policy interventions.

3.2 Literature review and hypotheses

Resource-based and behavioural theories of innovation regard the level of firms' internal financial resources as an important driver of their research and innovation (R&I) activities (Cyert and March 1963; González-Bravo *et al.* 2021). The financial literature on innovation proposes that firms may substitute internal financial resources with external finance (Hubbard 1998). However, market failures in financial markets may hinder firms' ability to access external finance for R&I, leading to firms typically relying on their internal financial resources for these activities (Himmelberg and Petersen 1994; Bond *et al.* 2005; Hall *et al.* 2016). Some recent studies, such as González-Bravo *et al.* (2021), De Massis *et al.* (2018) and Schäfer *et al.* (2015), have also demonstrated that firms typically prefer using internal financial resources for R&I, rather than incurring debt. Therefore, our focus on firms' levels of internal financial resources impacting their R&I activities is important. In this section, we review the literature on the importance of internal financial resources for R&I, and develop the hypotheses guiding the empirical analysis that follows.

3.2.1 Internal financial resources and scientific research and development

Firms typically face a trade-off between allocating limited R&D financial resources to explorative and/or exploitative research activities (Lee *et al.* 2014).

However, Arora *et al.* (2018) demonstrate that firms increasingly favour exploitative over explorative research. This may lead firms to become increasingly dependent on external knowledge, and to curtail their ability to innovate in the future (Czarnitzki *et al.* 2011). Arora *et al.* (2018) specifically call for more research to unveil the factors driving these trends. We contribute to this topic by analysing how firms' levels of internal financial resources affect their engagement in scientific research *and* development.

3.2.1.1 Internal financial resources and scientific research

Scientific research is the 'R' of R&D (Czarnitzki *et al.* 2011), and focuses on generating logical explanations about physical, biological, and social phenomena by basic and applied research (Borrás and Edquist 2014). It enables firms to explore new ways of problem-solving for understanding and/or informing new technologies (Fleming and Sorenson 2004; Cassiman *et al.* 2018). This is important for building absorptive capacity, defined as a firm's ability to identify and benefit from external knowledge (Cohen and Levinthal 1990), and for avoiding technology lock-ins (Chadha 2011). However, scientific research may entail significant costs for hiring, training, and retaining highly skilled employees (Arora *et al.* 2018). Most of these costs are sunk and highly volatile, as the returns on the investment may be lost if R&D employees leave the firm (Hall *et al.* 2016). The knowledge generated by scientific research is also difficult to protect from other firms, and may not necessarily lead to commercial success (Dedrick *et al.* 2015). The conjectural nature of scientific research, and its long-term focus, may lead firms to undervalue this activity (Aghion *et al.* 2009).

There are at least three mechanisms through which greater levels of financial resources can lead to firms engaging in scientific research. First, firms with high levels of internal financial resources can relax the expected returns of their research investments and engage in riskier research activities, because their internal financial resources can act as a safety net if these activities fail (Radas and Bozic 2012; Jissink *et al.* 2019). Second, greater levels of internal financial resources can enable longer-term investments in research activities that enrich firms' knowledge breath, and potentially enhance their competence base (Lee *et al.* 2014). Finally, high levels of internal financial resources can ease firms' performance monitoring, and enable R&D employees to pursue non-core explorative research projects (Nohria and Gulati 1996; Jissink *et al.* 2019). This suggests our first hypothesis:

H1: Higher levels of firms' internal financial resources positively determine their probability of engaging in scientific research.

3.2.1.2 Internal financial resources and development

Development is the next stage, or the 'D', of R&D, and refers to the application of knowledge to, for instance, the development of innovations (Czarnitzki *et al.* 2011; OECD 2015). Development is an exploitative type of research, and firms engage in this activity to transform ideas and concepts into marketable technologies (Lee *et al.* 2014; Cassiman *et al.* 2018). Development can be resource intensive in terms of expenditure, but it is closer to the market and builds on existing knowledge (Czarnitzki *et al.* 2011). This means that firms may foresee potential returns to their investments, and reorganise their internal financial resources to finance development projects, especially those that are most valuable and near completion (Greve, 2003; Berends *et al.*, 2014). Firms can reduce the financial burden of development by engaging in collaboration (Grimpe and Sofka 2016; De Massis *et al.* 2018). They may also engage in new ways of value creation by recombining existing available resources, a process that Baker and Nelson (2005) term the 'bricolage' approach. This is similar to the notion of 'bounded creativity', as proposed by Hoegl *et al.* (2008). However, there are still significant financial demands for this activity, and internal financial resources are critical for financing development projects (Radas and Bozic 2012; Arora *et al.* 2018). This suggests:

H2: Higher levels of firms' internal financial resources positively determine their probability of engaging in development.

3.2.2 Internal financial resources and process and incremental product and service innovation

We now consider the role of firms' internal financial resources as they pertain to process innovation, and incremental forms of innovation regarding products and services. Process innovation refers to improvements in production practices, such as the introduction of new technologies, methods of logistics, and maintenance systems (Tavassoli and Karlsson 2015). Incremental product innovation is defined as the introduction of goods that are significantly improved, or new to the firm, but that may already exist in the market (Berends *et al.* 2014). As process innovations may lead to new products, and new products may require new processes, their simultaneous consideration has significant benefits for firms (Percival and Cozzarin 2008; Hullova *et al.* 2019).

The literature supports the theory that internal financial resources are important for process and product innovation activities (De Falco and Renzi 2015; González-Bravo *et al.* 2021). Besides the costs associated with human capital, firms may need to obtain other tangible and intangible knowledge-creating resources when developing new processes and products, such as capital equipment, software, and licensed technology (D'Este *et al.* 2016; Montresor and Vezzani 2016). The uncertainty of innovation, however, typically leads to firms financing innovation activities internally (Hall *et al.* 2016; González-Bravo *et al.* 2021). Thus, greater levels of internal financial resources may facilitate firms to engage in more process and product innovation activities, and to dedicate more time and resources to these activities (Greve 2003; Jissink *et al.* 2019). The prevailing empirical evidence supports the view that firms' levels of internal financial resources are important determinants for adopting new production technologies (Gomez and Vargas 2009), and developing new products (Nohria and Gulati 1996; Weiss *et al.* 2017). This suggests:

H3: Higher levels of firms' internal financial resources positively determine their probability of engaging in process and incremental product innovation.

Incremental service innovation refers to the introduction of services that are significantly improved, or new to the firm (Love *et al.* 2011). In the context of this paper, incremental service innovation refers to firms extend and/or tailoring existing services to suit the specific needs of new or existing clients. This is very different than more radical forms of service innovation, as discussed in Section 3.2.3, in which firms may need to develop wholly new technologies (OECD 2015). While previous studies focused on incremental service innovation in the context of service firms, manufacturing firms increasingly adopt incremental service innovation as part of their competitive strategy (Witell *et al.* 2017). Firms may engage in incremental service innovation to improve productivity and increase sales (Hullova *et al.* 2019). Yet, this form of service innovation departs from the technologically oriented nature of innovation in processes and products (see Section 3.2.3 for a discussion on more radical forms of service innovation). Search strategies for incremental service innovation are typically informal, and build on internal and external collaborations (Love *et al.* 2011; Mennens *et al.* 2018). Firms may work closely with clients when extending existing services, thereby reducing uncertainty, and lowering the need for financial resources (Nijssen *et al.* 2006; Love *et al.* 2010; Mennens *et al.* 2018). Mina *et al.* (2014) propose that incremental service innovation mainly arises from existing organisational and human resources, rather than from the availability of tangible assets. This suggests:

H4: Firms' levels of internal financial resources do not determine their probability of engaging in incremental service innovation.

3.2.3 Internal financial resources and radical innovation

In this section, we turn our attention to radical innovation, which we define as the development of products and services that are new to the market (Percival and Cozzarin 2008; Hewitt-Dundas *et al.* 2019). Earlier, in Section 3.2.2, we proposed that firms' levels of internal financial resources may have a differential causal effect between their engagement in product and service innovation. However, these differences may erode when innovation in products and services entails high levels of novelty (Mina *et al.* 2014; Witell *et al.* 2017). Firms may face important knowledge discontinuities when bringing novel products and services to market, and their level of internal financial resources can impact their decision to engage in these activities (Percival and Cozzarin 2008).

There are two opposing arguments in the literature regarding the importance of financial resources for radical innovation. The first argument understands radical innovation as a function of its resource inputs (Weiss *et al.* 2017). Radical innovation is riskier than incremental innovation and more prone to fail, and internal financial resources are important for minimising these risks (Radas and Bozic 2012; Choi *et al.* 2019). Firms can experience knowledge discontinuities when innovating radically, and internal financial resources can enable firms to engage in more explorative and forward-looking search strategies to address them (Weiss *et al.* 2017; Jissink *et al.* 2019; Choi *et al.* 2019). This suggests:

H5: Higher levels of firms' internal financial resources positively determine their probability of engaging in radical innovation.

The second argument is in line with the notion of "necessity is the mother of innovation" (Gibbert and Scranton 2009, p. 385). Limited financial resources may prompt firms to overcome knowledge discontinuities by deviating from existing path-dependencies, and find new cost-effective ways of doing things (Hoegl *et al.* 2008; Keupp and Gassmann 2013; Witell *et al.* 2017). They can find new ways of using their existing organisational resources, and/or exploit physical, social, or institutional inputs that other firms rejected or ignored (Baker and Nelson 2005). Furthermore, given that resources are limited, and that the potential rewards are high, managers may become more tolerant of riskier innovative projects that may improve their position in the market (Greve 2003). Thus, as proposed by Keupp and Gassmann (2013), firms' need to innovate (because of financial scarcity) can trigger new radical innovative efforts. Despite this, as proposed by Gonzalez-Bravo *et al.* (2021), low levels of financial resources may indicate that firms are underperforming, and thus, firms may be less likely to survive should their R&I investments fail.[22] Based on this, we hypothesise that:

H6: Lower levels of firms' internal financial resources positively determine their probability of engaging in radical innovation (as long as firms survive).

3.2.4 Internal financial resources and organisational innovation

The final innovation activity considered is organisational innovation. This consists of new models of decision-making that support innovation by, for example, implementing new ways of managing relationships (within and outside the firm), and innovation portfolios (Birkinshaw *et al.* 2008). According to Volberda *et al.* (2013), the drivers of organisational innovation remain under-researched. With specific relevance to our paper, the authors highlight that organisational innovation arises from changes within the firm, and may be unrelated to firms' levels of internal financial resources (Volberda *et al.* 2013). Furthermore, since this activity is neither R&D-based nor income-generating, resource-based arguments of innovation, such as the "R&D sunk cost" argument, may not apply in this context (Tavassoli and Karlsson, 2015, p. 1891). This suggests:

H7 Firms' levels of internal financial resources do not determine their probability of engaging in organisational innovation.

[22] It is possible that firms that have limited financial resources and invest in radical R&I activities but fail to innovate, may not survive. Our data may not capture such dynamics, as we only have observations on active firms. This, in turn, may lead to survival bias.

3.2.5 Differences between small-sized and larger-sized firms

Finally, we focus on levels of internal financial resources having a heterogeneous effect on the research and innovation (R&I) activities of *small* (i.e. 10 to 49 employees) and *larger-sized* firms (50+ employees). Previous studies show that firm size is positively associated with the level of firms' internal financial resources (Freel 2000; Love and Roper 2015), and with their engagement in R&I (Himmelberg and Petersen 1994; Bond *et al.* 2005; Hall *et al.* 2016). As a result, the literature tends typically to agree that *small-sized* firms' engagement in R&I is usually constrained by a lack of internal resources, especially financial resources (González-Bravo *et al.* 2021). However, higher levels of internal financial resources may not necessarily lead to more R&I by *small-sized* firms. This is because, as Berends *et al.* (2014, p. 618) highlight, theories of innovation mainly relate to *large-sized* firms but "small firms are not miniature versions of large firms".

Small-sized firms, especially those that are private and family-owned, may prefer growth and R&I strategies that preserve their long-term sustainability, as opposed to highly risky strategies (Schäfer *et al*. 2017; De Massis *et al.* 2018; Croce *et al.* 2019; Garrido-Prada *et al.* 2021). The competitive advantage of *small-sized* firms mainly resides in their behavioural resources, rather than in their capital and financial resources (Freel 2000). The flexibility of decision-making, for example, is a key behavioural advantage to refocus organisational objectives and routines when markets change (Berends *et al.* 2014). The high costs of R&I can hinder these behavioural advantages because the resources needed for these activities are largely sunk and not transferable to other areas (e.g. from research to marketing). Freel (2000), Bicen and Johnson (2014), and Berends *et al.* (2014), highlight that *small-*

sized firms' R&I activities are typically informal, opportunistic, and more dependent on external knowledge and spillovers, rather than on internal R&D investments. On this basis, we examine the following and final hypothesis:

H8: The positive impacts of firms' levels of internal financial resources on their R&I activities will be greater in larger-sized firms in comparison to small-sized firms.

3.3 Data and empirical approach

Progressing on from the conceptual development, this section describes the dataset, the construction of the variables, and the empirical strategy adopted in this paper.

3.3.1 Data

Our analysis uses a novel unbalanced panel dataset with information on firms in Ireland covering the period from 2008 to 2016. Our unbalanced panel merges several datasets from the Irish CSO. The Innovation in Irish Enterprises survey (IIE, formerly known as the Community Innovation Survey [CIS]) served as the base dataset. This is a biennial survey, with information on the internal characteristics and innovation activity for firms with at least 10 employees. Data from four survey waves (i.e. carried out in 2010, 2012, 2014 and 2016) were available to this study, covering a nine-year period from 2008 to 2016. To disaggregate firms' engagement in R&D into engagement in scientific research and engagement in development, the Business Expenditure in Research and Development (BERD) survey was merged with the IIE for the same period. This is a biennial survey containing detailed information on R&D expenditure by firms across all business sectors of the economy. The BERD survey indicates whether firms engaged in basic and applied (i.e. scientific), and experimental (i.e. development) research (See Section 3.2).

Both the IIE and BERD surveys are conducted every two years (2010, 2012, 2014, and 2016). In the IIE survey, the questions refer to firms' innovation activities during the previous three years (e.g. the 2012 IIE survey data provides information on innovation activities for the period 2010-2012). In the BERD survey, the questions refer to a two-year period (e.g. the 2012 BERD survey data provide information on R&D activities for the period 2011-2012).[23] Section 3.2 provides details on the specific variables used. Moreover, the IIE survey is a representative sample of manufacturing firms, and firms in select services.[24] The BERD survey is "designed to be a census of all enterprises that are believed to be engaged in research and development activities in all business sectors of the economy" (CSO 2017, p. 4).[25] However, only around 45 percent of firms included in the BERD survey dataset typically engage in R&D across the different survey waves (e.g. 1,900 firms out of a sample of 4,200 firms performed R&D in the 2016 wave). Our available BERD data thus include information on R&D-active firms,

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[23] The BERD survey is carried out in the middle of each two-year period. It contains actual expenditure in the first year and planned expenditure in the second year of the survey (e.g. the 2012 survey records actual expenditure for 2011 and planned expenditure for 2012).

[24] Specifically, the IIE survey is a stratified sample of enterprises with at least 10 and a maximum of 49 persons engaged, and a census of all firms with 50 persons engaged or more, in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73. For further details see: https://www.cso.ie/en/methods/scienceandtechnology/innovationinirishenterprisesformerlyknownascommunityinnovationsurvey.

[25] The BERD survey includes firms that the Irish CSO identifies as R&D-active firms across all business sectors of the economy. Such enterprises are identified from: (a) previous BERD surveys data; (b) other CSO data, such as the IIE survey; and (c) administrative data sources, such as Balance of Payments data. For further details, see https://www.cso.ie/en/methods/surveybackgroundnotes/businessexpenditureonresearchdevelopment/.

and also on firms that do not engage in these activities. Some previous studies specifically focus on R&D-active firms when analysing the impact of financial constraints on firms' R&I investments (see, amongst many others, Bond *et al.* 2005; Brown *et al.* 2012). However, the focus of our study is on firms' engagement in R&I, and not just on firms' investments levels in research activities. As highlighted by González-Bravo *et al*. (2021, p. 8), it is "necessary to consider both companies that do and do not engage in R&D" when studying the factors that drive firms to engage in R&I. Having data on firms that engage, and that do not engage, in R&D is thus appropriate in the context of our study.

Financial data to measure firms' levels of internal financial resources were obtained from the Census of Industrial Production (CIP) and the Annual Services Inquiry (ASI). These surveys are carried out every year by the CSO, and include data on firms' income and expenditure, thus allowing Net Operating Surplus, as the residual between income and expenditure, to be calculated (see Section 3.3). Both surveys are needed, as the CIP contains data on manufacturing firms, while the ASI focuses on firms in the service sector. Firms tend to base investment decisions on their internal financial resources generated in the previous period (Keupp and Gassmann 2013). Therefore, *a-priori*, one might expect a firm's decision to engage in research, development, or innovation in period *t* to be dependent on a firm's financial position in period *t-1*. For this reason, the financial data from the CIP and ASI data were merged with the IIE and BERD surveys to account for this lag. For example, the 2012 wave of the IIE and BERD datasets, covering the period 2010-

2012 for the IIE and 2011-2012 for the BERD, were merged with the 2010 data in the CIP and ASI.[26]

The final dataset, with the lag structure built-in, is an unbalanced panel with 2,531 observations from 1,446 firms. Around 45 percent of firms in the sample featured only once (674 firms), 50 percent featured at least twice (543 firms), 10 percent featured three times (147 firms), and 6 percent featured four times (83 firms). Around 63 percent of observations are from the 2014 and 2016 IIE and BERD survey waves (i.e. the two most recent waves available to this study). A total of 631 firms are *small-sized*, and 806 are *larger-sized* firms. Table 3-1 in Section 3.4.1 describes the sample in more detail.

3.3.2 Measuring research and innovation activity

Our study analyses the impact of firms' internal financial resources on their engagement in: (i) scientific research; (ii) development; (iii) process innovation; (iv) product innovation; (v) service innovation; (vi) radical goods and services innovation; and (vii) organisational innovation. Firms' engagement in each of these activities is measured in binary form. *Scientific Research* equals 1 if a firm records any expenditure on basic and/or applied research; otherwise, the value is zero. *Development* equals 1 if a firm invests in experimental research; otherwise, the value is zero. We consider basic and applied research activities as part of one indicator because both activities focus on generating new knowledge (Borrás and Edquist 2014). As Czarnitzki *et al.* (2011) explained, firms may engage in basic research when considering whether a concept and/or idea is viable in terms of

[26] The CIP and ASI surveys cover the accounting year from May to April. There is an overlap in the IIE of four months between the independent variable and the outcome variable in each panel wave.

fundamental scientific principles. Applied research, in turn, addresses potential challenges for the application of scientific concepts and/or ideas. These two research activities are fundamentally different from experimental research, which involves the process of adopting and scaling up the application of knowledge, including scientific knowledge, into products and services (Czarnitzki *et al.* 2011). The five innovation variables are also constructed in binary form, and take a value of 1 if a firm introduces the type of innovation considered, or otherwise zero. Panel A in Appendix 3-A explains each variable.

3.3.3 Measuring internal financial resources

Internal Financial Resources is our key independent variable of interest and measures the ratio of Net Operating Surplus (NOS) to total turnover. This is similar to the measures of internal financial resources used by numerous studies, including Czarnitzki (2006), Czarnitzki *et al.* (2011), Hottenrott and Peters (2012), and González-Bravo *et al.* (2021). NOS was obtained from the CIP and ASI datasets, by subtracting the following expenditure categories from total turnover: (i) total purchases of all goods and services other than capital items; (ii) changes in capital assets of the enterprise during the year; (iii) changes in intangible assets of the enterprise during the year; (iv) employment gross earnings; (v) other additional personnel costs (i.e. direct taxes and associated costs); and (vi) indirect taxes. We normalised by total turnover to account for heterogeneity arising from firm size (Schäfer *et al.* 2017). Total turnover is directly declared by firms in both datasets. The resulting variable is continuous, with a possible maximum of 1 (all turnover is available as NOS) and a possible minimum of minus 1, as the data includes firms that exhibit losses.

While some literature focuses on financial slack (Jissink *et al.* 2019) or cash-flows (for a review see Hall *et al.* 2016), such measures concern firms' internal and external financial resources, and require data on liabilities, which was not available to our study. As discussed in Section 3.2, we assume that firms tend to typically prefer financing their R&I activities internally, rather than incurring debt (Hall *et al.* 2016; De Massis *et al.* 2018; Peia and Romelli 2020). Our available BERD survey data support this assumption. During the period covered in our study (i.e. 2008 to 2016), our BERD survey data show that internal financial resources were responsible for almost 90 percent of all firms' investments in these activities, with public support for R&D representing around 6 percent, and all other sources of funding (including external finance) representing the remaining 4 percent.

The financial literature on innovation proposes that firms may seek external finance when faced with potentially profitable investments, such as R&I activities (Hubbard 1998). However, the period covered in this study (i.e. 2008 to 2016) coincides with the period following the Global Financial Crisis (GFC) of 2008, where commercial lending significantly decreased in Ireland (Central Bank of Ireland 2019). Hoffmann and Sørensen (2015) explain that firms' access to credit was particularly limited in Ireland following the 2008 GFC, as domestic banks' inability to access international interbank credit led to stringent credit rationing. O'Toole *et al.* (2013, p. 3) emphasise that credit constraints were especially severe for small and medium-sized enterprises (SMEs), that "have traditionally been heavily reliant on bank-based lending". Reports from the Irish CSO, based on the Access to Finance Survey (CSO 2010; CSO 2016b), indicate that the percentage of enterprises seeking loans fell from 37 to 31 percent between 2007 and 2010, and less than 25 percent from 2012 to 2014. Loan success rates also ranged between 50 to 70 percent during most of this period, while the incidence of other sources of finance, such as equity finance, remained very low, at around 5 percent.[27] As presented in Table 3-1, our available BERD survey data indicates that only around 4 percent of the firms in our sample used some form of external finance for R&I from 2008 to 2010, with this percentage declining to around 2 percent during the 2012 to 2016 period. Profits were thus the main source of finance for R&I by firms in Ireland during most of the period covered in our study.[28]

According to Peia and Romelli (2020), tight credit supply, and uncertainty caused by the 2008 GFC hampered firms' R&I activities in the European Union (EU), including Ireland, even if firms did not directly finance their R&I activities through debt. Therefore, although limited access to credit was particularly severe for firms in Ireland, firms in other EU countries faced similar circumstances (Hall *et al.* 2016; Giebel and Kraft 2019; Peia and Romelli 2020). Furthermore, as the current Covid-19 pandemic is having similar effects in Ireland (CSO 2020) and globally (Cowling *et al.* 2020), our focus on firms' internal financial resources is highly relevant in the current context.

3.3.4 Additional independent variables

As is common in the literature, we controlled for firm size as the natural logarithm of the number of employees, and firms' levels of human capital as the percentage of employees that dedicate time to R&I (Shefer and Frenkel 2005;

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[27] Data from the Access to Finance Survey (AFS) were not available for our study. Furthermore, the Irish CSO has changed the format of the AFS questionnaire between the 2010 and 2014 survey waves, resulting in the 2010 survey wave no longer being available to researchers.

[28] In Section 3.4, we discuss how we controlled for public financial support for R&I in our empirical analysis.

D'Este *et al.* 2016). Consistent with studies using Irish data, such as Doran and Ryan (2014b), we included a dummy variable to identify if firms are domestic or foreign-owned. A continuous variable measured the age of firms (in years), and accounts for possible heterogeneous effects between young and established firms. We also included a binary variable measuring if firms were exporters or not, as exporting is a widely recognised driver of firm-level research and innovation (Love and Roper 2015). Moreover, we included a dummy variable denoting whether firms were owned by an enterprise group or not, to control for potential access to resources, including financial resources, from the group (Jissink *et al.* 2019). Firms can compensate for a lack of financial resources by accessing external knowledge through collaborations (Grimpe and Sofka 2016). Thus, we included four dummy variables capturing collaborations with: (i) clients; (ii) suppliers; (iii) other firms; and (iv) public knowledge providers.

Our data did not permit explicitly controlling for firms' access to finance for R&I, nor their leverage, which may influence their R&I activities (Hubbard 1998). However, we attempt to capture access to external finance for R&I in the following ways. The BERD survey required firms to indicate how they have financed their R&I activities, as follows: (i) internal/own financial resources; (ii) from other firms; (iii) Government subsidies; (iv) other public funding; (v) higher education institutes; (vi) private non-profit institutes; and (vii) other sources. The survey repeats the question to identify if the above funding sources are from Ireland, or from outside of Ireland. Given the specificity of these categories, firms likely declared using external finance in the 'other sources' category, as this is the only possible option in the survey to include such a source.[29]

In light of the above, we construct four dummy variables, measuring whether: (a) firms received public financial support for R&I from the Irish Government; (b) firms received public financial support for R&I from the EU; (c) firms used external financial resources for R&I from Ireland; and (d) firms used external financial resources for R&I from outside of Ireland. The latter two variables (i.e. [c] and [d]) were constructed by grouping all external funding sources, as included in the BERD survey, apart from own funding, and government subsidies. While these variables do not explicitly account for the use of external finance for R&I, this is the best possible strategy permitted by our data. However, as discussed in Section 3.3.3, the vast majority of the firms in our sample primarily financed their R&I activities internally, and access to external finance was very limited for firms in Ireland during the period covered in our study (i.e. 2008 to 2016).

Finally, sectoral controls using one-digit NACE Rev. 2 classifications, and survey wave dummies (i.e. year), were included to control for sector and period effects as adopted in other studies such as Katila and Shane (2005). Panel B in Appendix 3-A explains the construction of the additional independent variables.

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[29] We consulted the pertaining statistician at the Irish CSO responsible for the BERD survey about this issue. He informed us that, while this is a likely scenario (i.e. that firms used the 'other sources' category to include using external finance for R&I), most firms did not specify the types of sources in the 'other sources' category.

3.3.5 Empirical approach

Our study focuses on unveiling causal relationships between firms' levels of internal financial resources and their engagement in research and innovation (R&I) activities. Hicks (1980, p. 28) posited that establishing cause and effect relationships "has to begin from some proposition, some relation between characteristics that has already been recognized". Earlier in Section 3.2, we have unveiled the theoretical and logical mechanisms through which firms' levels of internal financial resources are expected to impact their engagement in the seven R&I activities considered, as emerging from the prevailing literature. Therefore, provided that our results support our hypotheses, we could interpret such results as causal "on the basis of both logic and existing theory" (Lenihan *et al.* 2019, p. 10). However, to ascertain causal relationships empirically, we need to consider issues of endogeneity that may influence the direction of causality (Reeb *et al.* 2012), such as firms' financial profiles being determined by their previous innovative performance, and other unobserved factors (Hubbard 1998).

Previous similar studies to ours controlled for endogeneity by lagging suspected endogenous variables (see, for example, Czarnitzki 2006; Keupp and Gassmann 2013). Reed (2015) demonstrates that such an approach is not suitable in cross-sectional research designs, such as the one adopted in our study, as inter-temporal relationships between endogenous and outcome variables may remain. A valid solution to address endogeneity in the context of our study is to employ an instrumental variable approach (Czarnitzki *et al.* 2012). Here, suspected endogenous independent variables are instrumented by exogenous variables that: (i) correlate with the endogenous variable; and (ii) only influence the dependent variable through the endogenous variable (Reeb *et al.* 2012; Montresor and Vezzani

2016). In the absence of suitable exogenous instruments, similar studies to ours used the lags of the suspected endogenous variables as instruments (see, for example, Tiwari *et al.* 2007; Borisova and Brown 2013; Lokshin and Mohnen 2013; Piekkola and Rahko 2019). Czarnitzki *et al.* (2012, p. 1560) note that using the lags of suspected endogenous variables as instruments is "common in the literature". Reed (2015) demonstrates that this is an effective approach provided that: (a) the lagged instruments are sufficiently correlated with the suspected endogenous variable; and (b) do not themselves belong to the respective estimation equation.

Considering the above, we employed an instrumental variable approach using firms' lagged levels of internal financial resources, as an instrument for our main variable of interest *Internal Financial Resources.* Specifically, for each wave of the IIE and BERD surveys, from where we derived our dependent variables (i.e. *t*=0), we used firms' average levels of internal financial resources for the years *t*-2 and *t*-3. For example, for the 2016 IIE and BERD survey wave (covering the period from 2014 to 2016), we used firms' average levels of internal financial resources for the periods 2011-2012 and 2012-2013 (which correspond to *t-3* and *t-2,* respectively), as an instrument for our main variable of interest *Internal Financial Resources*. Using the two-year average was necessary to smooth changes in firms' internal financial resources, and obtain an instrument that is highly correlated with our suspected endogenous variable (i.e. the resulting correlation coefficient was 0.83). Moreover, our instrument does not belong to the contemporaneous equation, given that firms mainly base their R&I decisions on their immediate financial performance (i.e. *t-1*) rather on that of 2 to 3 years ago (Greeve 2003; Jissink *et al.* 2019). Our instrument thus meets the conditions as highlighted by Reed (2015).

We tested the validity of our instrument using regression-based tests, following Wooldridge (2010, p. 105). Such tests yielded F-statistics well above 10, which as Staiger and Stock (1997) have demonstrated, support the relevance of our instrument. Wald tests for endogeneity, however, only rejected the null hypothesis of exogeneity of the regressors in some of the R&I activities considered, and mainly in the context of *larger-sized* firms (see Table 3-4). This indicates that endogeneity was present in some, but not all, of the R&I activities considered. Therefore, as presented in Section 3.4.3, we repeated our analysis with two alternative estimators (i.e. random effect probit model and multivariate probit model), to ensure that our results were robust across different estimators and model specifications.

The impact of firms' levels of internal financial resources on their engagement in scientific research, development and innovation was estimated using the following equations:

$$IO_{itj} = \alpha_{it} + \beta xIV_{it-1} + \phi z_{it-1} + \varepsilon_{it} \tag{3-1}$$

$$xIV_{it-1} = \alpha_{it} + \beta x_{it-2,3} + \phi z_{it-1} + u_{it} \tag{3-2}$$

Equation (3-1) is an innovation production function (Geroski, 1990) where IO_{it} is a binary variable taking the value of 1 if firm i in period t engages in the research/innovation activity j under consideration, or zero otherwise. The model was estimated seven times, once each for: (i) scientific research; (ii) development; (iii) process innovation; (iv) product innovation; (v) service innovation; (vi) radical innovation in goods and services; and (vii) organisational innovation. The β term is the associated coefficient of interest for xIV_{it-1}, (i.e. the endogenous continuous variable *Internal Financial Resources* ranging from -1 to 1), which we instrumented by Equation (3-2). z_{it-1} denotes the set of explanatory variables as discussed in

Section 3.4, with ϕ denoting their associated coefficients. Finally, ε_{it} is the error term. In Equation (3-2), xIV_{it-1} is our endogenous variable from Equation (3.1), which is the endogenous continuous variable *Internal Financial Resources* ranging from -1 to 1. This is assumed to be linearly determined by our instrument $x_{it-2,3}$, which is firms' average level of internal financial resources for the periods 2011-2012 and 2012-2013 (i.e. *t-3* and *t-2,* respectively), and the same set of control variables as included in Equation (3-1). u_{it} is the error term.

Equation (3-1) was estimated with an instrumental variable probit model with standard errors clustered at the industry level (i.e. one-digit NACE Rev. 2 classification), and Equation (3-2) with ordinary least squares. Both equations were estimated simultaneously.[30] The coefficient β in Equation (3-1) allows us to test hypotheses 1 through 7, where a positive and significant coefficient would provide support for hypotheses 1 to 3, and Hypothesis 5. Moreover, a negative and significant coefficient would provide support for Hypothesis 6, and non-significant coefficients would provide support to hypotheses 4 and 7. Section 3.3.6 details how we used the same model specifications to test Hypothesis 8 by firm sizes.

3.3.6 Financial resources in small-sized and larger-sized firms

Our study unravels the potential heterogeneous effects of financial resources between the engagement in research and innovation (R&I) by *small* (10 to 49 employees) and *larger-sized* (50+ employees) firms. Analysing *medium* (50 to 249 employees) together with *large-sized* (250+ employees) firms as one group is a

[30] While we report the Wald Statistics derived from Equation (3-2) in our results, we do not include the tables with the results for Equation (3-2), as these are not central to our paper. Results for Equation (3-2), however, are available upon request to the corresponding author.

commonly adopted approach in the Irish context (See Hewitt-Dundas 2006; Vahter *et al.* 2014; McGuirk *et al.* 2015). This is because *small-sized* firms represent most firms in Ireland (98.9 percent), with *larger-sized* firms representing only 1.1 percent of firms (CSO 2020). Likelihood ratio tests to assess parameter stability across these three disaggregated firm size categories confirmed that the estimates from the instrumental variable probit model were statistically similar to the sub-categories of *medium* and *large-sized* firms. However, they were significantly different for *small-sized* firms for most of the research and innovation activities considered (e.g. Chi2(22) = 83.06, P < 0.001 for scientific research).

A natural starting point to carry out the analysis as noted above, is to interact our continuous variable *Internal Financial Resources* with a binary variable denoting *small-sized* firms. This is appropriate in a model estimated via ordinary least squares (or another appropriate estimation technique). However, as outlined by Norton *et al.* (2004) and Karaca-Mandic *et al.* (2012), the magnitude of interaction effects in non-linear models are conditional on the varying impact of the interacting variables (e.g. *Internal Financial Resources* and *Small Firms*), and all other explanatory variables. This makes interpreting interaction terms difficult in non-linear models, as the interaction effect cannot be summarised in one single coefficient (Norton *et al.* 2004). As probit models are a form of a non-linear model, this restriction applies to the current paper.

In light of the above, we followed Karaca-Mandic *et al.* (2012) by repeating the analysis for each subgroup of firms. Equation (1) and Equation (2) were firstly estimated for a sub-sample of *small-sized* firms only. Separately, the same equations were estimated for a sub-sample of *larger-sized* firms. This provided comparable marginal effects of all the independent variables on firms' engagement in the various types of R&I activities for each size classification. Splitting the sample is standard in the literature on financial constraints, as firms' structural characteristics can influence their ability to both generate, and direct financial resources to R&I (see for example, Hottenrott *et al.* 2016). As noted above, Likelihood Ratio tests confirmed the stability of the parameters across these two firm-size groups. For completeness and robustness, we present a model including the interaction term in Section 3.4.3.

3.4 Empirical findings

This section reports the empirical findings. We focus on the average marginal effects for *Internal Financial Resources,* as this variable allows us to test our hypotheses. The coefficients for this variable measure the increase/decrease in the probability of firms engaging in each of the research and innovation (R&I) activities considered, given a one-unit change in their level of internal financial resources as a proportion of turnover. Before presenting our main results, we describe our sample and the variables used.

3.4.1 Descriptive statistics

As presented in Table 3-1, more than half of the firms in our sample engaged in at least one of the seven R&I activities, during each of the periods considered (i.e. 2010, 2012, 2014, and 2016). From Table 3-1, we also observe that a higher proportion of *larger-sized* firms engaged in the R&I activities considered, in comparison to *small-sized* ones. Correlation analysis indicates that firms typically engaged in more than one R&I activity during the same period. Around 47 percent of firms that engaged in scientific research, also engaged in development.

Moreover, 62 percent of firms that engaged in product innovation, also engaged in radical innovation regarding products and services. Finally, 44 percent of firms that engaged in process innovation also engaged in organisational innovation. The correlation between other forms of R&I was generally low (i.e. below 0.3). These correlations are similar across the different survey wave years.

Table 3-1: Descriptive statistics by year and firm sizes

	Total Sample				Larger Firms (>- 50)				Small Firms (> 10 & < 50)			
	2010	2012	2014	2016	2010	2012	2014	2016	2010	2012	2014	2016
DEPENDENT VARIABLES					mean	mean	mean	mean	mean	mean	mean	mean
Scientific Research	0.453	0.401	0.343	0.361	0.547	0.445	0.395	0.437	0.292	0.338	0.282	0.290
Development	0.509	0.482	0.438	0.415	0.607	0.524	0.494	0.523	0.340	0.421	0.373	0.315
Process Innovation	0.563	0.574	0.439	0.499	0.615	0.640	0.525	0.602	0.472	0.457	0.337	0.465
Product Innovation	0.545	0.529	0.459	0.459	0.615	0.637	0.482	0.529	0.465	0.474	0.433	0.394
Service Innovation	0.243	0.209	0.211	0.261	0.231	0.220	0.222	0.312	0.264	0.193	0.197	0.214
Radical Innovation	0.611	0.612	0.555	0.609	0.640	0.652	0.591	0.700	0.563	0.553	0.512	0.524
Organisational Innovation	0.547	0.567	0.595	0.560	0.636	0.634	0.662	0.639	0.396	0.469	0.518	0.487
VARIABLES												
Irish Owned	0.627	0.644	0.648	0.648	0.470	0.515	0.537	0.544	0.896	0.829	0.778	0.744
Enterprise Group	0.453	0.444	0.434	0.430	0.603	0.610	0.605	0.645	0.194	0.206	0.236	0.231
Export	0.754	0.827	0.787	0.789	0.834	0.875	0.823	0.924	0.618	0.759	0.745	0.665
Fund EU	0.000	0.000	0.048	0.056	0.000	0.000	0.050	0.070	0.000	0.000	0.047	0.042
Fund National	0.000	0.000	0.372	0.337	0.000	0.000	0.395	0.419	0.000	0.000	0.345	0.262
Other Funding Sources (IRL)	0.040	0.007	0.013	0.012	0.029	0.009	0.011	0.009	0.059	0.004	0.014	0.014
Other Funding Sources (Outside IRL).	0.039	0.005	0.005	0.001	0.028	0.006	0.005	0.000	0.057	0.004	0.005	0.003
Cooperation Clients	0.179	0.176	0.110	0.132	0.202	0.186	0.120	0.112	0.139	0.162	0.155	0.142
Cooperation Suppliers	0.169	0.128	0.113	0.097	0.206	0.165	0.139	0.156	0.104	0.075	0.082	0.042
Cooperation Other Firms	0.044	0.031	0.039	0.021	0.045	0.040	0.040	0.015	0.042	0.018	0.038	0.025
Cooperation Public	0.187	0.196	0.176	0.136	0.235	0.220	0.213	0.202	0.104	0.162	0.134	0.076

Table 3-1: Descriptive statistics by year and firm sizes (Continued)

	Total Sample				Larger Firms (>- 50)				Small Firms (> 10 & < 50)			
	2010	2012	2014	2016	2010	2012	2014	2016	2010	2012	2014	2016
Internal Financial Resources												
Mean	0.115	0.106	0.0985	0.121	0.139	0.123	0.104	0.125	0.073	0.081	0.0925	0.118
SD	0.217	0.216	0.214	0.222	0.179	0.209	0.188	0.208	0.266	0.223	0.241	0.234
Min	-0.856	-0.939	-0.966	-0.91	-0.856	-0.75	-0.856	-0.833	-0.85	-0.939	-0.966	-0.905
Max	0.947	0.875	0.996	0.914	0.77	0.778	0.739	0.914	0.947	0.875	0.996	0.861
Financial Mean (T-2,3)												
Mean	0.111	0.0997	0.0999	0.117	0.127	0.122	0.104	0.124	0.083	0.0679	0.095	0.111
SD	0.165	0.199	0.2	0.203	0.15	0.193	0.184	0.192	0.184	0.204	0.218	0.212
Min	-0.649	-0.939	-0.966	-0.91	-0.422	-0.63	-0.748	-0.646	-0.65	-0.939	-0.966	-0.905
Max	0.919	0.716	0.808	0.86	0.622	0.716	0.739	0.836	0.919	0.659	0.808	0.859
Size (Ln Employees)												
Mean	4.382	4.295	4.133	3.98	5.135	5.108	5.048	5.023	3.089	3.125	3.074	3.021
SD	1.272	1.255	1.247	1.239	0.928	0.965	0.954	0.943	0.511	0.425	0.464	0.459
Min	2.303	2.303	2.303	2.303	3.912	3.912	3.912	3.912	2.303	2.303	2.303	2.303
Max	8.042	8.722	8.776	8.633	8.042	8.721	8.776	8.632	3.892	3.892	3.892	3.892
Employees (R&D)												
Mean	8.615	8.268	9.835	11.51	7.104	5.656	6.458	10.55	11.212	12.021	13.751	12.394
SD	17.721	16.372	18.351	21.232	14.391	11.206	12.143	20.53	22.08	21.223	22.991	21.842
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	85.29	96.54	100	100	100	100	100
Age												
Mean	20.821	23.084	23.642	23.981	22.06	25.16	24.86	24.97	18.68	20.102	22.224	23.081
SD	11.152	12.161	11.621	11.307	12.06	12.893	12.38	12.25	9.046	10.343	10.535	10.292
Min	0	0	0	0	0	0	0	2	0	0	4	0
Max	47	49	51	53	47	49	51	53	47	49	51	53
Observations	391	586	829	725	247	339	423	327	144	247	395	383

T-Test (Pooled Sample)	Difference	P-value
Internal Financial Resources (Larger – Small)	0.025	0.006
Financial Mean (T-2,3) (Larger – Small)	0.024	0.002
Percentage RD Staff (Larger – Small)	-5.22	6.962
Age (Larger – Small)	2.846	0.000
Irish owned	0.27	0.001
Enterprise Group	0.397	0.006
Export	0.151	0.001
Fund EU	0.001	0.821
Fund National	0.003	0.788
Other funding (IRL)	-0.02	0.652
Other funding (Out.)	0.078	0.078
Cooperation Clients	0.021	0.192
Cooperation Suppliers	0.012	0.149
Cooperation other Firms	0.118	0.138
Cooperation Public	0.003	0.343

Source: Authors' own elaboration using data from the Innovation in Irish Enterprises Survey (IIE), Business Expenditure on Research and Development (BERD) survey, Census of Industrial Production (CIP) and Annual Services Inquiry (ASI). The lower panel shows the average differences between larger-sized and small-sized firms across the independent variables used in the analysis, weighted by year.

Table 3-2 (below) shows that, on average across the period 2008 to 2016, firms that engaged in most of the seven R&I activities had significantly higher levels of internal financial resources when compared to firms that did not engage in these activities ($p < 0.05$). This is apart from firms that engaged in service innovation, where the opposite is true ($p < 0.01$), and organizational innovations, where no differences are found. The table also shows that younger firms, and firms that engaged more in cooperation with clients, suppliers, and public knowledge providers, also engaged more in R&I ($p < 0.05$). The same occurred for exporting, and firms' levels of human capital ($p < 0.05$). Finally, firms that declared using external financial resources for R&I from outside of Ireland, generally engaged less in R&I ($p < 0.05$), but this was not the case for firms using external financial resources from Ireland, where no differences are found. As reported by Montresor and Vezzani (2020), firms may invest in other R&I related activities, such as branding and reputation building, and training. This may explain why firms that used external financial resources from abroad engaged less in the R&I activities considered in our study.

Table 3-2: Descriptive statistics by research and innovation activities

	Scientific Research			Development			Process Innovation			Product Innovation			Service Innovation			Radical Innovation			Organisational Innovation		
VARIABLES	Yes	No	Diff	Yes	No	Diff	Yes	No	Diff	Yes	No	Diff	Yes	No	Diff	Yes	No	Diff	Yes	No	Diff
	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean	mean
Irish Owned	0.627	0.653	-0.021	0.592	0.685	-0.101**	0.613	0.675	-0.069	0.631	0.655	-0.029	0.634	0.646	-0.023	0.617	0.661	-0.040	0.605	0.694	-0.078*
Size (Ln Employees)	4.456	3.958	0.513**	4.458	3.89	0.569***	4.432	3.847	0.342**	4.318	3.983	0.339**	4.273	4.108	0.165**	4.378	3.991	0.397**	4.394	3.817	0.573***
Enterprise Group	0.533	0.375	0.151**	0.558	0.334	0.234***	0.487	0.381	0.111**	0.502	0.372	0.133***	0.502	0.415	0.081**	0.514	0.382	0.128**	0.501	0.351	0.152***
Export	0.897	0.728	0.173***	0.906	0.7	0.212**	0.487	0.713	0.165**	0.905	0.685	0.225**	0.858	0.772	0.090	0.893	0.724	0.171**	0.863	0.698	0.167**
Fund EU	0.0481	0.022	0.032	0.036	0.03	0.011	0.487	0.023	0.021	0.042	0.022	0.0211	0.059	0.023	0.042	0.052	0.018	0.03	0.044	0.015	0.020
Fund National	0.335	0.143	0.201**	0.328	0.12	0.212**	0.487	0.133	0.169**	0.311	0.126	0.182***	0.315	0.186	0.129***	0.335	0.136	0.202***	0.296	0.109	0.191***
Other Funding Sources (IRL)	0.027	0.097	-0.033	0.021	0.111	0	0.487	0.078	0.011	0.054	0.086	-0.010	0.070	0.070	-0.051	0.056	0.080	-0.011	0.054	0.091	0
Other Funding Sources (Outside IRL).	0.009	0.095	-0.053	0.008	0.108	-0.058**	0.487	0.075	-0.010**	0.041	0.083	0.011**	0.054	0.065	-0.043	0.039	0.078	-0.003	0.043	0.089	-0.013**
Cooperation Clients	0.111	0.043	0.069***	0.115	0.031	0.091**	0.487	0.021	0.093**	0.121	0.021	0.101**	0.121	0.053	0.073**	0.111	0.041	0.072*	0.101	0.027	0.069*
Cooperation Suppliers	0.186	0.081	0.114**	0.163	0.084	0.082**	0.487	0.033	0.173**	0.189	0.055	0.137**	0.178	0.103	0.082**	0.189	0.074	0.126**	0.186	0.033	0.161**
Cooperation Other Firms	0.052	0.019	0.033	0.042	0.022	0.021	0.487	0.008	0.041	0.051	0.013	0.039**	0.072	0.019	-0.049	0.053	0.017	0.030	0.050	0.006	0.042*
Cooperation Public	0.304	0.087	-0.061**	0.265	0.091	0.185***	0.487	0.067	0.211***	0.274	0.070	0.202***	0.259	0.143	0.124**	0.275	0.099	0.181**	0.253	0.058	0.188***
Internal Financial Resources	0.135	0.089	0.049**	0.132	0.086	0.051**	0.122	0.090	0.032	0.128	0.087	0.041*	0.0732	0.117	-0.043*	0.119	0.099	0.025	0.111	0.101	0.011
Financial Mean (T-2,3)	0.124	0.092	0.032**	0.126	0.086	0.039*	0.116	0.091	0.026	0.123	0.086	0.038*	0.0673	0.115	-0.051*	0.114	0.097	0.028	0.108	0.099	0.015
Employees (R&D)	18.412	4.818	13.581***	18.641	2.817	15.823**	11.491	8.339	3.152*	13.39	6.696	6.692**	18.931	7.254	11.680***	16.33	5.704	10.631***	11.662	7.681	3.983*
Age	22.321	23.44	-1.123	22.310	23.591	-1.281	22.472	23.592	-1.122	22.96	23.071	-0.112	19.843	24	-4.131	22.201	23.562	-1.362	22.521	23.672	-1.152
Observations	956	1,575		1,141	1,390		1,294	1,237		1,230	1,301		584	1,947		1,011	1,520		1,441	1,090	

Source: Authors' own elaboration using data from the Innovation in Irish Enterprises Survey (IIE), Business Expenditure on Research and Development (BERD) survey, Census of Industrial Production (CIP) and Annual Services Inquiry (ASI). Columns 'Diff' across the seven R&I activities indicate the existence of significant differences, and significance level, for each independent variable between firms that engage, and do not engage in the seven R&I activities considered (weighted by year). *** p<0.01, ** p<0.05, * p<0.1.

Our descriptive analysis indicates that, on average, *larger-sized* firms had higher levels of internal financial resources than *small-sized* ones (around 2.5 percent [$p < 0.01$]). *Larger-sized* firms were also 2.8 years older ($p < 0.01$). Moreover, around 60 percent of *larger-sized* firms were owned by an enterprise group, compared to only around 20 percent amongst *small-sized* firms ($p < 0.01$). Sm*all-sized* firms, however, dedicated a higher share of their employee base to R&I activities, in comparison to their *larger-sized* firm counterparts (around 5 percent more [$p < 0.01$]). This is consistent with studies highlighting that *small-sized* firms tend to have a more informal approach to R&I activities, where not only R&D employees, but also other types of employees (such as manufacturing employees and firms' owners) contribute to such activities (see, for example, Freel, 2000; Berends *et al.*, 2014). *Small-sized* firms were also predominantly Irish-owned, while this was the case in only half of *larger-sized* firms (i.e. the difference between *larger* and *small-sized* firms is 27 percent on average, $p < 0.01$). Between 60 to 75 percent of *small-sized* firms exported, depending on the survey wave year considered (i.e. 2010, 2012, 2014, and 2016), while exports accounted for between 75 to 85 percent amongst *larger-sized* firms (i.e. the average difference, weighted by survey period, is 15 percent [$p < 0.01$]). Finally, around 4 percent of firms used external financial resources for R&I during the period from 2008 to 2010, declining to around 2 percent from 2010 to 2016. Such decline, however, was accompanied by an increase in the use of public financial support for R&I.

3.4.2 Main findings

Our main findings were obtained by estimating Equation (1) with an instrumental variable probit model and are presented in Table 3-3 and Table 3-4.[31] Wald-tests for exogeneity of the regressors are included in both tables. McFadden's pseudo R^2s also indicate that the goodness of fit of our models ranged between 0.25 and 0.4, which according to McFadden (1977, p. 35), indicates a good model fit.

Columns 1 and 2 of Table 3-3 show that firms' levels of internal financial resources affect their probability of engaging in scientific research and development differently. A one-percent increase in firms' internal financial resources (measured as net operating surplus divided by turnover) increases their probability of engaging in scientific research by 0.1 percent (Column 1). However, such resources do not determine firms' probability of engaging in development (Column 2). These results support Hypothesis 1, which posits that higher levels of firms' internal financial resources positively determine their engagement in scientific research, but do not support Hypothesis 2, which posits the same for development. As highlighted in the literature, our results may be attributed to the fact that scientific research is uncertain and requires long lead times (Fleming and Sorenson 2004; Cassiman *et al.* 2018; Mulligan *et al.* 2022). High levels of internal financial resources can allow firms to have more relaxed expectations regarding their explorative research investments (Lee *et al.* 2014; Jissink *et al.* 2019). In contrast, firms may prioritise investments in development activities because they can lead to outcomes that are

[31] Estimations of Equation (3-2) can be made available upon request to the corresponding author.

commercially viable in the short term (Czarnitzki *et al.* 2011; Arora *et al.* 2018). This is especially the case if firms focus on improving existing products and services that are familiar to them (Czarnitzki *et al.* 2011; Radas and Bozic 2012). For these reasons, firms may engage in development activities regardless of their internal financial position.

Progressing on to our innovation indicators, Table 3-3 shows that firms' levels of internal financial resources have no impact on their engagement in process innovation and product innovation (Columns 3 and 4). Thus, our findings do not support Hypothesis 3, which posits that firms' internal financial resources positively determine their engagement in process and/or product innovation activities. Furthermore, our findings indicate that firms engage in service innovation when their levels of financial resources are low (Column 5). Here, an increase of one percent in firms' internal financial resources leads to a 0.04 percent decline in their probability of engaging in service innovation. Such findings do not support Hypothesis 4 that posits no relationship. Service innovation, therefore, may represent a way to innovation for firms with lower levels of internal financial resources (Mennens *et al.* 2018).

Table 3-3: Impact of internal financial resources on firms' engagement in research and innovation (in average marginal effects)

	Scientific Research	Dev.	Process Innov.	Product Innovation	Service Innov.	Radical Innov.	Org. Innov.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	dy/dx	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**
Estimator	**IV Probit**	**IV Probit**	**IV Probit**	**IVProbit**	**IV Probit**	**IV Probit**	**IV Probit**
VARIABLES							
Firm Characteristics							
Internal Financial Resources	0.117***	-0.102	0.107	0.0319	-0.04**	-0.068	-0.025
	(0.044)	(0.095)	(0.099)	(0.048)	(0.01)	(0.048)	(0.050)
Size (Ln Employees)	0.058***	0.069***	0.069***	0.0110	0.018**	0.041***	0.057***
	(0.008)	(0.007)	(0.009)	(0.009)	(0.007)	(0.009)	(0.009)
Employees (R&D)	0.007***	0.011***	0.001*	0.003***	0.002***	0.005***	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Age	-0.001	-0.001**	-0.003***	-0.0008	-0.002**	-0.001	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Irish Owned	0.057***	-0.004	0.014	0.0431**	-0.004	0.010	-0.020
	(0.019)	(0.017)	(0.021)	(0.020)	(0.017)	(0.020)	(0.021)
Export	0.062***	0.081***	0.092***	0.1865***	0.045**	0.114***	0.093***
	(0.022)	(0.021)	(0.024)	(0.023)	(0.021)	(0.024)	(0.023)
Enterprise Group	0.008	0.040**	-0.040*	0.0299	-0.020	-0.004	-0.003
	(0.019)	(0.018)	(0.022)	(0.020)	(0.018)	(0.021)	(0.021)
Support/Finance							
Fund EU	-0.023	-0.132**	-0.054	-0.0109	0.060	0.083	0.065
	(0.050)	(0.054)	(0.059)	(0.051)	(0.039)	(0.055)	(0.062)
Fund National	0.132***	0.131***	0.175***	0.2009***	0.077***	0.179***	0.204***
	(0.023)	(0.023)	(0.025)	(0.024)	(0.021)	(0.025)	(0.026)
Other Funding Sources (IRL)	0.038	-0.014	0.065***	0.0652	-0.030	0.058	-0.003
	(0.051)	(0.051)	(0.009)	(0.070)	(0.039)	(0.048)	(0.053)
Other Funding Sources (Outside IRL).	-0.385***	-0.361***	-0.126***	-0.2263***	-0.024	-0.101**	-0.099
	(0.062)	(0.058)	(0.038)	(0.074)	(0.044)	(0.055)	(0.085)
Cooperation							
Cooperation Clients	-0.038	0.119***	0.175***	0.1663***	0.117***	0.077*	0.113**
	(0.038)	(0.037)	(0.047)	(0.045)	(0.032)	(0.040)	(0.047)
Cooperation Suppliers	0.012	-0.050*	0.221***	0.0919***	0.016	0.072**	0.201***
	(0.031)	(0.030)	(0.038)	(0.034)	(0.026)	(0.033)	(0.038)
Cooperation Other Firms	0.046	-0.018	0.134*	0.0912	0.110***	0.042	0.165**
	(0.048)	(0.054)	(0.072)	(0.061)	(0.039)	(0.056)	(0.079)
Cooperation Public	0.170***	0.080***	0.136***	0.1469***	0.060***	0.098***	0.147***
	(0.026)	(0.026)	(0.031)	(0.029)	(0.022)	(0.028)	(0.032)
Industry Control	yes	yes	yes	yes	yes	yes	yes
Survey wave control	yes	yes	yes	yes	yes	yes	yes
	0.510***	0.443***	0.510***	0.485***	0.233***	0.397***	0.568***
Constant	(.002)	(0.001)	(0.001)	(0.000)	(0.000))	(0.000)	(0.002)
Observations	2,531	2,531	2,531	2,531	2,505	2,531	2,531
McFadden Pseudo R^2	0.402	0.365	0.451	0.391	0.401	0.421	0.426
Wald Test Exogeneity (null = yes)	0.32	2.35	0.414	0.511	0.52	1.020	0.871

Results presented in average marginal effects obtained IV Probit Model. Robust standard errors clustered at the industry level in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included. *** p<0.01, ** p<0.05, * p<0.1.

Similarly, our results in Column 6 in Table 3-3 do not support Hypotheses 5 and 6, regarding higher (and lower) levels of internal financial resources positively (and negatively) determining firms' engagement in radical innovation (regarding goods and services). These results may suggest that firms' engagement in radical innovation is mainly motivated by their ability to recombine existing resources, rather than the size of their financial resource base (see Hoegl *et al.* 2008; Gibbert and Scranton 2009; Bicen and Johnson 2014; Colclough *et al.* 2019). Colclough *et al.* (2019), for example, highlight that firms' financial resources may not be an essential determinant of their engagement in radical innovation. In their view, this type of innovation is primarily driven by firms' innovation orientation, which is determined by the growth ambitions of firms' managers and owners. Our findings support these arguments. In contrast, however, our findings support Hypothesis 7, as levels of financial resources have no impact on firms' engagement in organisational innovation (Column 7). This innovation activity centres on reorganising routines for R&I, and it may be the case that firms rely on their existing human capital resources and/or may collaborate with external partners when carrying out these changes (Volberda *et al.* 2013; Tavassoli and Karlsson 2015).

Our analysis unravels significant differences when it is carried out for *small*, and *larger-sized* firms separately. Table 3-4 shows that the positive relationship between firms' levels of internal financial resources and their probability of engaging in scientific research only applies in the context of *larger-sized* firms (Column 1 in Panel B). Regarding innovation activities, we do not find that financial resources encourage innovation in the case of *small-sized* firms. Panel A also shows that small firms' levels of internal financial resources negatively determine their probability of engaging in service and organisational innovation (Columns 5 and 7). In contrast, a one-percent increase in firms' internal financial resources increases the probability of *larger-sized* firms engaging in process and product innovation by 0.2 percent (Columns 3 and 4 in Panel B). These results support to some extent Hypothesis 3, but only for this firm-size group, and are consistent with resource-based and behavioural theories of innovation (Nohria and Gulati 1996; González-Bravo *et al.* 2021). Therefore, taken together, our results support Hypothesis 8, which proposes that the impact of firms' levels of financial resources on their engagement in R&I will be greater in the context of *larger-sized* firms, when compared to *small-sized* firms.

As firm size typically correlates with the level of firms' financial and human capital resources (Freel 2000), *larger-sized* firms may be more able to engage in scientific research than *small-sized* firms (Arora *et al.* 2018). Size naturally represents a limit to the number of research projects that firms can undertake, and *small-sized* firms may concentrate on fewer, but higher-quality projects (Greve 2003; Berends *et al.* 2014). Thus, they may refrain from investing additional financial resources in research activities when their R&D resources are fully occupied (Berends *et al.* 2014). Moreover, *small-sized* firms may prefer research projects that focus on applying their existing expertise, rather than projects that require expanding their expertise, especially when operating in niche markets where they hold knowledge advantages (De Massis *et al.* 2018).

Table 3-4: Impact of internal financial resources on firms' engagement in research and innovation by firm size (in average marginal effects)

	Panel A: Small-sized Firms (>=10 & < 50 Employees)							Panel B: Larger-sized firms (50 + Employees)						
	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ. Innov.	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ. Innov.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	dy/dx	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**
VARIABLES /ESTIMATOR	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**
Firm Characteristics														
Internal Financial Resources	0.133	-0.231	0.037	-0.082	-0.062**	0.013	-0.015*	0.230***	0.109	0.226***	0.184***	-0.004	-0.244	-0.042
	(0.086)	(0.211)	(0.074)	(0.110)	(0.030)	(0.031)	(0.009)	(0.044)	(0.071)	(0.069)	(0.056)	(0.056)	(0.410)	(0.034)
Size (Ln Employees)	0.119*	0.110***	0.045***	-0.038	-0.011	-0.003	0.097***	0.026***	0.060***	0.079***	0.016	0.004	0.029	0.052**
	(0.066)	(0.036)	(0.013)	(0.027)	(0.015)	(0.014)	(0.014)	(0.007)	(0.013)	(0.023)	(0.021)	(0.008)	(0.029)	(0.021)
Employees (R&D)	0.007***	0.011***	0.001	0.004***	0.002***	0.004***	-0.000	0.007***	0.011***	0.002**	0.002***	0.003***	0.006***	0.001***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Age	0.001	-0.000	-0.003*	0.001	0.002*	0.001***	0.000	-0.002***	-0.002***	-0.003***	-0.002***	-0.004***	-0.002***	-0.003***
	(0.001)	(0.000)	(0.002)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Irish Owned	0.033*	-0.000	-0.056**	-0.002	-0.032**	0.004	-0.038	0.082***	-0.006	0.072***	0.083	0.008	0.022	-0.008
	(0.020)	(0.059)	(0.023)	(0.020)	(0.016)	(0.027)	(0.045)	(0.016)	(0.024)	(0.017)	(0.071)	(0.026)	(0.039)	(0.026)
Export	0.014	0.082***	0.074***	0.208***	0.048***	0.124***	0.093***	0.074*	0.058*	0.105**	0.131***	0.033	0.082**	0.071**
	(0.047)	(0.026)	(0.018)	(0.035)	(0.013)	(0.021)	(0.023)	(0.039)	(0.033)	(0.047)	(0.029)	(0.034)	(0.036)	(0.034)
Enterprise Group	-0.017	-0.026	-0.038	0.034	-0.020	0.006	0.028	0.006	0.079***	-0.039***	0.033***	-0.027	-0.019	-0.025
	(0.012)	(0.017)	(0.030)	(0.021)	(0.038)	(0.021)	(0.025)	(0.017)	(0.024)	(0.012)	(0.011)	(0.019)	(0.019)	(0.019)
Support/Finance														
Fund EU	-0.022	-0.061*	-0.036	0.072	0.025	0.058	0.142**	0.007	-0.198***	-0.059	-0.084	0.085	0.103	0.003
	(0.041)	(0.035)	(0.036)	(0.057)	(0.035)	(0.046)	(0.069)	(0.053)	(0.073)	(0.068)	(0.061)	(0.057)	(0.076)	(0.056)
Fund National	0.073**	0.074***	0.197***	0.216***	0.084*	0.206***	0.227***	0.159***	0.162***	0.149***	0.188***	0.064***	0.143***	0.176***
	(0.032)	(0.022)	(0.007)	(0.071)	(0.046)	(0.018)	(0.034)	(0.027)	(0.032)	(0.039)	(0.016)	(0.017)	(0.019)	(0.020)
Other Funding Sources (IRL)	0.120***	0.106***	0.053	0.054	0.032	0.059	0.012	-0.040	0.039	-0.052*	0.038	-0.012*	0.054***	0.011
	(0.032)	(0.033)	(0.036)	(0.074)	(0.032)	(0.072)	(0.041)	(0.058)	(0.063)	(0.023)	(0.037)	(0.036)	(0.010)	(0.046)
Other Funding Sources (Outside IRL).	-0.450***	-0.271**	-0.118**	-0.111***	-0.000	-0.052***	-0.119	-0.332***	-0.421***	-0.24**	-0.173***	-0.012	-0.142***	-0.063**
	(0.022)	(0.103)	(0.046)	(0.046)	(0.074)	(0.058)	(0.083)	(0.070)	(0.081)	(0.053)	(0.046)	(0.037)	(0.041)	(0.030)
Cooperation														
Cooperation Clients	0.011	0.095**	0.185***	0.106	0.181***	0.085**	0.088**	-0.087***	0.137***	0.165***	0.200***	0.051*	0.061	0.135***
	(0.025)	(0.037)	(0.029)	(0.095)	(0.036)	(0.040)	(0.039)	(0.031)	(0.048)	(0.034)	(0.030)	(0.031)	(0.054)	(0.028)
Cooperation Suppliers	-0.066	-0.038**	0.201***	0.125***	0.011	0.093***	0.186***	0.065***	-0.055	0.234***	0.082*	0.029	0.070	0.203***
	(0.044)	(0.018)	(0.066)	(0.044)	(0.058)	(0.034)	(0.022)	(0.021)	(0.039)	(0.016)	(0.044)	(0.051)	(0.043)	(0.023)
Cooperation Other Firms	0.107**	-0.020	0.158	0.171**	0.064***	0.042*	0.242***	0.027	0.048	0.126	0.060	0.161***	0.051	0.107
	(0.052)	(0.040)	(0.101)	(0.076)	(0.014)	(0.021)	(0.060)	(0.038)	(0.066)	(0.096)	(0.049)	(0.036)	(0.095)	(0.079)
Cooperation Public	0.179***	0.086**	0.156***	0.207***	0.075**	0.105*	0.116***	0.162***	0.076**	0.113***	0.120***	0.057***	0.103***	0.161***
	(0.032)	(0.037)	(0.044)	(0.048)	(0.034)	(0.057)	(0.034)	(0.016)	(0.034)	(0.021)	(0.020)	(0.019)	(0.012)	(0.019)
Industry Control / Survey wave control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	0.290**	0.359***	0.420***	0.429***	0.213**	0.331***	0.479***	0.443**	0.523**	0.588***	0.532***	0.250	0.454***	0.645
Constant	(0.003)	(0.001)	(0.007)	(0.00))	(0.001)	(0.003))	(0.006)	(0.001)	(0.0.02)	(0.006)	(0.004)	(0.004)	(0.004)	(0.002)
Observations	1,169	1,139	1,169	1,169	1,158	1,169	1,169	1,362	1,362	1,362	1,362	1,347	1,362	1,362
McFadden Pseudo R^2	0.371	0.450	0.433	0.388	0.399	0.481	0.401	0.439	0.422	0.395	0.355	0.473	0.419	0.401
Wald Test Exogeneity (null = yes)	5.23**	21.3***	0.62	018	0.16	0.0	0.23	3.73**	0.02	0.93	2.32	12.45***	12.46***	1.53

Results presented in average marginal effect: Robust standard errors clustered at the industry level in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included. *** p<0.01, ** p<0.05, * p<0.1.

Regarding innovation activities, González-Bravo *et al.* (2021) suggest that the availability of resources in absolute terms may not be as important for innovation as firms' ability to generate them efficiently. Thus, small market presence and uncertain international markets, may deter *small-sized* firms from engaging in more innovation, even if they have sufficient financial resources (Berends *et al.* 2014; De Massis *et al.* 2018). Added to this, managers in *small-sized* firms may engage in some forms of innovation, such as new services, as a means of generating new revenue streams when their levels of financial resources are low (Greve 2003; Mennens *et al.* 2018). Equally, they may focus on implementing organisational changes as a means of becoming more efficient at innovating (Volberda *et al.* 2013). In this sense, financial scarcity may trigger new innovative efforts by *small-sized* firms (Keupp and Gassmann 2013). Our results, therefore, concur with authors such as Bicen and Johnson (2014) and Berends *et al.* (2014), when proposing that the conventional wisdom regarding the importance of financial resources for innovation may not apply to *small-sized* firms.

The control variables show that firm size, the number of R&D employees, and exporting all drive *small* and *larger-sized* firms to engage in all R&I activities considered. Furthermore, both firm-size groups benefit from cooperation in a similar manner. Cooperation with public knowledge providers (i.e. research centres and universities) drives both firm-size groups to engage in scientific research and development. Cooperating with clients also drives firms to engage in development, and most cooperation variables are positive and significant for all innovation activities. *Larger-sized* firms that are domestically owned, are more likely to engage in scientific research, and product innovation, than their foreign-owned firm counterparts. Our findings concur with those of Roper and Arvanitis (2012) who found that Irish-owned firms may be more likely to source knowledge internally, by investing in R&D, in comparison to foreign-owned firms. Our findings, however, differ from those of McGuirk *et al.* (2015), who found Irish-owned firms to be less likely to innovate when compared to foreign-owned firms. We attribute such difference to our sample, which comprises firms that are believed to perform R&D activities, as identified by the Irish CSO, while McGuirk *et al.* (2015) analysed data comprising of a sample of all firms in Ireland from a workplace survey (i.e. the Irish National Centre for Partnership and Performance [NCPP] 2009 Workplace Survey).

Finally, public financial support for R&I increases the probability of engaging in all activities considered for both firm-size groups. Moreover, the impact of external sources of finance depends on whether such sources are from Ireland or from abroad, and on the size of the firms. That is, obtaining financial resources from domestic sources increases *small-sized* firms' probability of engaging in scientific research and development activities. External sources of finance from domestic sources increases larger-sized firms' probability of engaging in radical innovation. However, obtaining financial resources from abroad negatively impact firms' engagement in all R&I activities considered, by both firm-size group. As noted in Section 3.4.1, firms may use external financial resources for specific R&I-related activities, such as branding and reputation building, but may mainly finance their R&I activities internally.

3.4.3 Robustness checks

To ensure that our results are robust to reasonable alternative specifications of the model, we replicated the analysis using different specifications of Equation (3-1), and by estimating the full equation with different estimators. In all cases, the direction and significance of the impacts identified by our main analysis were supported by our robustness checks.

To ensure that our results are not affected by multicollinearity, we re-estimated Equation (3-1), but excluded some of the variables from our original model in the analysis. That is, Equation (3-1) was firstly re-estimated (for the whole sample), but only included the variables measuring firms' characteristics. We repeated this approach by estimating Equation (3-1), but only included the variables measuring firms' characteristics, and external sources of funding (i.e. excluding the cooperation variables). As presented in Appendix 3-B, excluding variables from our model did not affect our results.

Secondly, we re-estimated Equation (3-1) with a random effect estimator, to account for unobserved heterogeneity, by using the panel dimension of the data. While the random-effect approach does not fully control for unobserved heterogeneity (as it allows the error term to be correlated with unobserved firms' characteristics), it has some desirable advantages. This is in comparison to a fixed-effect estimator, which would fully control for unobserved heterogeneity. For example, a key advantage of the approach used here is that it permits obtaining the coefficients for key time-invariant control variables (e.g. foreign, export, enterprise group), which would not be possible with a fixed-effect estimator (Baltagi 2005;

Wooldridge 2010). Obtaining the coefficient for these key time-invariant control variables is important to assess the robustness of our main model, when compared to alternative specifications. Appendix 3-C shows that the results obtained with a random effect probit model for *small* and *larger-sized* firms support the direction and significance of the results obtained by the instrumental variable probit estimator. Some small differences in the coefficients are observed, which is as expected, given the different modelling techniques.

Thirdly, as firms may engage in a portfolio of R&I activities at a given time (Klingebiel and Rammer 2014), we re-estimated Equation (3-1), but now considered the correlation between different R&I activities with a multivariate probit model (Galia and Legros 2004). Following Roper *et al.* (2008), the efficiency gains derived from a multivariate probit model are limited when the vector of explanatory variables are strongly correlated across the different outcomes. This was expected here, given that these variables capture firms' internal and external determinants of the different types of science and innovation activities considered in our study. Appendix 3-D thus confirms that the results of the multivariate probit model are very similar to our main findings as presented in Table 3.4.

Finally, we re-estimated Equation (3-1) for the whole sample, but now included an interaction term between the continuous variable *Internal Financial Resources* and a dummy variable that equals 1 if the firm is *small-sized* (10 to 49 employees), or zero otherwise. In this specification, the variable *Internal Financial Resources* measures the effect of internal financial resources on *larger-sized* firms' probability of engaging in the research/innovation activity under consideration.

The interaction variable does the same for *small-sized* firms. Following Norton *et al.* (2004), we present average marginal effects for the interaction term computed as the full derivative, instead of the partial derivative or partial effect.[32] Appendix 3-E shows that the results of this specification largely support our main results, with the only difference being that the coefficient for *Internal Financial Resources* is now positive and significant for development in the context of *larger-sized* firms. This may be due to the increased precision of the standard errors, given the larger sample size. Our robustness checks indicate that our main results obtained with the instrumental variable probit model are robust across different model specifications and econometric approaches.

3.5 Conclusions and implications for policy

Our paper compares the impact of levels of internal financial resources between *small* (10 to 49 employees) and *larger-sized* (50+ employees) firms' engagement in scientific research, development, and five types of innovation activities. To the best of our knowledge, this is the first study to provide such a detailed analysis regarding the impact of firms' internal financial resources on their research and innovation (R&I) activities. Our study, therefore, extends previous studies that mainly focused on R&D, process innovation and product innovation (De Falco and Renzi 2015; González-Bravo *et al.* 2021). Our findings shed new

[32] Specifically, the average marginal effect for the interaction term was obtained with the "*inteff*" command in Stata, as developed by Norton *et al.* (2004)).

light on a topic that remains highly contested in the prevailing literature (Weiss *et al.* 2017), by providing a more nuanced understanding of the "significance of the innovation under study" (Percival and Cozzarin 2008, p. 371). These insights are crucial for the formulation of a "much-needed unifying theory of the role of financial resources in innovation management at large" (Hoegl *et al*. 2008, p. 1389).

From a theoretical perspective, our research provides further insights into three key issues that remain largely unresolved in the prevailing literature. First, it highlights the importance of considering firms' levels of internal financial resources for understanding their increasing focus on development, while their investments in scientific research decline (Arora *et al.* 2018). As scientific research has long lead times and unexpected outcomes, firms may undervalue this research activity (Aghion *et al.* 2009). Thus, they may only engage in scientific research when they have high levels of financial resources (Jissink *et al.* 2019). In contrast, development is closer to the market, and firms may engage in this activity regardless of their financial position, as they may foresee concrete returns to their investments (Czarnitzki *et al.* 2011).

Second, our paper demonstrates that it is important to extend the focus beyond process and product innovation when analysing the role of financial resources for firm-level innovation. In line with behavioural and resource-based theories, we find that financial resources drive firms to engage more in process and product innovation, but only in the context of *larger-sized* firms. However, firms may not need high levels of financial resources for other types of innovation, such as service, organisational and radical innovation (regarding goods and services). Here, firms may favour 'bricolage' (Baker and Nelson 2005) or 'bounded creativity' (Hoegl *et al.* 2008) approaches, where the recombination of existing resources in new ways can mitigate the need for financial resources. Finally, our research unravels important differences regarding the influence of financial resources on the R&I activities of *small* and *larger-sized* firms. In particular, our results suggest that *small-sized* firms may view R&I as a counter-measure to when their performance in the market falls, as opposed to an opportunity to grow, which is consistent with arguments of financial scarcity leading to more R&I (Hoegl *et al.* 2008; Keupp and Gassmann 2013; Witell *et al.* 2017).

Our analysis uses data for firms in Ireland for the period following the 2008 Global Financial Crisis, which has similarities with the current Covid-19 crisis (CSO 2020). Therefore, the insights arising from this paper are highly topical as they can elucidate the potential impact of the Covid-19 pandemic on firms' research and innovative activities through their effects on firms' financial resources. The insights provided here can serve as a platform for discussions and analyses regarding the design and implementation of more targeted science and innovation policy interventions to help firms to innovate their way out of the current Covid-19 crisis (Roper 2020; Morgan *et al.* 2020). In particular, the prevailing literature widely regards public financial support as a critical innovation policy intervention to promote R&I by *small-sized* firms (Hall *et al.* 2016). Our results suggest that such support may be complemented with other types of government intervention (i.e. beyond financial instruments) that specifically target, for example, the development of innovative human capital, and other means to inspire and enable *small-sized* firms to engage more in these activities (McGuirk *et al.* 2015; Lenihan *et al*. 2019). Policies to accelerate new models of collaboration amongst *small-sized* firms, and with public knowledge providers, can further support these firms to innovate (Hewitt-Dundas and Roper 2018). Though beyond the scope of the current paper, these are certainly areas worthy of further exploration and investigation.

Regarding *larger-sized* firms, the positive relationship between their level of internal financial resources and their engagement in scientific research may signal policy entry points for governments who want to encourage firms to engage more in this activity. Public financial support may further stimulate investment in scientific research activities (Czarnitzki and Hottenrott 2011). This support, however, should target scientific research projects with high social rates of return to avoid substituting private investments (Mazzucato 2016), and thus avoiding issues of deadweight spending effects (Lenihan 2004).

As our results arise from a sample of firms that are believed to engage in R&D, as identified by the Irish Central Statistics Office (CSO), caution should be exercised when extrapolating the results of our study. This is a limitation of the current study, as such firms may have higher levels of internal capabilities for R&I *vis-à-vis* less innovative firms. Thus, it would be interesting if future research were to apply a similar analysis in other settings, and with more general and representative samples, to elucidate the extent to which the findings of the current study can be generalised to less innovative firms. Future studies may also usefully employ more detailed data on firms' access and use of external finance, in addition to firms' levels of leverage. Our findings, however, highlight that a more encompassing theory of the impact of firms' internal financial resources on firms' engagement in research and innovation might beneficially consider heterogeneities across different research and innovation activities, and firms of different sizes. Particularly, it may reconsider the extent to which financial resources trigger research and innovation in *small-sized* firms.

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Chapter 4: Can public financial support help firms overcome non-financial constraints to research and innovation?

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Authors' Contributions:

I, Mauricio Perez-Alaniz, am the first author of the academic paper. The remaining authors are listed in order of contribution. I was responsible for: (1) the conceptual development of the paper; (2) choosing and refining the methodology; (3) preparing the empirical setting; (4) carrying out the empirical analysis; (5) writing the original draft paper; (6) and incorporating the co-authors' suggestions and comments into the final paper. Helena Lenihan provided expert advice and guidance on all of the above listed activities (1-6), as well as reviewing and editing the paper. She also enabled the research to access the necessary data and resources (i.e. in her role as Principal Investigator [PI] of the Science Foundation Ireland funded project funding this research). Justin Doran provided expert advice on all of the above listed activities (1-6), as well as reviewing and editing the paper. Stephen Roper provided expert advice on the initial conceptualisation of the paper, the methodology, and in reviewing the paper.

Abstract:

Perceived financial, knowledge and market constraints may restrict firm-level research and innovation (R&I) and future growth. Matching administrative and innovation-survey data, our study demonstrates that public financial support for R&I can help firms to overcome perceived financial, knowledge and market constraints at the time of support. By prompting engagement in more resource demanding, and distant, R&I activities, such support also results in firms perceiving further constraints in future periods. The insights of the study offer important implications for theory and policy.

4.1 Introduction

Firms typically face critical financial and non-financial constraints hindering their Research and Innovation (R&I) activities (Blanchard *et al.* 2013; Pellegrino and Savona 2017; Lahr and Mina 2021). Public financial support for R&I is an established policy intervention to address firms' financial constraints, and encourage firm-level R&I (Busom *et al.* 2014; Zúñiga-Vicente *et al.* 2014; Hottenrott *et al.* 2018). Blanchard *et al.* (2013) and Pellegrino and Savona (2017), however, highlight that the impact of such support can be hampered if firms also face non-financial constraints related to a lack of knowledge and/or demand for R&I. Supporting firms to overcome non-financial constraints is vital for encouraging more R&I by firms, but an understanding of the potential for policy interventions to address such constraints remains limited (D'Este *et al.* 2014). As Szambelan *et al.* (2020, p. 425) note, "while the types of innovation barrier[s] have already been identified, we know relatively little about how firms can overcome these barriers". Furthermore, as Pellegrino and Savona (2017, p. 511) have highlighted, a substantial number of studies have focused on the financial constraints perceived by firms, but that "it is more important for policy to extend analysis to non-financial obstacles". This is vital because addressing firms' non-financial constraints to R&I may require "selective, deliberate and systematic intervention to address systemic failure" (Antonioli *et al.* 2017, p. 861).

Our paper contributes to the above debate in two key ways. Our first contribution is to analyse the impact of public financial support for R&I on firms' ability to overcome their perceived financial and non-financial constraints.

Perceived constraints to R&I refer to firms' own direct assessments of the obstacles hampering their R&I activities (Savignac 2008; D'Este *et al.* 2012). Conceptually, as proposed by D'Este *et al.* (2012), such constraints may not necessarily mean that firms do not have resources and capabilities for R&I. Innovation may require firms to match their resources and expertise to specific R&I activities, and firms may perceive constraints once firms engage in these activities (Galia and Legros 2004). Therefore, perceive constraints capture the specific challenges that firms may encounter when engaging in R&I activities, that delay and/or hinder their R&I activities. Moreover, focusing on perceived constraints avoids issues of interpretation when establishing whether firms face constraints to R&I, which is typically the case in other approaches used in the literature, such as using cash-flows analysis for identifying financial constraints (Savignac 2008; Hall *et al.* 2016). Using measures of firms' perceived constraints also allows us to extend our analysis beyond the traditional focus on analysing the impact of public support for R&I on firms' financial constraints (see, for example, Silva and Carreira 2012; Mateut 2018).

In light of the above, our analysis considers two key perceived non-financial constraints (i.e. knowledge and market constraints), and how public financial support for R&I can encourage firms to develop both innovative capabilities and absorptive capacity (Clarysse *et al.* 2009; Radas *et al.* 2015; Hullova *et al.* 2019). More innovation can also improve firms' position in the market (Hewitt-Dundas and Roper 2010; Hottenrott and Lopes-Bento 2014). Public financial support can thus drive firms to overcome their perceived knowledge and market constraints (i.e.

non-financial constraints). To the best of our knowledge, our paper is the first to critically examine this issue.[33]

Our second contribution is to evaluate how, by enabling firms to overcome their perceived financial and non-financial constraints, public financial support for R&I affects firms' perceptions of constraints in subsequent periods. Promoting firm-level attitudes and capabilities for R&I is of increasing importance from both academic and policymaking perspectives (Chapman and Hewitt-Dundas 2018; Lenihan *et al.* 2019). Understanding the factors that can affect firms' perceived constraints to R&I is, therefore, crucial (Blanchard *et al.* 2013; Antonioli *et al.* 2017; Pellegrino and Savona 2017). As noted earlier, the literature on the additionality of public support for R&I denotes such support as a key public policy intervention to reduce firms' financial constraints. However, previous studies on the drivers of perceived constraints have demonstrated the existence of a positive relationship between public financial support for R&I and firms' likelihood of perceiving financial and non-financial constraints (see, for example, Silva and Carreira 2012; D'Este *et al.* 2014; Pellegrino 2018). According to D'Este *et al.* (2014) and Pellegrino (2018), this is likely because public financial support for R&I tends to target more innovative firms, which are typically more likely to perceive constraints. We extend these studies, by critically analysing the likelihood of firms that receive public financial support for R&I in one period, to perceive financial

[33] Falk (2007) is a notable exception, although his study only descriptively analyses how firms' perceived constraints affect the behavioural additionality of the effects of public financial support.

and non-financial constraints in subsequent periods. This is an issue which, to our knowledge, remains largely unexplored in the literature.

Our analysis uses specific questions regarding firms' perceived constraints to R&I from the 2010 and 2016 waves of the Innovation in Irish Enterprises Survey (IIE, formerly known as the Community Innovation Survey [CIS]).[34] We merged this survey data with novel administrative data on public financial support instruments for R&I available to firms in Ireland during the intervening period from 2011 to 2015. Our data captures the full spectrum of public financial support for R&I from Ireland's three main funding agencies (Enterprise Ireland, IDA Ireland, and Science Foundation Ireland). The data also capture R&D tax credits, from the Irish Revenue Commissioners. Our novel data permit extending our analysis to three key public financial support instruments for R&I used by many countries: (i) R&D tax credits; (ii) R&D subsidies; and, (iii) R&D subsidies that require collaboration between firms and local knowledge providers, such as Universities and Research Centres (Busom *et al.* 2014; Zúñiga-Vicente *et al.* 2014). Our sample comprises 1,296 firms, with a total of 233 firms receiving public financial support for R&I in the period from 2011 to 2015, from which 186 firms perceived constraints in 2010.

Our data structure allows us to control for selection bias affecting firms' likelihood of obtaining public financial support (Nilsen *et al.* 2020). It also permits

[34] The 2012 and 2014 waves of the Innovation in Irish Enterprises Survey did not include questions on firms' constraints to R&I so are not included in this analysis (See Section 3 and Appendix A).

controlling for the endogenous nature of firms' perceived constraints (Lahr and Mina 2021). This is because our data observe firms' R&I activities and their constraints before and after the treatment takes place. As a result, we can control for firms' characteristics influencing their likelihood of: (a) obtaining public financial support, and (b) perceiving constraints. This is important, as the literature indicates that firms' perceptions of constraints are endogenous to their R&I activities (Galia and Legros 2004; D'Este *et al.* 20012; Lahr and Mina 2021).

Previous studies in this vein have mainly used cross-section data, and controlled for endogeneity by jointly estimating firms' innovative efforts and their probability to perceive constraints at one point in time (Blanchard *et al.* 2013; Antonioli *et al.* 2017; Pellegrino and Savona 2017; Radicic 2021; Zahler *et al.* 2022). We use a more direct non-parametric matching approach (i.e. Propensity Score Matching), which matches firms depending on to their R&I activities, and their perceived constraints, in an initial year (i.e. 2010). We then follow the same groups of firms over an intervention period (i.e. 2011 to 2015), where some firms receive public financial support (i.e. treated firms), and others do not receive this support. Finally, we compare the innovative performance, and the perception of constraints, between treated firms with statistically similar firms that did not receive this support in a subsequent outcome year (i.e. 2016). As our focus is on non-financial constraints, the lag between the provision of public financial support, and our outcome variables, enables time for the non-financial effects of public financial support to take place (Hewitt-Dundas and Roper 2010; Lee 2011; Cunningham *et al.* 2016). Our approach, thus permits a more detailed understanding of how public financial support impacts the R&I activities, and perception of constraints, of financially and non-financially constrained firms.

Ireland represents an ideal locale for the current research. Firms in Ireland are primarily small and medium-sized enterprises (SMEs), with 99.8 percent of all firms being SMEs (CSO 2020).[35] Previous research has shown that perceived financial and non-financial constraints represent key obstacles to R&I for SMEs in Ireland (Hewitt-Dundas 2006; Roper and Arvanitis 2012). The Irish Government identifies that supporting firms, especially SMEs, to overcome challenges related to resources and capabilities for R&I is a key innovation policy priority (Skillnet Ireland 2020; DBEI 2020). The latter is also the case beyond Ireland as evidenced in innovation policy documents in other countries including the UK and Germany (HM Treasury 2017; Federal Ministry for Economic Affairs and Energy of Germany 2019). Our study can thus provide insights into potential avenues for using public financial support for R&I to help firms overcome their financial *and* non-financial constraints, which are relevant to Ireland and other countries.

Previous studies, such as Blanchard *et al.* (2013), Antonioli *et al.* (2017) and Pellegrino (2018), have emphasised the need for a mix of financial *and* non-financial innovation policy interventions to simultaneously address firms' financial and non-financial constraints to R&I. Our empirical analysis demonstrates that

[35] The European Union recommendation 2003/361 defines small-sized firms as firms with less than 50 employees, medium-sized firms as firms with at least 50 and fewer than 249 employees, and large firms, as firms with at least 250 employees. The recommendation also classifies firms according to their turnover or balance sheet (see http://data.europa.eu/eli/reco/2003/361/oj), but the number of employees is the most commonly used classification (Eurostat 2019). Data for firms with fewer than 10 employees were not available to this study.

public financial support for R&I can drive financially, and non-financially constrained firms, to increase their R&I efforts, and generate more sales from innovation. We interpret these findings as firms overcoming their financial and non-financial constraints, as a result of such policy support. Moreover, we demonstrate that firms that receive public financial support for R&I in one period, are more likely to perceive financial and non-financial constraints in subsequent periods. We attribute these findings to firms pursuing more radical (and riskier) R&I projects, defined as innovations that are new to the market (Beck *et al.* 2016; Hewitt-Dundas *et al.* 2019), as a result of such support. Our results suggest that firms' perceived constraints to R&I may not be permanently removed or lowered. However, given that public financial support may potentially induce long-term improvements in firms' capabilities for R&I, firms are better equipped to overcome such constraints. The insights of our paper, therefore, make a distinct contribution to current literature on this topic, and may be used to generate debate and consideration amongst academics regarding the use of public financial support for R&I to address firms' financial and non-financial constraints. From a policy perspective, the insights of our paper are timely, as designing and implementing innovation policy interventions to simultaneously boost financial investments in R&D, while stimulating firms' knowledge and market capabilities, may represent a challenge (and opportunity) for policymakers (Wanzenböck *et al.* 2013).

The remainder of this paper is organised as follows. Section 4-2 reviews the relevant literature and formulates hypotheses. Section 4-3 describes the data and the empirical approach. Section 4-4 presents the empirical findings. Section 4-5 discusses the findings in the context of the literature and concludes with implications for innovation policy interventions.

4.2 Conceptual framework and hypotheses

Our paper analyses the impact of public financial support for research and innovation (R&I) on firms' ability to overcome perceived financial and non-financial constraints. Furthermore, we focus on how, by helping firms to overcome their constraints, the support increases firms' likelihood to perceive such constraints in subsequent periods. Financial constraints relate to low levels of internal financial resources, the high cost of these activities, and limited access to external finance (Savignac 2008; Hall *et al.* 2016). The most critical perceived non-financial constraints are knowledge and market constraints (Galia and Legros 2004; D'Este *et al.* 2012; Pellegrino 2018).[36] Knowledge constraints pertain to low and/or inadequate levels of human capital resources (D'Este *et al.* 2014), and a lack of partners for R&I (Antonioli *et al.* 2017). Market constraints primarily relate to uncertain demand for R&I (Blanchard *et al.* 2013; Szambelan *et al.* 2020).

Most of the evidence regarding the impact of firms' perceived constraints on R&I pertains to financial constraints (see, for example, amongst many others, Savignac 2008; Silva and Carreira 2012; Schiavo 2014; Máñez *et al.* 2014; Carboni 2017; Lahr and Mina 2021). Only a small number of studies consider non-financial

[36] D'Este *et al.* (2012) also outline the importance of regulation constraints. However, as explained by Mohnen *et al.* (2008), addressing these constraints may entail shaping the regulatory environment, which extends beyond the scope of the current study.

constraints (see Blanchard *et al.* 2013; Antonioli *et al.* 2017; Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020). The limited available evidence indicates that perceived financial and non-financial constraints reduce firms' likelihood to engage in R&I activities, and increase firms' likelihood to delay and/or discontinue existing ones (Galia and Legros 2004; Blanchard *et al.* 2013; Antonioli *et al.* 2017). Such constraints can be particularly important for radical forms of innovation, as they impact the nature and scale of these types of R&I activities (Woschke *et al.* 2017; Caggese 2019; Radicic 2021). Financial and non-financial constraints, therefore, reduce firms' likelihood to innovate (Savignac 2008; Pellegrino and Savona 2017; Caggese 2019; Radicic 2021).[37] However, the process is more complex than this, as more innovative firms, as measured by the number of types of innovations introduced to the market, are typically more likely to perceive financial and non-financial constraints (D'Este *et al.* 2012; Hottenrott and Peters 2012). Therefore, perceived constraints to R&I may be endogenously determined (Lahr and Mina 2021).

Public financial support for R&I focuses on addressing market failures, such as asymmetric information and appropriability issues, that hinder firms' ability to finance and benefit from R&I activities (Busom *et al.* 2014; Haapanen *et al.* 2014; Becker 2015). However, academics and policymakers alike increasingly recognise that, by encouraging firm-level R&I, such support can prompt organisational learning, and behavioural changes in the way that firms carry out R&I activities

[37] Some studies, such as Keupp and Gassmann (2013) propose that financial and non-financial constraints may encourage firms to engage in more radical forms of innovation.

(Clarysse *et al.* 2009; Wanzenböck *et al.* 2013; Chapman and Hewitt-Dundas 2018). To the best of our knowledge, the extent to which public financial support for R&I can be used to address firms' perceived non-financial constraints remains unexplored in the literature. The remainder of this section develops a conceptual framework outlining the mechanisms through which public financial support for R&I can impact firms' financial and non-financial constraints to these activities. By so doing, we develop several hypotheses to guide the empirical analysis that follows.

4.2.1 Public financial support for overcoming perceived constraints to research and innovation

This section discusses how public financial support for Research and Innovation (R&I) can result in firms overcoming their financial and non-financial constraints to these activities.

4.2.1.1 Public financial support for overcoming financial constraints

Public financial support for R&I is a key innovation policy instrument to address firms' financial constraints (Colombo *et al.* 2013; Carboni 2017). This may take place through three main channels. The first channel is by providing firms with liquidity for R&I (Becker 2015). By reducing the cost of R&I, firms can engage in projects previously deemed as 'too expensive' or 'too risky' (Hottenrott and Lopes-Bento 2014; Hünermund and Czarnitzki 2019).

The second channel is by alleviating information asymmetries in capital markets hindering firms' abilities to access external finance for R&I (Hall *et al.*

2016). Information asymmetries occur when firms do not disclose information on innovative projects (to protect proprietary knowledge) and lenders cannot assess the viability and value of these projects (Hall *et al.* 2016). As a result, lenders may refrain from lending for R&I activities and/or require higher premiums (Hall *et al.* 2016; Hottenrott *et al.* 2018). Public financial support for R&I can signal promising R&I projects and reduce information asymmetries (Kleer 2010), and improve firms' access to external finance for R&I projects (Carboni 2017; Hottenrott *et al.* 2018).

Finally, the third channel consists of firms using some of the public financial support for R&I to acquire physical capital, which can serve as collateral when seeking external finance (Colombo *et al.* 2013). Therefore, such support can enable firms to overcome their perceived financial constraints, and subsequently invest more in R&I. This suggests our first hypothesis:

H1. Public financial support leads firms that perceive financial constraints to invest more in R&I.

4.2.1.2 Public financial support for overcoming knowledge constraints

We now discuss how public financial support for R&I can drive firms to overcome their perceived knowledge constraints. Knowledge constraints relate to firms' capabilities, which as Dosi *et al.* (2021) note, are the collective properties of firms' routines, are slowly accumulated, and exhibit a high degree of persistence, in terms of their strengths and weaknesses. Firms develop innovative capabilities by engaging in R&I, and by sourcing external knowledge (Roper *et al.* 2008; Uhlaner *et al.* 2013). According to Clarysse *et al.* (2009), public financial support for R&I can contribute to firms' R&I capabilities through at least three key avenues. Two of these avenues pertain to experiential and cognitive learning that relate to (i) learning-by-doing (Teece 2007), and (ii) absorptive capacity, with the latter defined as a firm's ability to incorporate and benefit from external knowledge (Cohen and Levinthals 1990).

Public financial support for R&I contributes to the above learning effects by increasing firms' R&I efforts, which generate new knowledge, and help firms to identify combinations of new and old knowledge for innovation (Radas *et al.* 2015). By highlighting R&I activities that are deemed important and/or desirable, such support also serves as a roadmap to more productive ways of resources allocation (Neicu *et al.* 2016; Huergo and Moreno 2017). For example, it can encourage firms to engage in riskier R&I activities that extend their knowledge base (Beck *et al.* 2016; Edler and Fagerberg 2017). Specifically, firms may focus more on radical innovation, defined as goods and services that are new to the market (Hewitt-Dundas *et al.* 2019), and on improving the management of R&I processes, as a result of public financial support for R&I (Percival and Cozzarin 2008; Hullova *et al.* 2019).

The third learning effect is inter-organisational learning, which arises from spillovers when collaborating with external partners (Clarysse *et al.* 2009). Several studies have demonstrated that public financial support for R&I may encourage collaborations between firms and universities and/or research centres, which can help firms to benefit more from their R&I activities (Scandura 2016; Vanino *et al.* 2020). This suggests that public financial support for R&I can result in firms increasing their capabilities for R&I, and thereby, overcoming their perceived knowledge constraints. We, therefore, hypothesise that:

H2. Public financial support for R&I leads firms that perceive knowledge constraints to increase their capabilities for R&I.

4.2.1.3 Public financial support for overcoming market constraints

Finally, we focus on public financial support for R&I causing firms to overcome their market constraints. As discussed earlier, such support lowers the risk-reward ratio of R&I activities, and can increase firms' tolerance to riskier R&I projects (Becker 2015). In turn, it can enhance firms' innovation orientation (Chapman and Hewitt-Dundas 2018), and motivate firms to identify new opportunities for R&I (Colclough *et al.* 2019; Szambelan *et al.* 2020). Moreover, as public financial support for R&I enhances firms' abilities to develop innovative processes, products, and services, firms can enhance their competitive advantages, at least temporarily (Roper *et al.* 2008). As a result, firms may be able to enter new markets and generate 'new' demand (Lee 2011). Some studies demonstrates that innovation, especially radical innovation, can trigger the restructuring of global markets in several industries, such as, for example, in steel (Lee and Ki 2015), mobile phones (Giachetti and Marchi 2013), and computing (Dedick and Kraemer 2015). Public financial support for R&I can thus enable firms to innovate more, and benefit more from innovation (Hewitt-Dundas and Roper 2010; Beck *et al.* 2016). This suggests our next hypothesis:

H3. Public financial support for R&I leads firms that perceived market constraints to benefit more from their R&I activities, in terms of their turnover generated from innovation.

4.2.2 Public financial support and firms' perception of constraints

We now focus on the impact of public financial support for Research and Innovation (R&I) impacts firms' perception of financial and non-financial constraints. Some previous studies, such as D'Este *et al.* (2014) and Pellegrino (2018), have found that public financial support for R&I is positively related to firms' likelihood to perceive financial and non-financial constraints. In their view, this is likely because the support tends to typically target more innovative firms (i.e. which are more likely to perceive constraints). Here, we develop an alternative, and more detail explanation, of the mechanisms through which such a positive relationship may occur. We specifically posit that, by enabling firms to overcome their perceived financial and non-financial constraints in one period, the support can result in firms being more likely to perceive constraints in subsequent periods.

4.2.2.1 Public financial support and perceived financial constraints

Firms typically have multiple R&I ideas competing for limited financial resources (Klingebiel and Rammer 2014). As firms become more innovative, they may increase their demand for financial resources for R&I, and perceive more financial constraints (D'Este *et al.* 2012; Hottenrott and Peters 2012). Public financial support for R&I can accelerate this process in at least three ways. Firstly, by encouraging firms to channel financial resources in a particular direction (i.e.

firms may focus on the publicly funded project), leading to firms placing other R&I ideas on hold (Busom *et al.* 2014; Huergo and Moreno 2017). Secondly, by enhancing firms' R&I capabilities, resulting in firms generating more new ideas for R&I, as well as benefiting from external ones (Vanino *et al.* 2020). Finally, by encouraging firms to engage in more resource-intensive R&I projects, and with high levels of novelty (Hottenrott and Lopes-Bento 2014; Beck *et al.* 2016). We thus hypothesise that:

H4. Firms that received public financial support in one period, will be more likely to perceive financial constraints in subsequent periods.

4.2.2.2 Public financial support and perceived knowledge constraints

As proposed in Section 4.2.1.2, public financial support for R&I can enable firms to develop new resources and capabilities for R&I. As a result, firms will increase their R&I efforts, pursue more radical forms of innovation, and thus, become more likely to perceive knowledge constraints. This is because increasing R&I efforts will build on existing R&D teams and/or employees, as it may be difficult to swiftly incorporate new talent by hiring new R&D employees (Song *et al.* 2003; Tzabbar *et al.* 2013). Existing R&D employees will thus manage higher workloads across a higher number of R&I projects. Moreover, as firms begin to focus on more radical forms of R&I, they may absorb and build on external knowledge outside of their core expertise (Cassiman *et al.* 2018; Hewitt-Dundas *et al.* 2019). This may require more trial and error, and testing, both at the development stage and at other stages closer to the market, such as marketing

(Hullova *et al.* 2019). As Yang *et al.* (2014) note, radical innovation may necessitate firms to unlearn previous routines and develop new ones. This suggests:

H5. Firms that received public financial support in one period, will be more likely to perceive knowledge constraints in subsequent periods.

4.2.2.3 Public financial support and perceived market constraints

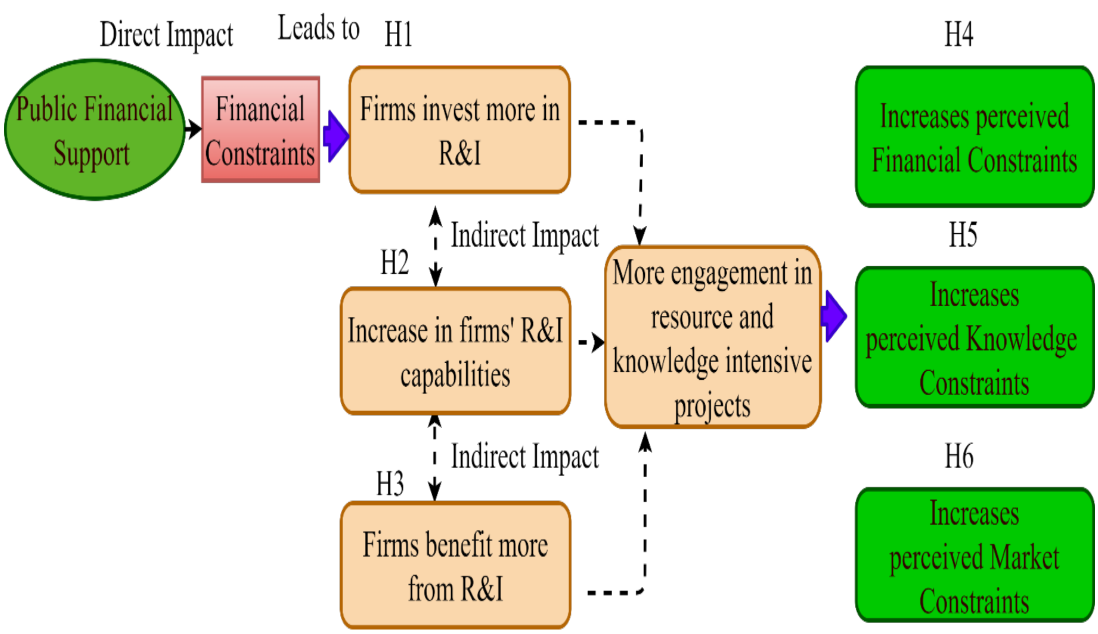
In a similar vein to knowledge constraints, by re-orienting firms' R&I activities to riskier and radical forms of innovation, public financial support for R&I may result in firms being more likely to perceive higher commercial risks associated with their innovations (Colombo *et al.* 2017). Furthermore, public financial support for R&I may prompt firms to re-evaluate the potential commercial value of other existing R&I ideas because, as noted in Section 4.2.1.2, it can signal specific areas that are deemed desirable and commercially viable (Neicu *et al.* 2016). Firms may thus avoid R&I projects falling outside of these desirable areas (Percival and Cozzarin 2008). Following Szambelan *et al.* (2020, p. 427), increased R&I efforts in one particular project (i.e. the funded project), may affect the "affordable loss" attached to other R&I projects. Here, affordable loss refers to firms refraining from investing more than they are willing to lose, and holding on to other potential projects until the commercial performance of their existing innovations becomes clear. This suggests our final hypothesis:

H6: Firms that received public financial support in one period, will be more likely to perceive market constraints in subsequent periods.

4.2.3 Conceptual Framework

Here, we summarise our conceptual framework based on the theories as proposed in Section 4.2.1 and Section 4.2.2. As Figure 4-1 illustrates, public financial support for R&I can result in firms overcoming their perceived financial constraints and investing more in R&I activities (H1). As firms invest more in R&I, because of such support, they will also begin to develop new innovative capabilities, and may overcome their knowledge constraints (H2). In turn, firms may introduce more, and better, innovations to the market, increasing their ability to benefit from R&I, and overcoming their market constraints (H3). Increased R&I efforts (specifically with regards to more radical R&I activities), in response to public financial support for R&I, however, may result in firms being more likely to perceive new financial and non-financial constraints (H4 to H6).

Figure 4-1: Impact of public financial support for R&I on firms' perceived financial and non-financial constraints



4.3 Data and empirical approach

In this paper, we focus on: (i) public financial support for R&I helping firms to overcome their perceived financial and non-financial constraints to research and innovation (R&I); and (ii) how, as a result, it increases firms' likelihood to perceive financial *and* non-financial constraints. Our analysis uses information on firms' perceived constraints included in the 2010 and 2016 waves of the Innovation in Irish Enterprises survey (IIE, formerly known as Community Innovation Survey [CIS]).[38] Appendix 4-C shows the framing of the questions relevant to our study in each IIE survey wave considered. We merged these survey data with administrative data containing the full range of public support for R&I available to firms in Ireland during the intervening period (from 2011 to 2015), from the Irish Revenue Commissioners, and Ireland's three main funding agencies (i.e. Enterprise Ireland, IDA Ireland, and Science Foundation Ireland).

The IIE is a biennial survey with information on firms' internal characteristics, their research and innovation activities, and their perceived constraints to R&I. The IIE dataset includes information on firms with at least 10 employees (i.e. no data on micro-firms).[39] We selected data from the two most recent IIE survey waves that included questions on firms' perceived constraints

[38] Questions on firms' perceived constraints were not included in the 2012 and 2014 waves of the IIE survey.

[39] Specifically, the IIE survey is a stratified random sample of enterprises with at least 10, and a maximum of 49, persons engaged, and a census of firms with at least 50 persons engaged. The survey only includes enterprises in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73. For further details see: https://www.cso.ie/en/methods/scienceandtechnology/innovationinirishenterprisesformerlyknownascommunityinnovationsurvey.

(presented in Appendix 4-C). These are the 2010 and 2016 survey waves, with information for the period from 2008 to 2010, and from 2014 to 2016, respectively. Our analysis requires observing firms' R&I activities before and after the receipt of public financial support to control for: (a) potential bias arising from firm-level heterogeneity affecting firms' likelihood of perceiving constraints (Pellegrino 2018; Lahr and Mina 2021); and (b) firms' likelihood of obtaining public financial support for R&I (Hottenrott and Lopes-Bento 2014; Nilsen *et al.* 2020). Therefore, we limit our sample to firms present in both, the 2010 and 2016, IIE survey waves.

Our novel administrative data includes data on R&D tax credits from the Irish Revenue Commissioners, and all public financial instruments for R&I activities available to firms in Ireland by Ireland's three main funding agencies as outlined above, from 2011 to 2015. The Irish Revenue Commissioners oversees all tax-related matters in Ireland. Enterprise Ireland (EI) provides a comprehensive suite of supports for Irish-owned firms from start-up to maturity, with a particular focus on innovation and exporting (Enterprise Ireland 2019). The Industrial Development Agency (IDA) Ireland focuses on attracting and supporting investments into Ireland by foreign-owned companies (IDA 2020). We only consider financial support instruments from EI and IDA that focus on firm-level R&I. Science Foundation Ireland (SFI) primarily funds scientific research in higher education institutions. This is a vital pillar of the innovation policy system in Ireland, as SFI funded institutions can provide cutting edge knowledge to firms through co-funded collaborative research projects (SFI 2018). Our data captures whether firms engage in these co-funded collaborative research projects. Using administrative data is an important advantage of our analysis as it permits a detailed understanding of the public financial support instruments for R&I considered (Hottenrott *et al.* 2017; Nilsen *et al.* 2020). This enables us to distinguish between (i) R&D tax credits, (ii) R&D subsidies; and (iii) R&D subsidies that require collaboration between firms and local knowledge providers, as detailed in Section 4.3.2.

The final dataset comprises two repeated cross-sections from the IIE (i.e. for 2010 and 2016) for 1,296 firms which are present in both surveys. A total of 233 firms received at least one public financial support instrument for R&I in the period from 2011 to 2015, but only 186 of these firms have perceived constraints in 2010.

A potential limitation of using a sub-sample of a representative survey, such as the IIE, is that our effective sample may no longer be representative of the overall sample of firms in the original survey. This, in turn, may affect the representativeness of our results. The 2010 IIE survey includes a total of 3,245 firms, while the 2016 IIE survey features 2,576 firms. Only 1,296 firms feature in both survey waves (i.e. are thus suitable for our analysis). However, as Appendix 4-A demonstrates, the firms featured in our sample largely maintain the representativeness of the IIE survey. In addition, out of a total of 292 firms that declared receiving public financial support covering the period from 2012 to 2016 in the IIE survey, a total of 223 firms are featured in our administrative data.[40] Besides a loss of observations, a potential issue here is that such loss of observations may take place in a systematic (i.e. non-random) way, which may result in issues of self-selection. Here, Appendix 4-B shows that the group of firms that received public financial support in our analysis is very similar, in terms of their characteristics and innovative performance, to the larger sample of firms which declared receiving support in the IIE survey (i.e. the attrition is not systematic). This means that the results of our analysis are not biased by systematic attrition.

4.3.1 Dependent Variables

We organise our analysis in two stages. The first stage tests Hypotheses 1 to 3, regarding public financial support for R&I enabling firms to overcome their perceived financial and non-financial constraints. Public financial support for R&I is considered to enable firms to overcome their perceived financial constraints if it leads to more R&I investments by financially constrained firms (see Becker 2015, for a review). We test Hypothesis 1 by using the natural logarithm of firms' total investment in R&I (Borisova and Brown 2013; Marino *et al.* 2016). Total investment in R&I was obtained from the IIE survey, as the sum of the following R&I investment categories: (i) in-house R&D; (ii) external R&D; (iii) acquisition of machinery, equipment, software, and buildings; (iv) acquisition of knowledge

[40] This may be because, besides the three main funding agencies considered in our paper, firms may have obtained this support from other regional support agencies, such as the Western Development Commission. This commission focuses on promoting social and economic development in the Western Region, that is counties of Donegal, Leitrim, Sligo, Mayo, Roscommon, Galway and Clare. (see https://westerndevelopment.ie/about/).

from other enterprises or institutions; and (v) all other innovation activities (including design, marketing, and other relevant activities).

In our study, we consider that firms overcome their perceived knowledge constraints if they: (i) invest more in R&I, for which we use the same variable as explained above, but now the analysis focuses on differences between firms that perceive and do not perceive knowledge constraints (as opposed to firms that perceive financial constraints); (ii) increase their breadth of collaborators (measured as a count variable ranging from 0 to 4 to account for suppliers, clients, other firms and public knowledge providers, similarly to Larsen and Salter [2014]); (iii) are more likely to innovate, as measured by a dummy variable measuring whether firms introduced significantly improved or new-to-firm goods and services, and a dummy variable measuring if firms introduced new-to-market goods and services; (iv) enhanced their breadth of innovations introduced to the market, as measured by a count variable ranging from 0 to 4 depending on whether firms innovated in processes, products, services and new forms of organisation (D'Este *et al*. 2012); and finally, (v) if they introduced changes to their management of R&I (Hullova *et al*. 2019), measured with a dummy variable that equals one if firms introduced organisational innovations and zero otherwise.

The above variables capture most of the activities that firms may engage in when overcoming knowledge constraints. Investing in R&I contributes to firms' absorptive capacity (Cohen and Levinthal 1990). Firms' likelihood to innovate is an indication of their innovative capabilities (Hottenrott and Peters 2012). Firms' breadth of R&I activities highlights their ability to hedge risks associated with innovation, and make strategic decisions to maximise their innovative performance (Klingebiel and Rammer 2014). Engaging in collaborations can help firms to obtain new knowledge for R&I, and requires firms to develop specific collaborative capabilities (Antonioli *et al.* 2017; Hewitt-Dundas *et al.* 2019). Finally, introducing changes to the way firms manage innovation can signal explicit efforts to improve their innovative performance (Hullova *et al.* 2019).

We consider that firms overcome their market constraints if market-constrained firms increase (i) their turnover derived from new to the firm goods and services, and/or (ii) their turnover derived from new-to-market goods and services (both as the percentage of turnover). These variables are widely used in the literature when analysing firms' economic returns from innovation (Becket *et al.* 2016; Hewitt-Dundas *et al.* 2019). We obtained these variables from specific questions in the IIE survey where firms indicate the percentage of turnover that was derived from new to the firm, and new to the market goods and services, separately.

Table 4-1 summarises our dependent variables between treated and untreated firms, with treated firms being those firms receiving public financial support for R&I from 2011 to 2015. The table shows that firms that received public financial support during the period from 2011 to 2015 (i.e. treated firms), performed better across all of the indicators considered, on average, in comparison to firms that did not receive the support. For example, treated firms invested around 4 log points more than untreated firms. In addition, while around 58 percent of treated firms introduced innovations to the market, only 17 percent of untreated firms did so. On average, treated firms introduced 1.58 innovations to the market, while untreated firms introduced maximum of 1 innovation to the market.

Table 4-1: Dependent variables (Stage 1)

		Treated=0 (N=1073)				**Treated**= 1 (N= 223)			
	Dependent Variables	Mean	SD	Min	Max	Mean	SD	Min	Max
Financial	Ln Total R&I investments	2.732	3.874	0	12.922	6.711	3.935	0	11.863
Knowledge	Breadth of Collaborators for R&I (0 to 4).	0.113	0.443	0	4	0.419	0.702	0	4
	Changes in Management of Innovation (1=Yes)	0.377	0.484	0	1	0.585	0.491	0	1
	Breadth of Innovation (0 to 4)	0.983	0.899	0	4	1.583	0.958	0	4
	New to firm goods and services (1=Yes)	0.172	0.372	0	1	0.578	0.495	0	1
	New to market goods and services (1=Yes)	0.129	0.335	0	1	0.435	0.497	0	1
Market	Percentage turnover new to firm goods and services/total turnover	3.772	10.881	0	100	8.950	15.821	0	100
	Percentage turnover from new to market goods and services/total turnover	2.210	9.862	0	100	7.782	16.412	0	100

In the second stage we test Hypotheses 4 to 6. These relate to firms that received public financial support in one period being more likely to perceive financial and non-financial constraints in subsequent periods. Here, we use a set of dependent variables measuring firms' perceived constraints from the IIE survey data. The IIE 2010 survey includes data on nine constraints (See Appendix 4-C, Panel A). The 2016 survey includes data on eight constraints, but only six constraints matched the same constraints as those included in the 2010 survey (See Appendix 4-C, Panel B). Our analysis focuses on these six constraints. In both survey waves, firms specify the intensity to which each perceived constraint affected their R&I activities in the last three years, as follows: 1=high importance; 2=medium importance; 3=low importance, and 4=not encountered.

In line with Pellegrino and Savona (2017), we combine the above six categorical variables into three binary variables corresponding to three headline constraints (i.e. financial, knowledge and market), at any level of importance. For example, *Financial Constraint* is a headline measure, and takes the value of 1 if a firm perceived a lack of internal finance, a lack of credit, or if it perceived the cost of R&I as being too high in the last 3 years (at any level, such as low, medium, or high). Otherwise, the value is 0. Furthermore, following D'Este *et al.* (2012), we construct another three similar headline variables, where the variables take the value of 1 when at least one of the (sub) constraints are considered to be of high importance; zero otherwise (e.g. Financial Constraints High). Appendix 4-D explains the construction of the variables, with a summary of these variables presented in Table 4-2.

Table 4-2 Dependent Variables (Stage 2)

Headline Constraints	**All firms (%)**	**Non-treated firms (%)**	**Treated firms (%)**
Financial Constraints (1=yes)	62.910	57.972	91.402
Financial Constraints High (1= yes)	26.452	25.351	32.801
Knowledge Constraints (1= yes)	54.176	48.562	86.567
Knowledge Constraints High (1=yes)	6.832	5.965	11.831
Market Constraints (1=yes)	63.070	58.150	91.406
Market Constraints High (1=yes)	16.463	19.118	21.511

As a robustness test, we repeat the analysis by using the six variables corresponding to each (sub) constraint as explained above (i.e. categorical variables ranging from 1 to 4).[41] According to Iammarino *et al.* (2009), it is important to analyse each (sub) constraint individually, as these may be intrinsically different (e.g. a lack of internal funding and a lack of access to credit are typically grouped under the financial constraint headline).

4.3.2 Public financial support for R&I

Most previous studies concerned with perceived constraints to R&I only focussed on financial constraints using survey data, which does not allow for an analysis of different forms of public financial instruments (see, for example, Silva and Carreira 2012; Mateut 2018). An advantage of our paper is that our administrative data permit analysing different public financial support instruments for R&I. Appendix 4-E lists all public financial instruments for R&I considered in the analysis and classifies them as (i) R&D tax credits, (ii) R&D subsidies and (iii) R&D subsidies that require collaboration between firms and public knowledge providers. We base this classification on Busom *et al.* (2014) and Zúñiga-Vicente *et al.* (2014). R&D tax credits are available to all firms in Ireland which are liable for corporation tax, and that undertake R&D activities involving systemic, investigative, and experimental research activities in the field of science and technology (Revenue 2020). R&D subsidies are allocated directly to firms through a competitive process. Firms are required to demonstrate the importance of the proposed projects, their expected outcomes, and firms' abilities to complete such

[41] Here, we recoded the variables to reverse the scale. That is, 4 = High Importance and 1 = Not Important.

projects (Enterprise Ireland 2021; IDA Ireland 2021). R&D subsidies that require collaboration between firms and public knowledge providers are also competitive in nature. However, as the funding is allocated to the knowledge providers (i.e. universities and research centres), and not to the firms, the applications need to be submitted by the knowledge providers (SFI 2016; Enterprise Ireland 2021; IDA Ireland 2021).

The instruments in Appendix 4-E were combined into four binary variables. *Public Financial Support for R&I* equals 1 if firms received any of the financial instruments featured in Appendix 4-D from 2011 to 2015; otherwise, the value is 0. The remaining three variables follow the same methodology for each of the following categories: (i) R&D tax credits; (ii) R&D subsidies; and (iii) R&D subsidies that require collaboration between firms and local knowledge providers, such as universities and research centres. Table 4-3 summarises these variables.

Table 4-3: Public financial support instruments for R&I used in the analysis

	Number of Firms (n)	Percentage (%)
Panel A		
Public financial support for R&I	186	14.769
No support	1,073	85.231
Panel B: Type of financial support instruments for R&I	(n)*	(186 = 100%)
R&D Tax credits	67	36.021
R&D Subsidies	52	27.929
R&D Subsidies (collaborative)	49	26.342

*The remaining 18 firms not featured in Panel B consist of firms receiving a mix of instruments. We include these firms in the *Public financial support for R&I* indicator, but we do not analyse them as a stand-alone category due to small sample size.

4.3.3 Empirical approach

As outlined in Section 4.3.2, we structure our analysis in two stages. The first stage analyses whether public financial support for Research and Innovation (R&I) enables firms to overcome their financial and non-financial constraints (H1 to H3). In line with studies focussed on the additionality of public financial support for R&I, we control for selection bias in the use of public financial support for R&I by employing a propensity score matching (PSM) methodology (Czarnitzki and Lopes-Bento 2013; Vanino *et al.* 2020). The PSM approach relies on the conditional independence assumption (CIA), where treatment and outcome are assumed to be statistically independent for firms with the same set of observable characteristics (Rubin 1977). Assuming that the matching is performed correctly, the average treatment effect of public financial support for R&I on firms' ability to overcome their constraints to R&I can be obtained as follows:

$$E(aTT_{ij}) = E(YT_{ij}|S = 1, X = x) - E(YC_{ij}|S = 0, X = x) \qquad (4\text{-}1)$$

In Equation (4-1), aTT denotes the average treatment effect of public financial support for R&I *i* (*i= Public Financial Support for R&I, R&D Tax Credits, R&D Subsidies,* and *R&D Subsidies that require collaboration with local knowledge providers*) on several outcome variables (*j*) that directly measure the activities related to their financial *and* non-financial constraints (i.e. variables in Table 4-1). $YTij|S = 1$ is the outcome variable *j* for firms that received public financial support for R&I *i*, which is observable. $YT_{ij}|S =0$ is the outcome variable *j* for the counterfactual scenario if treated firms had not received such support (*S=0*). $YT_{ij}|S = 0$ needs to be estimated, and consists of firms that did not receive public financial support for R&I, but that are statistically similar across observable characteristics to those firms receiving such support before the treatment took place (Radas *et al.*, 2015).

Following Czarnitzki and Lopes-Bento (2013) and Radas *et al.* (2015), we perform the PSM routine for Equation (4-1) by estimating firms' propensity to receive public financial support for R&I conditionally upon a set of exogenous variables (X) before the treatment took place (i.e. in 2010). The predicted probabilities were compiled into a single index (i.e. the propensity score), and firms are matched according to this index. Table 4-4 explains the observable variables used in the matching process.

Table 4-4: Variables used in the matching process

Stage	Matching Variables	Explanation
Both	Irish Owned (1=Yes)	1= Firm is Irish owned
	Enterprise Group (1= Yes)	1= Firm is part of an Enterprise Group
	Export (1= Yes)	1= Firm exports
	Ln Total R&I Investments (2010)	Ln of Total investment in R&I in 2010
	Percentage turnover from Innovation (2010)	Percentage of total turnover from innovation in 2010
	Breadth of Innovation partners (0 to 4)	Count variable (0 to 4) measuring the breadth of innovation partners
	Breadth of Innovation (0 to 4)	Count variable (0 to 4) measuring the breadth of innovation activities
	New to market good or service (2010)	1= Firm introduced new to market good and/or services in 2010
	Financial Constraints (1 = Yes in 2010)	1= Firm perceived financial constraints in 2010
	Knowledge Constraints (1 = Yes in 2010)	1= Firm perceived knowledge constraints in 2010
	Market Constraints (1 = Yes in 2010)	1= Firm perceived market constraints in 2010
Stage 2 only	Ln Total R&I Investments (2016)	Ln of Total investment in R&I in 2016
	Percentage turnover from Innovation (2016)	Percentage of total turnover from innovation in 2016
	New to market good or service (2016)	1= Firm introduced new to market good and/or services in 2016

As Table 4-4 shows (in Panel Both), we use a set of binary variables which measure the following key firms' characteristics: (i) whether firms are Irish owned (Doran and Ryan 2014a); (ii) whether firms are part of an enterprise group (Jissink *et al.* 2019); and (iii) whether firms are exporters (Love and Roper 2015). Moreover, we measure firms' innovative efforts, and outcomes, in 2010, by including: (a) a binary variable measuring whether firms introduced radical innovations in 2010; (b) a continuous variable measuring firms' total investments in R&I in 2010 (in Ln); (c) a count variable ranging from 0 to 4, measuring the breadth of innovation partners in 2010 (i.e. clients, customers, other firms, and public knowledge providers); (d) firms' percentage of turnover from innovation in 2010; and (e) a count variable measuring firms' breadth of innovation activities ranging from 0 to 4 (i.e. process, product, service, and organisational innovation). Matching according to firms' R&I efforts before the treatment takes place is important as such efforts have been shown to influence firms' likelihood to obtain public financial support (Busom *et al.* 2014; Mina *et al.* 2021). In addition, as D'Este *et al.* (2012) have demonstrated, firms' R&I efforts also influence firms' likelihoods to perceive financial and non-financial constraints to R&I. Finally, we use three dummy variables to measure whether firms perceived financial, knowledge and/or market constraints in 2010.

Following Hottenrott and Lopes-Bento (2014), we employ a nearest neighbour approach, matching each treated firm with up to three comparator firms with the recommended calliper of 0.2 points of the standard deviation of the propensity score (Austin 2011). We only allow matches between (i) firms that experience the same perceived constraints in 2010; (ii) firms of the same size, as measured by the categorical variables denoting 1=small, 2=medium and 3= large-sized firms, according to their number of employees[42]; and (ii) firms within the same sector, using one-digit NACE Rev. 2 classifications. Our approach is similar to the direct matching methodology employed by Vanino *et al.* (2019). Table 4-5

[42] As described in Footnote 2, small-sized firms are firms with between 10 to 49 employees, medium-sized firms are firms with at least 50 and fewer than 249 employees, and large firms are firms with at least 250 employees.

presents the standard tests which confirm that there is no significant difference between the treatment and control groups across all the observable variables used.

Table 4-5: Balance check Stage 1

Matching Variables	Treated	Control	Diff (T - C)	P-Value
Irish Owned (1=Yes)	0.702	0.676	0.026	0.591
Enterprise Group (1= Yes)	0.157	0.153	0.04	0.463
Export (1= Yes)	0.897	0.904	-0.007	0.815
Breadth of cooperation partners (0 to 4)	0.647	0.667	-0.02	0.844
Ln Total R&I Investments (2010)	6.93	6.85	0.008	0.838
Percentage of turnover from Innovation (2010)	10.08	10.24	-0.168	0.82
Breath of Innovation (0 to 4)	2.62	2.62	0	0.981
New to market good or service (2010)	0.468	0.885	-0.417	0.740
Financial Constraints (1 = Yes in 2010)	0.731	0.751	-0.02	0.674
Knowledge Constraints (1 = Yes in 2010)	0.417	0.421	-0.004	0.926
Market Constraints (1 = Yes in 2010)	0.657	0.644	0.013	0.821
Rubin's B = 13.5. Mean Bias = 3.2; Median Bias = 2.6. R = 0.69				
*** Denotes significance at the 99% level, ** 95% level and * 90% level				

In the second stage, we analyse whether firms that received public financial support for R&I in one period, were more likely to perceive financial *and* non-financial constraints in subsequent periods (H4 to H6). Here, in addition to controlling for selection bias in the allocation of public financial support, we consider issues of reverse causality (i.e. endogeneity) between firms' R&I efforts and their perceived constraints (Savignac 2008: Lahr and Mina 2021). This is carried out as follows:

$$E(aTT_{ij}) = E(YT_{ij}|S = 1, X = x, P = p) - E(YC_{ij}|S = 0, X = x, P = p) \qquad (4\text{-}2)$$

Equation (4-2) is similar to Equation (4-1) but now *j* corresponds to firms' perceived constraints (*j= Financial, Knowledge and Market*). Moreover, the equation includes an additional matching restriction (denoted as P) to account for firms' research and innovation efforts, and outcomes in 2016 (i.e. the outcome period). The bottom panel of Table 4-4 explains these variables. As described in the table, we include: (a) the natural logarithm of firms total R&I investments in 2016; (b) firms' percentage of turnover from Innovation in 2016; (c) and whether firms introduced radical innovations in 2016.

As noted in Section 4.2, firms are more likely to experience financial and non-financial constraints as they become more innovative (D'Este *et al.* 2012; Hottenrott and Peters 2012). However, the relationship between firms' innovative efforts, and their probabilities to perceive constraints is not necessarily linear, in the sense that more R&I automatically translates into more constraints. That is, firms may perceive constraints differently, depending on their specific level of R&I efforts and outcomes (D'Este *et al.* 2012). Previous studies control for issues of reverse causality by jointly modelling firms R&I efforts and their likelihood to perceive constraints (Blachard *et al.* 2013; D'Este *et al.* 2014; Radicic 2021). Other studies perform their analysis on specific groups of firms (i.e. firms that innovate, firms that do not innovate, and firms that want to innovate but fail) (Pellegrino and Savona 2017; Pellegrino 2018; Zahler *et al.* 2022).

Our approach extends the above studies, by not only controlling for firms' decisions to innovate, but also controlling for their innovative perfomance before, and during, the period of intervention. This is because our approach results in a counterfactual of firms that: (i) are statistically similar across the observable characteristics in 2010; (ii) experienced the same level of financial, knowledge and market constraints in 2010; (iii) engaged in R&I similarly to treated firms both in

2010 *and* 2016; and (iv) only differ in the treatment variable (i.e. S=1 and S=0). As a result, our approach may represent a more detailed way of dealing with potential unobserved heterogeneities driving firms' perception of constraints. A positive coefficient of interest would indicate that firms' probability of perceiving constraints to R&I has been increased solely because the receipt of public financial support for R&I, thus supporting Hypotheses H4 through H6. Table 4-6 shows the standard tests performed which ensure comparability between the treated and (constructed) control group. As the table shows, we do not find significant differences in any of the matching variables between treated and untreated firms.

Table 4-6: Balance check Stage 2

Matching Variables	Treated	Control	Diff (T - C)	P-Value
Irish Owned (1=Yes)	0.685	0.651	0.034	0.474
Enterprise Group (1= Yes)	0.159	0.156	0.003	0.613
Export (1= Yes)	0.882	0.904	-0.021	0.541
Breadth of cooperation partners (0 to 4)	0.611	0.635	0.024	0.747
Ln Total R&I Investments (2010)	6.733	6.746	-0.011	0.961
Percentage of turnover from Innovation (2010)	9.751	10.129	-0.429	0.664
Breath of Innovation (0 to 4)	2.631	2.510	0.126	0.535
New to market good or service (2010)	0.385	0.361	0.022	0.723
Financial Constraints (1 = Yes in 2010)	0.912	0.915	-0.012	0.721
Knowledge Constraints (1 = Yes in 2010)	0.111	0.095	0.015	0.479
Market Constraints (1 = Yes in 2010)	0.216	0.232	-0.024	0.610
Ln Total R&I Investments (2016)	6.425	6.424	0.021	0.951
Percentage turnover from Innovation (2016)	8.190	8.232	-0.047	0.974
New to market good or service (2016)	0.437	0.476	0.031	0.129
Rubin's B = 19.4. Mean Bias = 4.1; Median Bias = 3.13 R = 0.63				
*** Denotes significance at the 99% level, ** 95% level and * 90% level				

4.4 Empirical results

We now proceed to present our main results, which are presented as average treatment effects.

4.4.1 Public financial support for R&I enabling firms to overcome their constraints

Table 4-7 indicates that public financial support for research and innovation (R&I) drives firms to overcome their perceived financial constraints, thus providing support to Hypothesis 1. The coefficient for the variable *Ln Total R&D Investments* in Column 1, shows that such support causes financially constrained firms to invest up to 11.6 percent more in R&I, on average.[43] Columns 2 and 3, however, show that input additionality effects only pertain to R&D tax credits and R&D subsidies (i.e. with impacts of 24.2 and 26.8 percent, respectively). A Wald test elucidates that R&D subsidies have a larger impact on firms' R&I investments in comparison to R&D tax credits, by around 3 percent ($p < 0.05$), which is in line with previous research on this topic (see, for example, Carboni *et al.* 2013; Becker 2015; Marino *et al.* 2016; Mateut 2018).

[43] The percentage figures are obtained by the following exponential (a^e-1)*100, where *a* is the relevant coefficient.

Table 4-7: Impact of public financial support for R&I on firms overcoming their constraints

	Outcome variables (2016)	Treated	R&D Tax Credits	R&D Subsidies	R&D Subsidies (Collab)
		(1)	(2)	(3)	(4)
Financial	Ln Total R&D Investments	0.110** (0.451)	0.217** (0.804)	0.238** (0.755)	0.068 (0.707)
Knowledge	Ln Total R&D Investments	0.162** (0.478)	0.145* (0.768)	0.256** (0.850)	-0.467 (0.739)
	Breadth of Cooperation Partners (0 to 4)	0.084 (0.090)	0.300** (0.121)	0.200* (0.128)	0.020 (0.137)
	Change in Manag. of Innov. (Org. Innov)	0.014 (0.063)	0.055 (0.082)	0.113 (0.092)	0.101 (0.095)
	Breadth of Innovation activities (0 to 4)	0.211** (0.107)	0.320* (0.197)	0.281 (1.952)	0.284 (0.214)
	New to firm goods and services	0.086* (0.050)	0.135 (0.086)	0.136* (0.082)	0.106 (0.079)
	New to market goods and services	1.026* (0.061)	0.033 (0.033)	0.113* (0.079)	0.090 (0.082)
Market	Percentage of turnover from new to firm goods and services	0.156 (0.869)	-0.001 (0.115)	1.186 (1.224)	-0.948 (1.455)
	Percentage of turnover from new to market goods and services	2.083* (0.129)	0.434 (1.822)	3.093** (1.772)	1.637 (1.783)
	No. Treated	186	67	52	49

Coefficients are Average Treatment Effects with robust standard errors. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 refers to the receipt of any type of public financial support instrument for R&I, Column 2 to the receipt of R&D tax credits only, Column 3 to the receipt of R&D subsidies only, and Column 4 to the receipt of R&D subsidies that require collaboration between firms and public knowledge providers only. ATE is obtained by a difference in means test.

Column 4 shows that R&D subsidies that require firms to collaborate with public knowledge providers, such as universities and research centres (i.e. henceforth collaborative R&D subsidies), have no impact on firms' R&I investments. This concurs with Belluci *et al.* (2016) who report no input additionality effects of collaborative R&D amongst firms in Italy. Yet, our results differ from those of Scandura (2016), who reported that collaborating with universities increased R&D investments by firms in the UK. Cassiman *et al.* (2018) note that firms may collaborate with universities by outsourcing R&D activities that cannot be carried out internally. Collaborative R&D subsidies thus may not necessarily increase firms' R&I investments levels, but re-orient such investments to specific research activities, such as basic research. Our data, however, do not permit ascertaining whether this is indeed the case.

A novelty of our paper is that we analyse whether public financial support for R&I can help firms to overcome their knowledge and market constraints. Regarding knowledge constraints, firms' investments in R&I are important for developing R&I capabilities (Clarysse *et al.* 2009; Yigitcanlar *et al.* 2019). Table 4-7 (Column 1) shows that, on balance, public financial support for R&I causes knowledge constrained firms to invest approximately 16 percent more in R&I ($p < 0.05$). This coefficient (i.e. second row of Column 1 of Table 4-7) differs from the coefficient above (i.e. row 1) because it was obtained by matching firms with similar levels of knowledge constraints, as opposed to financial constraints, in row 1. However, as demonstrated in Columns 2 and 3, such impact only pertains to R&D tax credits and R&D subsidies, as outlined earlier.

Moreover, increasing the breadth of external partners for R&I collaborations enables firms to benefit more from external knowledge, and helps them overcome their knowledge constraints (Antonioli *et al.* 2017). From Column 1, we do not find that public financial support for R&I affects firms' breadth of collaborators for R&I. Columns 2 and 3, however, show that R&D tax credits and R&D subsidies drive firms to increase their breadth of R&I collaborators by an average of 0.3 and 0.2, respectively ($p < 0.05$).

According to Klingebiel and Rammer (2014), a wider breadth of innovations activities can translate into higher levels of turnover from innovation. Our results here suggest that public financial support for R&I causes knowledge constrained firms to increase their breadth of R&I activities by 0.2, on average (Column 1, $p < 0.05$). This effect, however, is not apparent when considering each public financial support instrument individually in Columns 2 to 4 of Table 4-7. In this case, Column 2 provides some weak indication that such impact is predominantly driven by R&D tax credits.

Firms' ability to introduce new goods and services is an indication of firms' R&I capabilities (D'Este *et al.* 2012; Hottenrott and Peters 2012). Here, Column 1 of Table 4-7 provides some evidence that public financial support for R&I has a positive and significant impact on firms' probability to introduce new to the firm products and services, as well as products and services that are new to the market (by 8 and 10 percent, respectively). However, Columns 2 to 4 indicate that such effects are solely driven by R&D subsidies. Our results, therefore, concur with Busom *et al.* (2014) in that R&D tax credits and R&D subsidies are not perfect substitutes. Furthermore, they are in a similar vein to Neicu *et al.* (2016), when observing different behavioural additionality effects between these two types of public financial support for R&I.

Finally, we find public financial support for R&I to have no impact on knowledge constrained firms introducing changes to the management of R&I (i.e. organisational innovation). Furthermore, collaborative R&D subsidies have no impact on any of the variables considered. This is unexpected, and worthy of future research, as collaborating with public knowledge providers can bring important benefits to firms' R&I capabilities (Scandura 2016; Vanino *et al.* 2020). According to Hewitt-Dundas *et al.* (2019), benefiting from such collaborations may require an initial learning process by both firms and collaborating partners, which may explain our results. On balance, therefore, our results provide some partial support for Hypothesis 2, but only for R&D tax credits and R&D subsidies.

Regarding the impact of public financial support on firms' ability to overcome their market constraints, our findings also partially support Hypothesis 3. Column 1 of Table 4-7 shows that such support has a positive and significant effect only on firms' turnover derived from new-to-market innovations (i.e. radical innovations, $p < 0.1$). Furthermore, such impact mainly takes place in the context of R&D subsidies (Column 3). That is, firms that received R&D subsidies have increased their turnover from new-to-market innovations (as a percentage of total turnover) by approximately 2 percent. The magnitude and significance of the coefficient in Column 3 is much larger than in the rest of the columns, which indicates that the positive coefficient in Column 1 is solely driven by R&D subsidies (i.e. the additionality is of 3 percent, $p < 0.05$). Our findings are consistent with Lee (2011) and Beck *et al.* (2016), who report that R&D subsidies encourage firms to improve the quality of their innovations, and innovate radically. Yet, the magnitude of the effect reported here is smaller than the effect as reported by these studies. For example, Beck *et al.* (2016) report R&D subsidies to have an output additionality effect on firms' turnover from radical innovation of between 5 and 10 percent.

4.4.2 Public financial support and firms' perceived constraints

We now focus on public financial support for R&I increasing firms' probability of perceiving financial and non-financial constraints in subsequent periods. As noted earlier, some literature reported the existence of positive relationships between public financial support for R&I, and firms' likelihood of perceiving financial and non-financial constraints (see, for example, Silva and Carreira 2012; D'Este *et al.* 2014; Pellegrino 2018). Yet, such positive relationships were explained to arise from support being allocated to more innovative firms, which are typically more likely to experience constraints (D'Este *et al.* 2014; Pellegrino 2018). To the best of our knowledge, our paper is the first to explicitly analyse the impact of public financial support for R&I on firms' probability to perceive constraints to R&I.

Column 1 in Table 4-8 shows that public financial support for R&I drives firms to being 9.2 percent more likely to perceive financial constraints, but only when these constraints are measured at the broadest level (i.e. low, medium, and high importance). Columns 2 to 4 show that such effect is primarily driven by firms that received collaborative R&D subsidies. This may suggest that firms receiving collaborative R&D subsidies perceive financial constraints as having a low to medium impact in their R&I activities because of receiving such support. This is because we find no differences on firms' perceived financial constraints between treated and untreated firms when our stricter measures of constraint are used, which measure such constraints having a high impact on firms' R&I activities. Our findings concur with D'Este *et al.* (2012) in that despite innovative firms being more likely to perceive constraints to R&I, these constraints may not completely deter their R&I activities (as firms do not see them as an important deterrent). This provides some support for Hypothesis 4.

Table 4-8: Impact of public financial support on firms' likelihood to perceive new constraints.

	Treated (1)		R&D tax credits (2)		R&D subsidies (3)		R&D subsidies with collaboration (4)	
Constraints	**ATT (L-M-H)**	**ATT (High)**	**ATT (L-M-H)**	**ATT (High)**	**ATT (L-M-H)**	**ATT (High)**	**ATT (L-M-H)**	**ATT (High)**
Financial Constraints	0.092** (0.043)	0.016 (0.049)	0.030 (0.077)	0.015 (0.061)	0.007 (0.094)	-0.010 (0.050)	0.131* (0.070)	0.083 (0.065)
Knowledge Constraints	0.029 (0.046)	-0.011 (0.037)	-0.034 (0.057)	-0.033 (.064)	0.110* (0.065)	0.000 (0.064)	-0.035 (0.047)	0.041 (0.056)
Market Constraints	0.168*** (0.049)	0.031 (0.029)	0.200** (0.073)	-0.035 (0.053)	0.111 (0.083)	0.083* (0.045)	0.246*** (0.072)	0.087 (0.058)
Observations	186	186	67	67	52	52	49	49

Coefficients are Average Treatment Effects with robust standard errors. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 refers to the receipt of any type of public financial support instrument for R&I, Column 2 to the receipt of R&D tax credits only, Column 3 to the receipt of R&D subsidies only, and Column 4 to the receipt of R&D subsidies that require collaboration between firms and public knowledge providers only. ATE is obtained by a difference in means test.

Our findings from Table 4-8 also partially support Hypothesis 5, regarding public financial support driving firms' probability of perceiving knowledge constraints. Column 1 indicates that the receipt of public financial support for R&I does not affect firms' probability of perceiving knowledge constraints. However, Column 3 shows that firms that received R&D subsidies are 11.6 percent more likely to perceive knowledge constraints, but only when measured at the broadest level (i.e. low, medium, and high importance). Again, as explained above, this may indicate that firms predominantly perceive these constraints as having a low to medium impact in their R&I activities. Our findings here are consistent with Table 4-7, in the sense that firms that received R&D subsidies appear to have increased their radical innovative efforts. As a result, they are more likely to perceive knowledge constraints. Furthermore, this is consistent with Hölzl and Janger (2014), which propose that firms operating at the frontier of knowledge are more likely to perceive knowledge constraints. Yet, the fact that these firms do not perceive knowledge constraints as highly important, following the receipt of public financial support for R&I, may relate to firms becoming more confident in their internal skills to address new challenges that arise as they engage in more distant R&I activities. Amore (2015), for example, demonstrates that by overcoming major obstacles, such as innovating during a financial recession, firms can develop specific capabilities and increase their confidence to overcome future obstacles. This means that although firms that receive R&D subsidies in one period, are more likely to perceive knowledge constraints in subsequent period, they are also more equipped to deal with these constraints.

Finally, Table 4-8 provides strong support for Hypothesis 6, regarding public financial support for R&I making firms being more likely to experience market constraints. Specifically, we find R&D tax credits, and collaborative R&D subsidies, to drive firms' probability to perceive market constraints, but only when these constraints are measured at the broadest level (i.e. low, medium, and high importance). Furthermore, R&D subsidies make firms around 8 percent more likely to perceive market constraints as highly important factors hindering their R&I activities. Again, according to Hölzl and Janger (2014), the importance that firms attach to these constraints is positively related to the proximity to their knowledge frontier. Therefore, our findings may relate to firms that received R&D subsidies being more likely to engage in more distant types of R&I activities, and hence perceiving market constraints.

4.4.3 Additional analysis

Appendix 4-F provides further insights regarding the robustness of our findings reported earlier in Section 4.4.2, by extending the analysis to each perceived (sub) constraint. Here, we find public financial support for Research and Innovation (R&I) to increase firms' probability to perceive a lack of internal funding and a lack of credit as constraints. Firms that received R&D tax credits were more likely to perceive a lack of internal funding as constraining their R&I activities, with firms receiving collaborative R&D subsidies perceiving their R&I activities to be constrained due to lack of credit. The receipt of R&D subsidies has no impact on firms' perceived financial constraints. This is likely because R&D subsidies represent a direct cash transfer to firms (Busom *et al.* 2014). Previous studies have also highlighted that R&D subsidies can help firms to gain more access to external finance for R&I due to certification effects (Kleer 2010; Colombo *et al.* 2013).

Consistent with Table 4-8, R&D subsidies and collaborative R&D subsidies do not affect firms' probability of perceiving a lack of qualified personnel or a lack of partners as constraining their R&I activities. R&D subsidies may enable firms to develop their internal capabilities by engaging in more radical forms of innovation

(Clarysse *et al.* 2009), while collaborating with public knowledge providers (as a result of collaborative R&D subsidies) can represent an important knowledge source for firms (Cassiman *et al.* 2018; Hewitt-Dundas *et al.* 2019). In contrast, firms that received R&D tax credits are more likely to experience a lack of qualified personnel as constraining their R&I activities. According to Busom *et al.* (2014), R&D tax credits tend to be preferred by firms with high levels of R&I capabilities, which according to Hölzl and Janger (2014), are more likely to perceive knowledge constraints.

Finally, our additional analysis confirms that public financial support increases firms' likelihood to perceive a lack of demand as constraining their R&I activities. This effect, however, is primarily driven by firms that received R&D subsidies. As alluded to earlier, this is likely due to R&D subsidies driving firms to pursue more radical forms of innovations, given the inherent uncertainty of bringing new products and services to the market (Hewitt-Dundas *et al.* 2019; Szambelan *et al.* 2020). The findings presented in Appendix 4-F, therefore, demonstrate that our results are robust to alternative specifications of the constraint variables.

4.5 Discussion and conclusion

Our paper analyses the impact of public financial support for Research and Innovation (R&I) on firms' ability to overcome their perceived financial and non-financial constraints. Additionally, we evaluate the likelihood of firms receiving this support in one period, to perceive new constraints in subsequent periods. Using survey data from the Innovation in Irish Enterprises Survey (IIE, formerly

Community Innovation Survey [CIS]) merged with novel administrative data on public financial support for R&I, our paper sheds light on two crucial issues that remain largely unexplored in the prevailing literature. The first issue pertains to identifying potential policy interventions to help firms overcome their perceived non-financial constraints to R&I. The use of public financial support for R&I for addressing firms' financial constraints is established in the literature (Busom *et al.* 2014; Carboni 2017; Mateut 2018). To our knowledge, however, this is the first paper to analyse the impact of public financial support for R&I on firms' perceived non-financial constraints.

Previous studies have posited that addressing firms' perceived non-financial constraints, such as knowledge and market constraints, may require a combination of micro and macro-level policies to target systemic failures (see, for example, D'Este *et al.* 2012; Antonioli *et al.* 2017). Mohnen *et al.* (2008) and Pellegrino and Savona (2017) have also highlighted that public financial support may not necessarily lead to more R&I if firms also perceive non-financial constraints. Our paper extends these studies by demonstrating that public financial support for R&I can help firms to overcome their perceived financial constraints, and also prompt them to overcome their perceived knowledge and market constraints. Based on our results, this may take place through two main avenues. Firstly, in line with studies focused on the impact of public financial support for R&I on firms' resources and capabilities for R&I (Clarysse *et al.* 2009; Yigitcanlar *et al.* 2019), by encouraging firms to engage in more, and in more distant forms of R&I activities. Secondly, in a similar vein to Hottenrott and Lopes-Bento (2014) and Antonioli *et al.* (2017), by enabling firms to increase their breadth of collaborators. As a result, firms can benefit more from their innovations (Hewitt-Dundas and Roper 2010; Beck *et al.* 2016) and overcome their perceived market constraints. In addition, our analysis identifies R&D subsidies as the most appropriate public financial support instrument for R&I to this end.

Furthermore, we connect two highly related bodies of literature that heretofore have remained highly separated (Mateut 2018). These are the literature concerning the additionality of public financial support for R&I, and the literature on firms' perceived constraints to R&I. By boundary-spanning these literature strands, we show that despite helping firms to increase their R&I resources and capabilities, public financial support for R&I may also result in firms being more likely to perceive financial and non-financial constraints. We attribute these findings to result from public financial support for R&I prompting firms to engage more in R&I, which may require more resources and capabilities, such as more radical forms of R&I (Radas and Bozic 2012; D'Este *et al.* 2016).

Our findings contribute to the literature, and the design and development of innovation policy interventions in two ways. Firstly, our findings elucidate that although firms are more likely to perceive financial and market constraints because of public financial support for R&I, such constraints may not hamper their R&I activities. This is because firms do not regard them as playing an important role. Thus, our findings support Galia and Legros (2004), Hottenrott and Peters (2012), and Lahr and Mina (2021), when proposing that as firms become more innovative, they are more likely to perceive financial and market constraints. Furthermore, we provide additional support to D'Este *et al.* (2012) in that the perceived constraints of more innovative firms may not necessarily impede their R&I activities. We extend these earlier studies by demonstrating that, despite perceiving more constraints, firms can innovate more and better. This is in the sense that they are more likely to introduce products and services that are new to the market. As a result, firms can benefit more from their R&I activities. Secondly, our findings indicate that despite public financial support for R&I prompting firms' engagement in more R&I, treated firms are as likely as untreated firms to perceive knowledge constraints. Therefore, such support may enable firms to enhance their R&I capabilities (Clarysse *et al.* 2009), which subsequently impacts their confidence and ability to engage in, and complete, more radical R&I projects (Amore 2015). Viewed this way, public financial support may lead to long-term improvements in firms' R&I capabilities.

Our findings may also point to a new perspective when interpreting information on perceived constraints to R&I, as included in innovation surveys, such as the Community Innovation Survey (CIS). Previous debates on this topic centred on whether perceived constraints hampered R&I (Pellegrino and Savona 2017), or whether they indicated firms' ability to overcome them (Baldwin and Lin 2002). In both cases, the arguments were informed by quantitative measures of firms' R&I activities, such as firms' likelihood to innovate, or their innovation intensity. Our results highlight the importance of focussing on more nuanced measures of innovation when analysing perceived constraints. While firms may innovate less when perceiving constraints, they may innovate better, by focussing on more radical R&I activities, with higher commercial value. In other words, perceived constraints may contribute to firms filtering R&I projects that are most beneficial to them (Keupp and Gassmann 2013).

There are some limitations to our paper, which point to opportunities for future research. From our available data, we could not clearly ascertain how collaborative R&D subsidies affect firms' perceived financial and non-financial constraints. This could provide a fruitful avenue for future research. Moreover, future studies might usefully consider the impact of perceived constraints on firms' decisions to innovate beyond engagement in R&D or the likelihood to innovate, which we could not do due to data limitations. More detailed analyses regarding the relationship between these constraints and the quality of firms' innovations would be beneficial. Finally, it would be interesting for future research to explore the impact of different R&I policy instrument mixes on firms' perceived constraints, an analysis which our data did not permit due to a limited number of firms receiving a mix of public financial support for R&I instruments.

Despite the above, our paper offers important insights for the design and implementation of more effective innovation policy interventions that address firms' non-financial constraints. This is because they demonstrate that public financial support for R&I can help firms to overcome their knowledge and market constraints, particularly in the case R&D subsidies. Providing knowledge and market constrained firms with such support can enable firms to become better innovators, and also improve their ability to deal with future constraints. This may entail deviating from the current objective oriented nature of public funding for R&I

leading to funding agencies 'picking the winners' (Cantner and Kösters 2012; Cunningham *et al.* 2016; Huergo *et al.* 2016). While there is a clear rationale for ensuring that public funding translates into tangible outputs, the insights of our study may be used by academics and policymakers alike to consider broadening the allocation of public financial support for R&I to knowledge and market constrained firms.

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Chapter 5: Subsidising innovation in knowledge-constrained firms: Policy failure or key to radical innovation additionality?

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Authors' Contributions:

I, Mauricio Perez-Alaniz, am the first author of the academic paper. The remaining authors are listed in order of contribution. I was responsible for: (1) the conceptual development of the paper; (2) choosing and refining the methodology; (3) preparing the empirical setting; (4) carrying out the empirical analysis; (5) writing the original draft paper; and (6) incorporating the co-authors' suggestions and comments into the final paper. Helena Lenihan provided expert advice and guidance on all of the above listed activities (1-6), as well as reviewing and editing the paper. She also enabled the research to access the necessary data and resources (i.e. in her role as Principal Investigator [PI] of the Science Foundation Ireland funded project funding this research). Justin Doran provided expert advice on all of the above listed activities (1-6), as well as reviewing and editing the paper. Christian Rammer provided expert advice on the conceptualisation of the paper, methodology, and in reviewing and editing the paper.

Abstract

How to effectively allocate public financial support for Research and Innovation (R&I) remains the focus of academic and policy debates. This is especially true with regard to using the support to encourage innovations with high economic and social returns, such as new-to-market goods and services (i.e. radical innovation). Our study is the first to critically analyse whether subsidising innovation in knowledge constrained firms results in sub-optimal rates of returns (i.e. policy failure), or higher radical innovation additionality. Using novel matched firm-level data from 2008 to 2016, and administrative data on public funding for R&I available to firms in Ireland, our study finds that: (a) subsidising innovation in firms with insufficient human capital resources may lead to policy failure; but (b) subsidising innovation in firms that lack information on technologies and markets can result in higher radical innovation additionality. Our study offers critical insights for theory, and for informing a more impactful allocation of public financial support for R&I.

5.1 Introduction

Governments in many countries provide firms with public financial support for their Research and Innovation (R&I) activities. Using scarce public resources in this way is usually justified on the basis of addressing market and systemic failures (e.g. the generation of knowledge spillovers, imperfect financial markets, or institutional disincentives for collaboration), that can curtail firms' R&I activities (Arrow 1962; Bleda and Del Río 2013; Jugend *et al.* 2020). Addressing market and systemic failures is desirable, as firm-level R&I can yield important social returns, such as improved productivity and high quality employment (Beck *et al.* 2016; Edler and Fagerberg 2017; Hewitt-Dundas *et al.* 2019). However, how exactly governments can maximise the innovative outputs and associated social return of public financial support for R&I remains unclear (Roper *et al.* 2013; Del Bo 2016; Mazzucato and Semieniuk 2017). Ensuring an efficient allocation of government support is paramount (Vanino *et al.* 2020), but as highlighted by Haapanen *et al.* (2014), information asymmetries can result in governments misallocating public financial support for R&I. In their view, this is a form of policy failure, which can potentially exacerbate the market and systemic failures that the support intends to address.

A widely accepted way in the literature to minimise policy failure, is to target public financial support for R&I to firms with limited internal financial resources and access to external finance (i.e. financially constrained firms) (Busom *et al.* 2014; Carboni 2017). The rationale is that allocating public funding to financially-constrained firms can minimise deadweight spending effects, which refer to public funding substituting, rather than complementing, private R&I investments (Lenihan and Hart 2004; Carboni 2017).

As suggested by Haapanen *et al.* (2014), another important way to minimise policy failure, which is the focus of this research, is to allocate public financial support for R&I to firms with high levels of R&I capabilities. The rationale here is that allocating public financial support for R&I to more capable firms can minimise potential policy failure, which may arise due to firms failing to produce returns from public R&I investments (Haapanen *et al.* 2014; Cowling 2016; Mina *et al.* 2021). A potential problem which may arise from targeting the support to highly R&I capable firms, however, is that such firms may use it to engage in R&I projects which can be completed with existing knowledge (Becker 2015). This, in turn, may result in lower levels of social returns, as the support may not translate into new knowledge (Del Bo 2016; Mazzucato and Semieniuk 2017).

Furthermore, as Wanzenböck *et al.* (2013), Becker (2015), and Nilsen *et al.* (2020) have observed, public financial support for R&I can induce higher input and output additionality effects in firms, which *a-priori*, have lower level of R&I capabilities (i.e. firms with limited R&I experience, and firms in less knowledge intensive sectors). This higher additionality likely results from less capable firms performing R&I activities that they would not normally perform, without government support (Clarysse *et al.* 2009; Wanzenböck *et al.* 2013; Chapman and Hewitt-Dundas 2018). Nilsen *et al.* (2020, p. 1), therefore, posit that public financial support for R&I should focus on firms with fewer R&I

capabilities, but with high levels of R&I ambition. As an illustrative example, they posit that the support should target "R&D-starters over R&D-incumbents, that is, shifting the focus from the intensive to the extensive margin".

Our paper makes a distinct contribution to the above debate, by critically examining how public financial support to R&I drives radical innovation activities between firms that perceive knowledge constraints, and firms not perceiving such constraints. In this paper, radical innovation is defined as the introductions of goods and services that are new to the market (Hewitt-Dundas *et al.* 2019). Our focus on radical innovation is crucial, as this R&I activity is widely recognised in the literature as a key to maximise the social returns of public financial support for R&I (Beck *et al.* 2016; Mina *et al.* 2021; Solomon 2021). This is because radical innovation may require firms to generate new knowledge, which is a key positive externality of firms' R&I activities (Autio *et al.* 2008; Laursen and Salter 2014). Radical innovation is also crucial for firms' competitiveness and overall productivity levels (Beck *et al.* 2016; Hewitt-Dundas *et al.* 2019).

Following Dosi *et al.* (2021), firms' R&I capabilities are cumulative and specific to each firm, and almost impossible to measure precisely. Our focus on perceived knowledge constraints is thus vital, as they represent firms' self-assessment of the specific knowledge obstacles curtailing their R&I activities (Pellegrino and Savona 2017; Szambelan *et al.* 2020). Perceiving knowledge constraints may not necessarily reflect that firms have no resources and capabilities for R&I. They primarily highlight that firms' existing resources and capabilities may be unsuitable to deal with specific challenges in their innovative paths, which may impede their ability to perform their desired R&I activities. This is because firms need to match their resources and expertise to specific R&I activities, and firms may perceive constraints once they engage in these activities (D'Este *et al.* 2012; Galia and Legros 2004). Overcoming perceived knowledge constraints may thus be a necessary step for developing R&I capabilities, and engaging in R&I activities, especially in more distant and radical ones (Hewitt-Dundas 2006; Antonioli *et al.* 2017; Radicic 2021).

Furthermore, the perception of constraints to R&I is widely recognised in the literature to be endogenous of firms' innovative efforts (Blanchard *et al.* 2013; Lahr and Mina 2021). Viewed in this way, the perception of constraints may indicate that firms aim to engage in more ambitious R&I projects, for which they may have insufficient capabilities and assets to complete (Galia and Legros 2004; Mohnen *et al.* 2008; D'Este *et al.* 2012). The focus on perceived knowledge constraints, therefore, is suitable for investigating the above contrasting views regarding how to best allocate public financial support for R&I. As is commonly operationalised by previous studies, such as D'Este *et al.* (2014) and Antonioli *et al.* (2017), we focus on the following perceived knowledge constraints: (a) a lack of qualified personnel within the enterprise; (b) a lack of information on technology and markets; and (c) difficulty in finding collaboration partners for innovation.

To the best of our knowledge, ours is the first study to critically analyse whether providing public support for R&I to knowledge constrained firms results in ‘policy failure’, or higher levels of additionality, in the context of radical innovation. This is a key contribution, as the theoretical rationale guiding the allocation of public financial support for R&I, which suggests that firms with high levels of R&I capabilities can maximise the social returns of such support, is not fully supported by the empirical evidence (Wanzenböck *et al.* 2013; Nilsen *et al.* 2020). From a policy perspective, programme officials may typically “favour ventures that promise to favorably contribute to employment growth and structural change” (Cantner and Kösters 2012, p. 923). However, targeting highly R&I capable firms may exacerbate existing gaps between more and less R&I capable firms, while having little impact on the critical mass of innovators in the economy (Berrutti and Bianchi 2020; Nilsen *et al.* 2020). This is a problem, as enhancing the pool of innovating firms is vital for societal and economic development (Hall *et al.* 2016; Pellegrino 2018). The insights of our study can thus inform the design and implementation of more effective and impactful allocation policies for public financial support for R&I to drive radical innovation in firms.

Furthermore, Pellegrino and Savona (2017) and Szambelan *et al.* (2020), have noted that an understanding of how firms can overcome their constraints to R&I remains limited. This is especially in the context of the knowledge constraints considered here (i.e. a lack of personnel; a lack of information on technologies and markets; and difficulties in findings partners to collaborate with). Keupp and Gassmann (2013, p. 1457), have also specifically highlighted that our existing understanding of how firms’ perceived constraints, such as knowledge constraints, affect radical innovation in firms remains limited. In particular, they posited that, "to date, few studies have analyzed resource constraints as antecedents of RI [radical innovation] outcomes". Here, our study makes a distinct contribution to an understanding of whether public financial support for R&I can be used to help firms overcome their knowledge constraints, and drive radical innovation in firms.

Our analysis uses a novel and detailed database with information on firms in Ireland. The data include information on firms' perceived knowledge constraints and their radical innovation activities, from two waves (i.e. 2010 and 2016) of the Innovation in Irish Enterprises Survey (IIE, formerly known as Community Innovation Survey [CIS]).[44] The data specifically observe firms' knowledge constraints during the period 2008-2010, and their radical innovation activities performed during the period 2014-2016. These survey data are merged with administrative data on public financial support instruments to drive firm-level R&I in Ireland, from the country's three main funding agencies. These are Enterprise Ireland (EI), IDA Ireland, and Science Foundation Ireland (SFI). Data on R&D tax credits from Ireland's Revenue Commissioners are also merged. Our administrative data cover the period 2011-2015, which is the intervening period between the two waves of the IIE survey. Our data thus enable us to perform a detailed analysis of how public financial support for R&I impacts the radical

[44] The IIE survey is a stratified random sample of enterprises with at least 10, and a maximum of 49, persons engaged, and a census of firms with at least 50 persons engaged. The survey only includes enterprises in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73. For further details see: https://www.cso.ie/en/methods/scienceandtechnology/innovationinirishenterprisesformerlyknownascommunityinnovationsurvey.

innovation activities of firms that perceived knowledge constraints, and firms that did not perceive such constraints. This is achieved by employing a two-stage process, by performing our econometric analysis on a balanced sample, which is obtained by using rigorous direct propensity score matching (PSM) methodologies (Czarnitzki and Lopes-Bento 2013; Vanino *et al.* 2020). Our sample comprises 1,296 firms, with a total of 223 firms receiving public financial support for R&I during 2011 to 2015, from which 150 firms perceived some form of knowledge constraints in 2010.

Ireland is an interesting locale for our study because knowledge constraints represent key obstacles to R&I for firms in Ireland, particularly in the context of radical innovation (Hewitt-Dundas 2006; Hewitt-Dundas and Roper 2010; National Competitive Council 2021). This is especially important for Small and Medium-sized Enterprises (SMEs), which represent approximately 99.8 percent of firms in the country (CSO 2020).[45] Similar trends have been observed in other countries in the European Union (Hölzl and Janger 2014; Marin *et al.* 2015), which makes the Irish case highly relevant for other EU countries. Moreover, the Irish Government identifies that supporting firms, especially SMEs, to overcome challenges related to knowledge constraints to R&I, and drive radical innovation in firms, as key innovation policy priorities (Skillnet Ireland 2020; DBEI 2020). This is also the

[45] The European Union recommendation 2003/361 defines small-sized firms as firms with less than 50 employees, medium-sized firms as firms with at least 50 and fewer than 249 employees, and large firms, as firms with at least 250 employees. The recommendation also classifies firms according to their turnover or balance sheet (see http://data.europa.eu/eli/reco/2003/361/oj), but the number of employees is the most commonly used classification (Eurostat, 2019). Data for firms with fewer than 10 employees were not available to this study.

case beyond Ireland, in countries such as the UK and Germany (see, for example, HM Treasury 2021; Federal Ministry for Economic Affairs and Energy of Germany 2019). The insights of our study can thus signal potential avenues for using public financial support for R&I to help firms overcome their knowledge constraints and drive firm-level radical innovation in different country contexts.

The remainder of the paper is organised as follows. Section 5-2 reviews the literature regarding how firms' knowledge constraints may affect the extent to which public financial support for R&I drives radical innovation in firms. The section also posits the hypotheses guiding the empirical research. Section 5-3 discusses the data and the empirical approach used. Section 5-4 presents and discusses our main findings *vis-à-vis* the prevailing literature. Section 5-5 concludes with some implications for innovation policy and avenues for future research.

5.2 Conceptual development and hypotheses

We evaluate the radical innovation output additionality of public financial support for Research and Innovation (R&I) between firms that perceive knowledge constraints, and firms that do not perceive such constraints. As outlined earlier, in this paper, radical innovation refers to the introduction goods and services that are new to the market (Hewitt-Dundas *et al.* 2019). As is common in the literature (D'Este *et al.* 2012; Antonioli *et al.* 2017; Pellegrino 2018; de Oliveira and Rodil-Marzábal 2019), we consider the following perceived knowledge constraints: (a) a lack of qualified personnel within the enterprise; (b) a lack of information on technology and markets; and (c) difficulty in finding collaboration partners for innovation.

Focusing on the above perceived knowledge constraints is important as they provide a direct indication of the specific knowledge obstacles affecting firms' R&I activities (Pellegrino and Savona 2017; de Oliveira and Rodil-Marzábal 2019). Firms' R&I capabilities are largely embodied in their employees (Borrás and Edquist 2013; Ryan *et al.* 2018). An adaptable, flexible, and proactive workforce is vital for responding to changes in markets and sustaining competitive advantage (D'Este *et al.* 2014; Wenke *et al.* 2021). Therefore, a perceived lack of qualified employees may hinder firms' abilities to develop R&I capabilities, and engage in R&I activities (Escribano *et al.* 2009; OECD 2011; D'Este *et al.* 2014). Firms' abilities to identify, assimilate, and benefit from external information regarding technologies and markets constitutes their absorptive capacity, which is a key R&I capability (Cohen and Levinthal 1990; Caloghirou *et al.* 2004; Garcia Martinez *et al.* 2017). As a result, a perceived lack of access to external information regarding the latest technological developments and market dynamics is a key limitation for developing R&I capabilities (Puente *et al.* 2015; Holl 2021). Firms may overcome internal resource constraints for R&I by engaging in collaborations with clients, suppliers, other firms, and public knowledge providers (i.e. universities and research centres) (D'Este *et al.* 2016; Antonioli *et al.* 2017). Firms that perceive difficulties in finding potential collaborators for R&I may be unable to internalise spillovers from collaborative R&I (Antonioli *et al.* 2017).

The above perceived knowledge constraints can represent important obstacles for radical innovation in firms (Radicic 2021). This is because radical innovation may require firms to develop new knowledge with disruptive potential (Mina *et al.* 2021), and access cutting-edge scientific and technological knowledge externally (Yang *et al.* 2014; D'Este *et al.* 2016). As outlined above, knowledge constraints may hinder firms' abilities to successfully perform these activities. However, firms may perceive constraints as they become more innovative, and focus on R&I activities for which they have insufficient capabilities and resources (Galia and Legros 2004; D'Este *et al.* 2012; Hölzl and Janger 2014). This means that perceived knowledge constraints are endogenous to firms' R&I activities (Lahr and Mina 2021). It is possible, therefore, that firms may use public financial support for R&I to develop new capabilities and absorptive capacity (Keupp and Gassmann 2013). This, in turn, may result in higher levels of radical innovation additionality (Wanzenböck *et al.* 2013).

Public financial support for R&I is expected to generate social returns, which are returns that surpass the risk-adjusted opportunity costs of capital (Stiglitz and Wallsten 1999). For such social returns to be realised, public financial support should result in additional R&I activities in firms (i.e. additionality) (Buisseret *et al.* 1995; Castellacci and Lie 2015; Czarnitzki and Delanote 2017). Furthermore, the social returns of the support may be highest when it drives R&I activities with high levels of risks and rewards, such as radical innovation (Beck *et al.* 2016; Mazzucato 2016). This is because firms may need to generate new knowledge and expand the technological frontier to innovate radically (Kobayashi *et al.* 2011;

Padilla-Pérez and Gaudin 2014). Given the non-rival nature of knowledge, the development of radical innovation can create positive externalities (Roper *et al.* 2013; Florio *et al.* 2016). By innovating radically, firms can increase sales and enter new markets (Hewitt-Dundas *et al.* 2019; Vanino *et al.* 2020). It can also indirectly benefit other firms, by for example, enabling innovation through imitation and/or reverse engineering (Kobayashi *et al.* 2011; Roper *et al.* 2017). Radical innovation may thus result in superior social returns of public financial support for R&I (Beck *et al.* 2016; Mazzucato and Semieniuk 2017).

The remainder of this section explores how the above knowledge constraints may moderate the extent to which public financial support for R&I results in firms successfully innovating radically.

5.2.1 Lack of qualified employees: Public financial support and radical innovation

Firms with higher levels of resources and capabilities for R&I are typically more likely to innovate (Weiss *et al.* 2013; Fudickar and Hottenrott 2019). Innovation requires knowledge-creating resources (e.g. capital equipment, innovative routines, and sufficiently qualified employees) and R&I capabilities, which are developed by firms' employees in an incremental fashion (Amara *et al.* 2016; Zobel *et al.* 2017). As proposed by Xue *et al.* (2021), low levels of R&I capabilities may translate into lower R&I productivity levels. Public financial support for R&I can drive radical innovation in firms (Beck *et al.* 2016), but a perceived lack of qualified employees can hinder the impact of this support in at least two ways.

Firstly, a perceived lack of qualified employees can hinder firms' abilities to solve complex knowledge problems when developing radical innovation (Corradini and De Propris 2017). As proposed by Cyert and March (1963), solving simple knowledge problems may require firms to engage in directional types of search, such as trial and error and learning by doing, whereby firms build on their existing expertise. Solving more complex problems, such as those inherent in radical innovation, may require more holistic search approaches (Nelson 2011; Lobo and Whyte 2017). In other words, firms may need to combine multiple strands of knowledge (e.g. scientific, technological), and develop deep knowledge competencies, including scientific knowledge, across a range of scientific, technological and market-related fields (Fleming and Sorenson 2004; Dosi *et al.* 2006; Fudickar and Hottenrott 2019). Identifying what knowledge is valuable, and how such value may be obtained, requires high levels of absorptive capacity, and specialised knowledge in the subject matter (Lim 2004; Heshmati and Loof 2006; Laursen and Salter 2014; Cohen and Fjeld 2016). For example, according to Escribano *et al.* (2009), scientific publications can be a vital source of new knowledge for radical innovation, but firms without R&D employees with previous publishing experience may be unaware of such publications.

Secondly, a perceived lack of qualified employees may result in a higher probability of radical innovation failure. As demonstrated by D'Este *et al.* (2016), firms' engagement in radical innovation, and their probability to fail, are highly interdependent. However, having a highly qualified R&D employee base is an important determinant of radical innovation success (D'Este *et al.* 2016). In a similar vein, Radas and Bozic (2012) demonstrate that weak R&I resources and capabilities are associated with a higher probability of firms abandoning R&I projects. As Cowling (2016, p. 576) posits, "you can throw as much money as you like at a firm with no coherent innovation strategy, strategic commitment, or intentionality to innovation and little tangible is likely to happen." This leads to our first hypothesis:

H1a: A perceived lack of qualified employees will have a negative effect on the extent to which public financial support for R&I drives radical innovation in firms.

In contrast, Keupp and Gassmann (2013, p. 1458) highlight that "perceptions of resource inadequacy may trigger a variety of novel search paths, such as socialization, recombination, and internalization". Therefore, as firms realise that they lack a key R&I resource (such as qualified R&I employees), they may seek to obtain public financial support for R&I as an opportunity to address this issue. For example, firms may focus on learning by doing, and/or provide formal training.

Moreover, firms that perceive to lack sufficiently qualified employees may be less likely to fall into 'competency traps' (Levinthal and March 1993). Competency traps refers to a situation where firms with deep internal knowledge competencies, face important opportunity costs when exploring other sources of knowledge (Levinthal and March 1993; McDermott and O'Connor 2002; Antolín-López *et al.* 2015). They can represent "a standard, potentially self-destructive product of learning" (Levinthal and March 1993, p. 106), as they can reinforce organisational inertia, rigid R&I routines, and technology lock-in (Chadha 2011; Borrás and Edquist 2013; Triguero *et al.* 2016). Ultimately, competency traps can lead to risk aversion to changes that could destabilise core competencies within the organisation, such as those changes enabled by radical innovation (Tushman and Anderson 1986; Christensen 1997; Klewitz and Hansen 2014; Torugsa and Arundel 2017). Firms that perceive to have lower levels of R&I capabilities, due to a lack of qualified employees, may face lower opportunity costs for developing more radical forms of innovation. This means that there is more scope for public financial support for R&I to induce more persistent behavioural changes in firms (Wanzenböck *et al.* 2013; Nilsen *et al.* 2020), such as re-orienting their R&I activities towards radical innovation (Beck *et al.* 2016). We, therefore, hypothesise that:

H1b. A perceived lack of qualified employees will have a positive effect on the extent to which public financial support for R&I drives radical innovation in firms.

5.2.2 Lack of information on markets and technology: Public financial support and radical innovation

A perceived lack of information on markets and technology refers to firms being unable to source commercially valuable information from the local business environment (D'Este *et al.* 2012). This can hinder the extent to which public financial support for R&I drives more radical innovation in firms through several mechanisms.

Firstly, the notion of an innovation being 'radical' implies that new goods and services have distinctive advantages over existing goods and services (McDermott and O'Connor 2002; Troilo *et al.* 2013). To ascertain that this is the case, firms need to have in-depth knowledge of existing technologies (Kim 1998; Adner 2006; He *et al.* 2006). Some specialised knowledge could be obtained through formal and codified channels (i.e. scientific publications and the education system). However, cutting-edge knowledge may be tacit, and highly localised (Koskinen and Vanharanta 2002; Hauser *et al.* 2007; De Massis *et al.* 2018). Moreover, firms also need to have a deep understanding of whether a market exists for radical innovation, and the potential challenges that may arise from the market (e.g. resistance by end users) (McDermott and O'Connor 2002). Therefore, to innovate radically, firms must be able to access and identify valuable information regarding the current markets dynamics, and how markets may behave in the future, at least in the short-term (McDermott and O'Connor 2002; Roper and Hewitt-Dundas 2015). The perception of absence of timely information on technologies and markets may increase the associated risks of radical innovation, by increasing uncertainty, which is a major deterrent of firm-level R&I (Hall *et al.* 2016).

Secondly, radical innovation may require firms to 'unlearn' previous knowledge and skills, and learn new knowledge and skills that did not previously exist within their organisational boundaries (Yang *et al.* 2014, p. 152). In doing so, firms may face strong internal resistance to change, as new organisational routines may entail re-shaping existing dynamics and organisational cultures (Nijssen *et al.* 2006; Chadha 2011; Holl 2021). Firms may need to have a strong rationale to justify why such changes are needed, and how they will ultimately lead to firm-level improvements, in order to cultivate motivation and a willingness to change (Montalvo 2006), which are vital drivers of R&I (Lenihan *et al.* 2019). Firms that perceive a lack of access to timely and reliable information on markets and technologies, may not be able to overcome internal resistance to change. We, therefore, hypothesise that:

H2a: A perceived lack of information on technologies and markets will have a negative effect on the extent to which public financial support for R&I drives radical innovation in firms.

There are some avenues through which public financial support for R&I can also lead to important positive changes in the way that firms perform R&I activities. Chapman and Hewitt-Dundas (2018), for example, demonstrate that some forms of public financial support, such as innovation vouchers, can lead to managers and owners being more open to external knowledge. In addition, according to Wanzenböck *et al.* (2013), public financial support for R&I can lead to firms to develop new R&I capabilities, by for example, engaging in knowledge exchange and transfer in R&I collaborations. Szambelan *et al.* (2020) also propose that firms' actions can have an impact on their mindsets. This, in turn, can enable firms to overcome some constraints to R&I, such as those arising from a perceived lack of market demand for innovation. Based on the above, public financial support for R&I can represent a vital opportunity for firms that perceive a lack of information on technologies and markets to engage in new knowledge creating activities, and innovate radically (Keupp and Gassmann 2013). We, therefore, hypothesise that:

H2b: A perceived lack of information on technologies and markets will have a positive effect on the extent to which public financial support for R&I drives radical innovation in firms.

5.2.3 Perceived difficulties to finding partners to collaborate with: Public financial support and radical innovation

Finally, we turn our attention to a perceived difficulty in finding collaborative partners for R&I projects. As de Faria *et al.* (2020) highlight, firms' R&I processes are increasingly dependent on joint ventures and collaborative agreements. By engaging in collaborative R&I, firms may avoid "wasteful duplication" of R&I efforts (Goel and Saunoris 2021, p. 2), develop more efficient allocation of R&I resources (Holl 2021), and assimilate technology, knowledge, and industry best practices (Davenport *et al.* 1998; Borrás and Edler 2020). According to Inauen and Schenke-Wicki (2012) and Jugend *et al.* (2018), firms are more dependent on external knowledge from R&I collaboration when developing radical innovations, than when developing incremental innovations. Engaging in R&I collaborations can also constitute a viable coping strategy for firms to overcome their constraints (Antonioli *et al.* 2017).

Public financial support for R&I can positively impact firms' propensities to adopt more open R&I strategies (see, for a recent review, Jugend *et al.* 2020). However, this may not be possible if firms perceive that they cannot identify suitable partners to collaborate with. This is especially the case for collaborations with local knowledge providers such as universities, which can enable access to specialised knowledge, that firms can use for radical innovation (Corradini and De Propris 2017; Cassiman *et al.* 2018). We thus hypothesise that:

H3a. Perceived difficulties in finding partners for collaborations will have a negative effect on the extent to which public financial support for R&I drives radical innovation in firms.

However, the situation is more complex than as described above. Firms may experience several constraints for engaging in collaborative R&I activities. Most notably, firms may experience constraints related to their ability to benefit from external knowledge, and manage R&I collaborations (Cassiman *et al.* 2018; Hewitt-Dundas *et al.* 2019). Amongst different types of R&I collaborations, collaborations with public knowledge providers may be particularly difficult to manage by firms with limited previous R&I experience (Hewitt-Dundas *et al.* 2019). According to Ryan *et al.* (2018), there are multiple challenges that may arise in industry-university collaborations that can result in tensions between partners, or even cause collaborative projects to fail. These include misunderstandings of roles and expectations, conflicting objectives and interests, different timescale expectations, and intellectual property disputes. In addition, as proposed by Scandura (2016, p. 1910), knowledge transfer between collaborative partners in industry-university collaborations is not seamless, as "the acquisition of external know-how through R&D cooperation requires internal efforts to be successfully implemented inside companies".

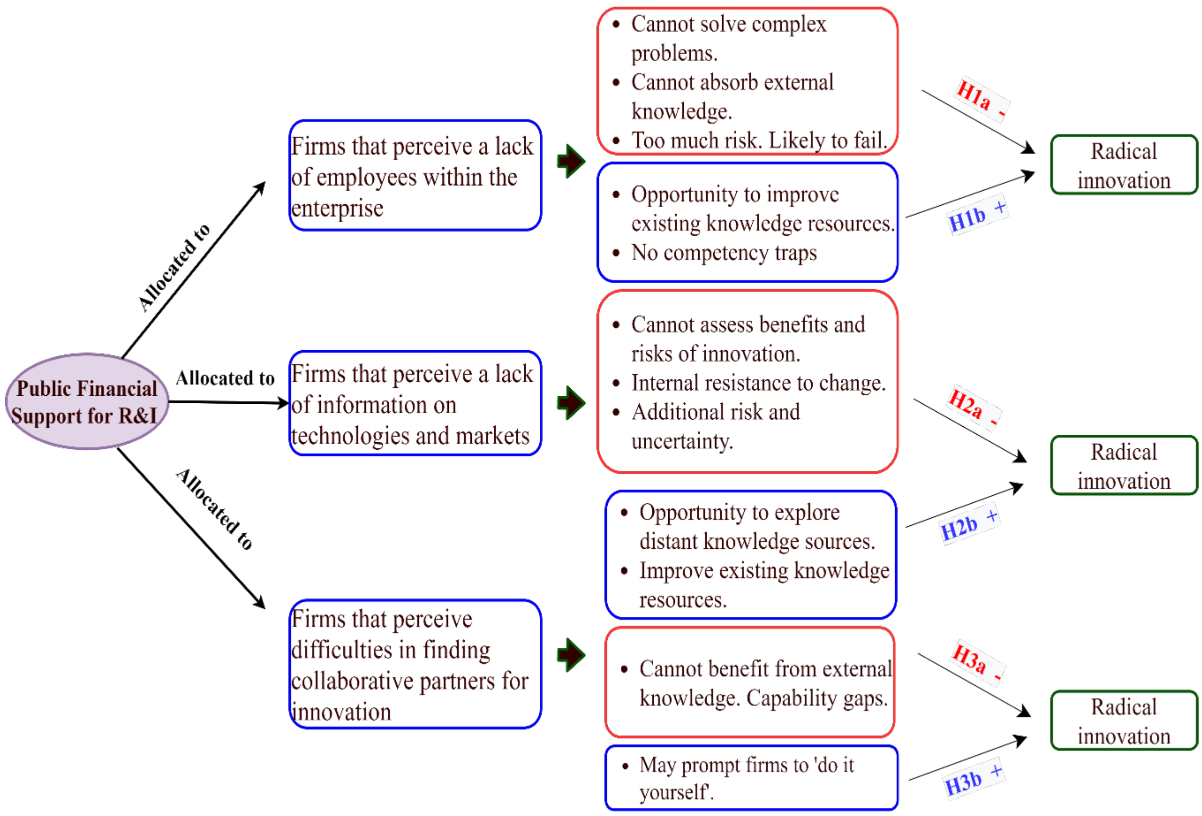
Considering the above, firms that perceive a lack of partners to collaborate with, may see public financial support for R&I as an opportunity to engage in more distant research activities internally, as a means to build R&I capability, and drive radical innovation (Clarysse *et al.* 2009; Wanzenböck *et al.* 2013). Such a strategy may also entail avoiding the potential risks that collaborating with external partners may bring about. This is especially when engaging in radical innovation, as this may already pose a challenge for firms, given that they need to extend their existing knowledge competencies. Based on this, we hypothesise that:

H3b. Perceived difficulties in finding partners for collaborations will have a positive moderating effect on the extent to which public financial support for R&I drives radical innovation in firms.

5.2.4 Hypotheses summary

Figure 5-1 summarises the hypotheses as proposed in Section 5.2.1 to Section 5.2.3. As the Figure illustrates, there are several mechanisms though which perceived knowledge constraints can moderate the impact of public financial support for Research and Innovation (R&I) on firms' radical innovation activities. In line with Haapanen *et al.* (2014) and Cowling (2016), allocating public financial support for R&I to knowledge constrained firms may indeed result in policy failure (H1a, H2a, and H3a). However, in a similar vein to Wanzenböck *et al.* (2013) and Nilsen *et al.* (2020), it is also possible that perceived knowledge constraints result in public financial support for R&I driving higher levels of radical innovation in firms (i.e. H1b, H2b, and H3b).

Figure 5-1: Summary of Hypotheses



5.3 Data and empirical approach

We critically analyse the radical innovation additionality of public financial support for Research and Innovation (R&I) between firms that perceive knowledge constraints, and firms that do not perceive such constraints. Our focus on radical innovation is because this form of R&I activity can lead to high social rates of returns (Beck *et al.* 2016; Mazzucato and Semieniuk 2017; Solomon 2021).

Our analysis uses a novel dataset with information on the perceived knowledge constraints, and R&I activities, of 1,296 firms that feature in the 2010 and 2016 waves of the Innovation in Irish Enterprises survey (IEE, formerly Community Innovation Survey [CIS]). The IIE survey is a biennial survey focused on the R&I activities of firms with at least 10 employees.[46] The 2010 IIE survey wave includes information for the period from 2008 to 2010, while the 2016 IIE survey wave covers the period 2014 to 2016. These are the two most recent IIE survey waves available to this study that include questions on firms' perceived constraints to R&I.[47] Evaluating the impact of public financial support for R&I requires controlling for firms' heterogeneities affecting their likelihood to obtain such support (Hottenrott and Lopes-Bento 2014; Nilsen *et al.* 2020). Moreover, our focus on perceived constraints necessitates considering potential endogeneity between firms' perceived constraints and their R&I activities (D' Este *et al.* 2012; Pellegrino 2018; Lahr and Mina 2021). To effectively control for such potential biases, we need to observe firms' R&I activities before and after the receipt of public financial support for R&I. Our analysis thus only considers firms that feature in both the 2010 and 2016 waves of the IIE survey.

The above survey data are merged with detailed administrative data on public financial support instruments to drive R&I in firms in Ireland, from the country's three main funding agencies. These are Enterprise Ireland (EI), Industrial Development Agency Ireland (IDA Ireland), and Science Foundation Ireland (SFI).

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[46] Specifically, the IIE survey is a stratified random sample of enterprises with at least 10, and a maximum of 49, persons engaged, and a census of firms with at least 50 persons engaged. The survey only includes enterprises in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73. For further details see: https://www.cso.ie/en/methods/scienceandtechnology/innovationinirishenterprisesformerlyknownascommunityinnovationsurvey.

[47] The 2012 and 2014 waves of the Innovation in Irish Enterprises Survey did not include questions on firms' constraints to R&I and are thus not included in this analysis.

EI provides a range of policy support instruments for Irish-owned firms from start-up to maturity, with a particular focus on innovation and exporting activities (Enterprise Ireland 2019). IDA Ireland mainly focuses on attracting and supporting investments into Ireland by foreign-owned multinational corporations (IDA 2020). Given the focus the current paper, our analysis is restricted to financial support instruments that focus on driving firm-level R&I. SFI primarily funds scientific research in higher education institutions, but SFI funded institutions can also provide cutting edge knowledge to firms through co-funded collaborative research projects (SFI 2018). Our data include information on firms that have engaged in R&I collaborations with SFI's research centres. Finally, information on R&D tax credits from Ireland's Revenue Commissioners, which oversees all tax-related matters in Ireland, are also merged.[48] The administrative data cover the period 2007 to 2016. However, given the data structure of the above IIE survey data, we limit our analysis to all public financial support instruments to drive firms' R&I activities from 2011 to 2015 (i.e. the intervening period between the two IIE survey waves).

The resulting dataset comprises information on the perceived knowledge constraints and R&I activities of 1,296 firms (i.e. from 2008 to 2010), information on the allocation of public financial support for R&I instruments for 223 firms (i.e. from 2011 to 2015), and information on the radical innovation activities of the same 1,296 firms for the period 2014 to 2016. From the 223 firms that received public

[48] R&D tax credits are available to all firms in Ireland. Firms can claim a 25% Tax Credit on the following R&D-related expenditure: systemic, investigative, or experimental activities, be in the field of science or technology, involve basic research, applied research, and/or experimental development, seek to make scientific or technological advancement, involve the resolution of scientific or technological uncertainty (Irish Revenue Commissioners, 2020).

financial support for R&I, 134 firms perceived a lack of qualified employees within the enterprise, 138 perceived a lack of information on technologies and markets, and 96 firms perceived difficulties in funding partners for R&I, in 2010. While firms typically perceive more than one form of knowledge constraint, we focus on each specific knowledge constraint. We do this because, as outlined in Section 5.2, the three constraints considered may have distinctive impacts on firms' radical innovation activities.

A potential limitation which may affect our data, is that the construction of such a detailed dataset resulted in a limited number of observations in our effective sample. This can be problematic, as the firms included in our effective sample may be different than the firms as featured in the IIE survey (i.e. which is representative for firms in Ireland in the following NACE Rev 2 Sectors: 05-39, 46, 49-53, 58- 63, 64-66, 71-73). However, as Table 5-1 demonstrates, this limitation does not affect our analysis. This is because the firms in the effective sample largely maintain the representativeness of the IIE survey (i.e. 2016 survey wave). Therefore, our findings continue to be representative of the firms in IIE survey.

Table 5-1 Composition of our Effective Sample in comparison to 2016 Innovation in Irish Enterprises (IEE) Survey wave

Variables	Innovation in Irish Enterprises Survey 2016 (n = 2,576)		Effective Sample (n = 1,296)	
	(n)	(%)	(n)	(%)
Irish Owned firms (Yes = 1)	1570	60.952	919	70.914
Small-sized firms (Yes = 1)	1681	65.261	832	64.212
Medium-size firms (Yes = 1)	726	28.182	366	28.239
Large-sized firms (Yes = 1)	169	6.565	98	7.557
Part of Enterprise Group (Yes = 1)	960	39.271	492	36.232
Sector B (Mining and Quarrying)	25	0.962	14	1.080
Sector C (Manufacturing)	933	36.284	483	37.272
Sector D (Electricity, Gas, etc.)	7	0.292	3	0.234
Sector E (Water Supply, etc.)	46	1.837	24	1.851
Sector G (Wholesale and retail)	650	25.232	347	26.777
Sector H (Transport and Storage)	289	11.215	139	10.732
Sector J (Information and Comm.).	247	9.671	124	9.574
Sector K (Financial Services)	223	8.670	98	7.561
Sector M (Scientific and Technical act.)	124	4.822	64	4.943
Product Innovation (Yes = 1)	1607	62.385	844	65.124
Process Innovation (Yes = 1)	1600	62.111	787	60.731
Organisational Innovation (Yes = 1)	1638	63.628	731	66.428
Received Public Financial Support for R&I (Yes = 1)	329	12.772	150	11.572

5.3.1 Dependent variables

Our study focuses on firms' radical innovation activities. In a similar vein to Doran and Ryan (2014a), D'Este *et al.* (2016) and Hewitt-Dundas *et al.* (2019), we measure firms' introduction of radical innovations in binary form. The variable

Rad_Innovation (See Appendix 5-B) takes the value of one if firms introduced new to the market goods and services in the three years of each of IIE survey wave, otherwise, the value is zero. A limitation of such a measure, in the context of this study, is that it does not indicate where firms' radical innovations have been successful in the market. This is important, as the social returns of financial support for R&I may only be fully realised if firms are able to generate economic benefits from their radical innovations (Cowling 2016; Nilsen *et al.* 2020). Based on this, and following Beck *et al.* (2016), we construct a second measure for radical innovation, which comprises the total turnover that firms obtain from engaging in the introduction of radical innovation in the market. Specifically, we use the natural logarithm of total turnover from radical innovation divided by their number of employees. Normalising by the number of employees is standard in the literature to control for structural differences between firms of different sizes (Heshmati and Loof 2006; Vanino *et al.* 2020).

5.3.2 Independent variables

Our independent variables of interest pertain to public financial support for Research and Innovation (R&I) and firms' perceived knowledge constraints. To measure the receipt of public financial support for R&I, we construct a binary variable that takes the value of one if firms received public financial support from R&I from any of the funding agencies discussed earlier (i.e. EI, IDA Ireland, SFI and the Revenue Commissioners). Otherwise, the value is zero. Some of the instruments considered here are not necessarily allocated to firms, but the funding is provided to local knowledge providers, such as universities and research centres (i.e. SFI funded collaborations). However, as Scandura (2016) and Vanino *et al.* (2020) have demonstrated, such type of public financial support is vital for driving more R&I efforts in firms. This is especially in the context of more explorative research, which is associated with radical innovation (Cassiman *et al.* 2018; Ryan *et al.* 2018). Moreover, given the multiple different types of public financial support instruments for R&I provided by the above funding agencies, as presented in Appendix 5-C, it is not possible to perform our analysis for each individual instrument. Using aggregated measures of public financial support for R&I is common in the literature (Czarnitzki and Lopes-Bento 2014). In addition, an advantage of our administrative data is that includes public R&I financial instruments, such as funding for industry-university collaborations, which are not typically recorded in innovation surveys (e.g. the Community Innovation Survey) (Czarnitzki and Lopes-Bento 2013; Hottenrott and Lopes-Bento 2014).

We measure firms' perceived knowledge constraints from specific questions in the IIE survey regarding the factors hampering firms' R&I activities, which is in line with previous studies on this topic (D'Este *et al.* 2012; Antonioli *et al.* 2017; Pellegrino and Savona 2017; Pellegrino 2018). The 2010 IIE survey includes a total of nine hampering factors, which are organised under three sub-headings: (a) cost factors; (b) knowledge factors; and (c) market factors. Appendix 5-D includes the framing of the question as included in the 2010 IIE survey wave. We construct our constraints measures from the above questions, but as our study specifically focuses on knowledge constraints, we only consider the perceived constrains under the sub-heading 'knowledge factors'. As detailed earlier in Section 5.2, these are (i) a lack of qualified personnel within the enterprise; (ii) lack of information on technology; (iii) a lack of information on markets; and (iv) difficulty in finding collaboration partners for innovation. As discussed in Section 5.2.2, a lack of information on technology, and a lack of information on markets, pertain to a lack of information in the firms' local environment. Therefore, they are operationalised as one variable (i.e. lack of information on technologies and markets).[49]

For each of the above perceived knowledge constraints, firms are required to indicate the extent to which the constraint affected their R&I activities in the previous three years, in the following way: 1=high importance; 2=medium importance; 3=low importance; and 4=not encountered. Following Pellegrino and Savona (2017), we create three binary variables, one for each of the above knowledge constraints, that equal one if firms perceived the constraint at any level of importance. For example, the variable '*Lack of qualified personnel'* (see Appendix 5-B) equals one if firms perceived a lack of qualified employees to have a low, medium or high level of importance for their R&I activities in the previous three years (i.e. 2008 to 2010). For robustness, we create three additional binary variables, which measure the constraints at each individual level of importance (i.e. low = 1, medium = 1, and high =1) (Iammarino *et al.* 2009). This results in a total

[49] We repeated our analysis with each individual variable, yielding almost identical results, than when the two variables are grouped into one single variable. An advantage to group the variables is that it enables more observations in the constrained-and constrained-untreated categories, thereby improving the precision of our findings.

of 9 additional binary variables (which, in addition to the initial 3 variables as described above, totals 12 variables). Appendix 5-E presents the distribution of the perceived constraints variables between treated and untreated firms.

5.3.3 Control variables

Our analysis controls for firms' key characteristics (i.e. from 2008 to 2010) that may affect their likelihood to obtain public financial support for R&I (i.e. from 2011 to 2015), and the subsequent impact of the support on their radical innovation activities (i.e. in 2014 to 2016). Specifically, our analysis controls for firm size, as measured by a categorical variable according to their number of employees (Colombo *et al.* 2013) (i.e. 1 =small-sized, 2 = medium-sized, and 3 = large-sized firms)[50], and three dummy variables measuring whether: (a) firms are Irish or foreign-owned (Doran and Ryan 2014b); (b) firms are part of an enterprise group (Jissink *et al.* 2019); and (c) firms are exporters (Love and Roper 2015).

Furthermore, we consider firms' R&I activities before receiving public financial support for R&I (i.e. from 2008 to 2010). Here, we include (i) a binary variable measuring if firms introduced new to market goods and/or services (Doran and Ryan 2014a); (ii) a count variable (0 to 4) measuring the breadth of innovation partners such as clients, suppliers, other firms, and universities and research centres (Roper *et al.* 2008); (iii) a continuous variable measuring the intensity of turnover

[50] The European Union recommendation 2003/361 defines small-sized firms as firms with less than 50 employees, medium-sized firms as firms with at least 50 and fewer than 249 employees, and large firms, as firms with at least 250 employees. The recommendation also classifies firms according to their turnover or balance sheet (see http://data.europa.eu/eli/reco/2003/361/oj), but the number of employees is the most commonly used classification (Eurostat, 2019). Data for firms with fewer than 10 employees were not available to this study.

derived from radical innovation (Beck *et al.* 2016); (iv) a count variable measuring the types innovations that firms engaged in (i.e. 0 to 4, as per product innovation, process innovation, service innovation, and organisational innovation) to capture the breadth of firms' innovation activities (D' Este *et al.* 2012; Leiponen 2012); and (iv) a set of binary variables measuring whether firms perceived financial, knowledge, and market constraints to R&I in 2010 (at low, medium and high level) (Mateut 2018). Finally, we include one-digit NACE Rev. 2 classifications, to control for sector effects (Katila and Shane 2005). Appendix 5-A describes and summarises all control variables included in our analysis.

5.3.4 Empirical approach

In line with Beck *et al.* (2016) and Barajas *et al.* (2021), we structure our analysis in two stages. In the first stage, we construct a counterfactual scenario comprising firms that received public financial support for Research and Innovation (R&I) (i.e. treated firms), and firms that are statistically similar to these treated firms but that did not receive the support in the period from 2008 to 2010 (i.e. control firms). In the second stage, we use the balanced sample obtained from the first stage, to compare the radical innovation additionality between treated firms that perceived knowledge constraints, and firms that did not perceive such constraints, in the period from 2008 to 2010 (i.e. our initial period).

The above first step is necessary, because evaluating the impact of public financial support for R&I requires controlling for firm-level heterogeneity affecting firms' likelihoods of obtaining public financial support for R&I (Hottenrott and

Lopes-Bento 2014; Nilsen *et al.* 2020). Furthermore, as D'Este *et al.* (2012) and Hölzl and Janger (2014) have demonstrated, firms' innovative levels may influence the extent to which they perceive knowledge constraints. This is carried out with a propensity score matching (PSM) methodology, in a similar way to Czarnitzki and Lopes-Bento (2014) and Vanino *et al.* (2020). PSM relies on the conditional independence assumption (CIA), where treatment and outcome are assumed to be statistically independent for firms with the same set of observable characteristics (Rubin 1977). Under the CIA assumption, the impact of public financial support for R&I can be obtained by comparing the innovative activities between firms that received the support (i.e. treated firms), with the constructed counterfactual of firms that did not receive such support (i.e. control group).

To construct our counterfactual, we estimate firms' probabilities of receiving public financial support, depending on the control variables as described in Section 5.3.3. Appendix 5-E presents the results of the probit regression model used to obtain these probabilities, which are then compiled into a single index, that is the propensity score. The matching of treated and control firms is performed according to the propensity score. In line with Hottenrott and Lopes-Bento (2014), we employ a nearest neighbour approach, by matching treated firms with up to three control firms. However, in the spirit of robustness, we also perform the matching routine with one-to-one matching. Moreover, to ensure that the matching is carried out correctly, we use a narrow caliper of 0.2 points of the standard deviation (Austin 2011), and only allow matches between firms of the same size-group (i.e. 1 = small, 2 = medium, and 3 = larger-sized firms), and one-digit NACE Rev 2 Sectors

(Vanino *et al.* 2020). Appendices 5-F and 5-G present the standard tests performed to ensure balance between treatment and control groups for the counterfactual obtained with 3-nearest neighbours, and one-to-one matching approaches, respectively. The tests show that the matching process has indeed led to a control group of firms that is statistically indistinguishable to the treated firms in the 2008 to 2010 period.

Our study compares how public financial support impacts the radical innovation activities between firms that perceived knowledge constraints, and firms that did not perceive such constraints. As a result, a simple treatment effect analysis is not sufficient. In our second stage, therefore, we disaggregate the impact of public financial support for R&I between firms that perceived, and did not perceive, knowledge constraints in 2010 (i.e. our initial period). To analyse the impact of the support, on firms' probabilities to introduce radical innovation to the market, and how knowledge constraints moderate such an impact, we estimate the innovation production function in Equation (5-1) (Geroski 1990). The analysis is carried out on the balanced sample resulting from the first stage (i.e. PSM):

$$IO_{i2016} = \alpha_i + \beta_1 x_{i2010} + \beta_2 c_{ij2010} + \beta_3 t_i + \beta_4 t_i * c_{ij2010} + u_{i2016} \qquad (5\text{-}1)$$

where *IO* is a binary variable taking the value of 1 if firm *i* in period *t* (i.e. 2016) introduces new to the market goods and services, or zero otherwise. $\beta_1 x_{i2010}$ represents the same set of control measures used for the PSM process (i.e. the variables in Section 3.3), while $\beta_2 c_{ij2010}$ captures whether firm *i* in the period from 2008 to 2010 perceived the knowledge constraint *j* (i.e. lack of qualified employees within the enterprise, lack of information on technology and markets, and difficulty in finding cooperation partners for innovation). $\beta_3 t_i$ denotes whether firms received public financial support for R&I, and $\beta_4 t_i * c_{ijt2010}$ is the interaction between receiving treatment and perceiving the knowledge constraint j. Finally, u_{i2016} is error term, which follows a binary distribution, and is clustered at the industry level using one-digit NACE Rev 2 Sectors codes.

Equation (5-1) is estimated using a probit regression model. We use a similar function to establish whether public financial support for R&I leads to improvements in firms' turnover from radical innovation. However, as our dependent variable is continuous in this second analysis, we estimate Equation (5-1) with ordinary least squares. As discussed above, both models are cross-sectional in nature, but are estimated using a balanced sample of firms that are statistically identical during the 2008 to 2010 period (i.e. before the treatment takes place, see Appendix 5-F and Appendix 5-G). As a result, using a simple probit regression model and ordinary least squares, respectively, is sufficient for obtaining unbiased cause-effect estimates (Rubin 1977; Becks *et al.* 2016; Vanino *et al.* 2020).

From Equation (5-1), $\beta_3 t_i$ informs us about the impact of public financial support for R&I on firms' likelihood to introduce radical innovations. We are interested in $\beta_4 t_i * c_{ijt2010}$, as this interaction term enables us to test our hypotheses. To simplify the interpretation of the coefficients, our results arising from the probit regression model are presented as average marginal effects. As discussed by Karaca-Mandic *et al.* (2012), the marginal effects of interaction terms in non-linear models can be influenced by all other control variables in the model. For this reason, the marginal effects of the interaction term $\beta_4 t_i * c_{ijt2010}$ are obtained by calculating the difference of the marginal effects between firms that received public financial support for R&I and perceived knowledge constraints, and firms that also received this support, but did not perceive such constraints. That is, by considering all control variables, we focus on the discrete change of the average marginal effect of treated firms depending on whether firms perceived knowledge constraints. Here, a negative and significant marginal effect would suggest that knowledge constraints lead to lower levels of radical innovation additionality (i.e. supporting hypotheses H1a, H2a and H3a, depending on the constraint j included in the model). In contrast, a positive and significant marginal effect would indicate that perceiving knowledge constraints results in public financial support for R&I having a larger radical innovation additionality (i.e. thus supporting hypothesis H1b, H2b and H3b, depending on the constraint j included in the model). A non-significant marginal effect would indicate that knowledge constraints do not moderate the impact of public financial support for R&I.

5.4 Empirical findings

Table 5-2 presents how firms' knowledge constraints moderate the extent to which public financial support for R&I drives radical innovation in firms. The results are presented as average marginal effects. In line with Beck *et al.* (2016), Column 1 of Table 5-2 shows that public financial support for R&I increases firms' probabilities to innovate radically, in the region of 14 percent ($p < 0.01$). From Columns 2 and 3, we observe that a perceived lack of qualified employees does not moderate the impact of public financial support for R&I when: (a) the constraint is measured at any level of importance (i.e. low, medium, and high); or (b) firms perceive the constraint as having a low or medium level of importance. However, we find that, when perceived as highly important obstacles, such constraint negatively moderates the impact that the support has on firms' probabilities to introduce radical innovation ($p < 0.05$). The magnitude of the negative coefficients for the interaction term *Constraint High X Treated* in Columns 3 and 4 (i.e. -0.114 and -0.122, respectively) indicate that the impact of public support on firms' probabilities to innovate radically is almost negated, when firms perceive a lack of qualified personnel as a highly important constraint.

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Table 5-2: Knowledge constraints influencing how public financial support drives radical innovation in firms

Introduction of Radical Innovation in Average Marginal Effects										
		A perceived lack of qualified employees			A perceived lack of information on technologies and markets			A perceived difficulty for finding collaborative partners for innovation		
	Rad_Innovation (1 = Yes) (1)	Rad_Innovation (1 = Yes) (dx/dy) (2)	Rad_Innovation (1 = Yes) (dx/dy) (3)	Rad_Innovation (1 = Yes) (dx/dy) (4)	Rad_Innovation (1 = Yes) (dx/dy) (5)	Rad_Innovation (1 = Yes) (dx/dy) (6)	Rad_Innovation (1 = Yes) (dx/dy) (7)	Rad_Innovation (1 = Yes) (dx/dy) (8)	Rad_Innovation (1 = Yes) (dx/dy) (9)	Rad_Innovation (1 = Yes) (dx/dy) (10)
Treatment	0.140***	0.137***	0.134***	0.192***	0.132***	0.138***	0.194***	0.133***	0.133***	0.192***
	(0.047)	(0.043)	(0.039)	(0.023)	(0.040)	(0.044)	(0.022)	(0.040)	(0.039)	(0.023)
Constraint		-0.026			0.047			0.024		
		(0.065)			(0.063)			(0.004)		
Treatment X Constraint		-0.068			0.035			0.020		
		(0.072)			(0.110)			(0.191)		
Constraint_low			0.027	-0.005		-0.059	-0.058		0.027	0.005
			(0.085)	(0.090)		(0.054)	(0.066)		(0.085)	(0.090)
Constraint_med			0.094***	0.086**		0.045	0.041		0.094***	0.086**
			(0.026)	(0.038)		(0.036)	(0.089)		(0.026)	(0.038)
Constraint_high			0.096	-0.015		-0.043*	-0.0156		0.096	-0.015
			(0.104)	(0.084)		(0.025)	(0.062)		(0.104)	(0.084)
Constraint_low X Treatment			-0.002	-0.051		-0.061	-0.251**		-0.002	-0.051
			(0.047)	(0.108)		(0.061)	(0.017)		(0.047)	(0.108)
Constraint_med X Treatment			-0.072	-0.054		-0.036	-0.063***		0.072	-0.054
			(0.084)	(0.162)		(0.082)	(0.016)		(0.084)	(0.162)
Constraint_high X Treatment			-0.114**	-0.122**		0.281***	0.272***		-0.114	-0.122
			(0.047)	(0.043)		(0.024)	(0.043)		(0.147)	(0.194)
Control	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	480	480	480	370	480	480	370	480	480	370
Matching approach	3-Neighbours	3-Neighbours	3-Neighbours	One-to-one	3-Neighbours	3-Neighbours	One-to-one	3-Neighbours	3-Neighbours	One-to-one

Coefficients are obtained with a probit regression analysis, and are presented as Average Marginal Effects, which are calculated as the discrete change of the Treatment variable between firms perceiving and not perceiving constraints. Standard errors in parenthesis. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 refers to the difference between Treatment and Control groups. Columns 3, 6, and 9 present the results obtained with a counterfactual comprising the nearest 3 neighbours for each treated firm. Columns 4, 7, and 10 present the results obtained with a counterfactual constructed with a one-to-one matching routine.

Moreover, we find that a lack of information on technologies and markets negatively moderates the extent to which public financial support for R&I drives firms' probabilities to innovate radically. This is observed in Columns 6 and 7 of Table 5-2 ($p < 0.05$ and $p < 0.01$, respectively), but only when firms perceive the constraint to be of low and medium importance. As Table 5-2 shows, this finding is highly sensitive to the matching approach used (e.g. the coefficients in Column 6, which are obtained with a nearest neighbour approach, are negative, but non-significant). In contrast, in the same Columns (i.e. 6 and 7), we find robust evidence which suggests that firms that perceive a lack of information on technologies and markets as highly important, are more likely to innovate radically when receiving public financial support for R&I ($p < 0.05$). This is in comparison to firms receiving the support, but not perceiving the constraint. Finally, we find no evidence that a perceived difficulty to find R&I partners moderates the impact that public financial support for R&I has on firms' probabilities to innovate radically.

Radical innovations can result in high levels of social returns from public financial support for R&I (Mazzucato and Semieniuk 2017). However, the social returns of the support may only be fully realised if firms' radical innovations enable tangible economic benefits (Nilsen *et al.*, 2020). Column 1 of Table 5-3 indicates that public financial support for R&I does indeed result in firms increasing their turnover from radical innovation. Firms that received the support generate in the region of € 20,000 more per employee from radical innovation, on average, than firms that did not receive the support ($p <0.01$). Here, Columns 2 to 4 indicate that a perceived lack of qualified employees within the enterprise may have a negative effect on firms' turnover from radical innovation, when perceived to be of low and medium importance ($p < 0.05$). Columns 2 to 4 show that such a constraint positively moderates the impact of public financial support for R&I on firms' levels of turnover from radical innovation when firms perceive it as highly important ($p < 0.05$ and $p < 0.01$, respectively).

Columns 5 to 7 of Table 5-3 show that a lack of information on technologies and markets, when perceived to be of low importance, does not moderate the radical innovation additionality of public financial support for R&I. However, we find some evidence which indicates that when firms perceive such constraint to be of medium importance, government support results in lower levels of turnover from radical innovation ($p < 0.01$ in Column 7). This in comparison to firms that receive support, but do not perceive this constraint. Yet, this is only the case when the matching of firms is carried out with one-to-one matching methodology (i.e. the coefficients are not significant when obtained with a 3-nearest neighbours' methodology, in Column 6). In addition, Table 5-3 provides robust evidence that firms that perceive a lack of information on technologies and markets as highly important, and received public financial support for R&I, generate more than double the amount of turnover from radical innovation ($p < 0.05$). This is in comparison to treated firms that do not perceive such constraint. Finally, our results in Table 5-3 indicate that a perceived difficulty in finding R&I collaborators may increase the impact of public financial support for R&I on firms' turnover from radical innovation (Column 8). Column 9 shows that this effect mainly driven by firms perceiving the constraints to be of low or medium importance.

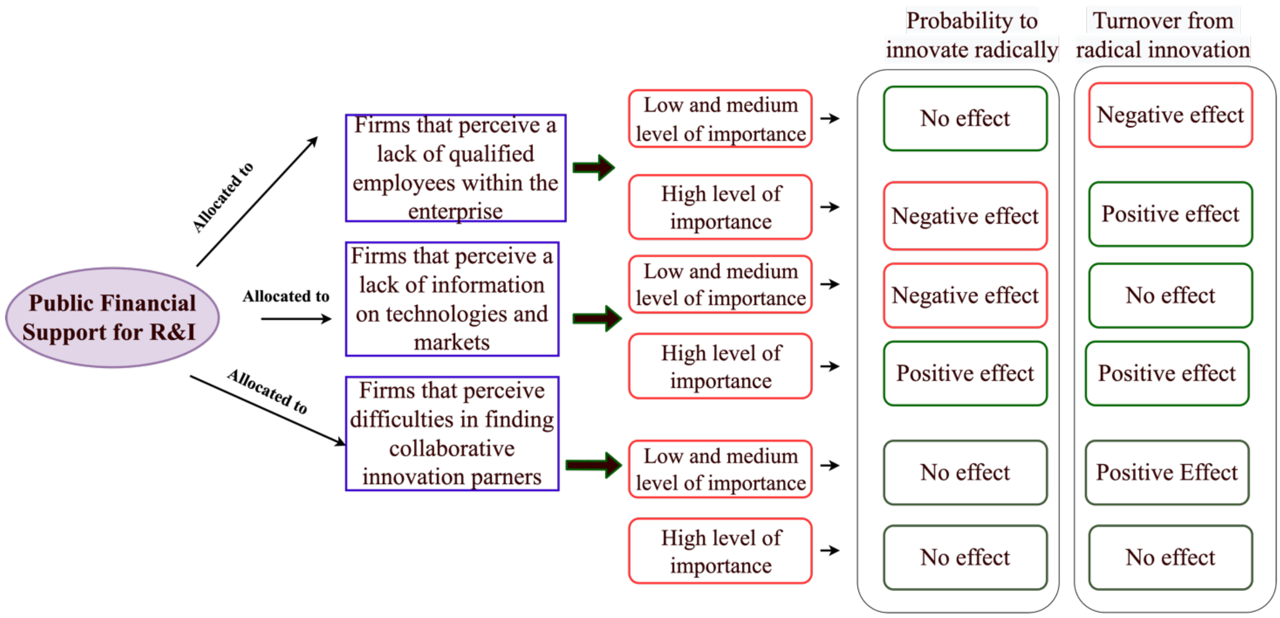
Table 5-3: Knowledge constraints influencing how public financial support drives turnover from radical innovation in firms

Intensity of Turnover from Radical Innovation (in Natural Logarithm and per number of employees)										
		A perceived lack of qualified Employees			A perceived lack of information on technologies and markets			A perceived difficulty for finding collaborative partners for innovation		
	Rad_Turnover (Ln) (1)	Rad_Turnover (Ln) (2)	Rad_Turnover (Ln) (3)	Rad_Turnover (Ln) (4)	Rad_Turnover (Ln) (5)	Rad_Turnover (Ln) (6)	Rad_Turnover (Ln) (7)	Rad_Turnover (Ln) (8)	Rad_Turnover (Ln) (9)	Rad_Turnover (Ln) (10)
Treatment	1.499***	1.905***	1.771***	2.549***	1.580***	1.609***	2.629***	1.006**	1.085**	1.756***
	(0.462)	(0.326)	(0.320)	(0.483)	(0.517)	(0.390)	(0.599)	(0.382)	(0.365)	(0.485)
Constraint		-0.022			-0.245			.517		
		(0.072)			(1.223)			(0.322)		
Treatment X Constraint		-0.053			-0.245			0.985***		
		(0.070)			(1.223)			(0.234)		
Constraint_low			-0.011	0.430		-0.317	0.636		0.181	0.241
			(1.193)	(0.938)		(0.857)	(1.334)		(0.587)	(0.523)
Constraint_med			0.384	0.842		0.763**	0.600		0.622***	1.289
			(1.091)	(1.383)		(0.307)	(0.884)		(0.150)	(1.221)
Constraint_high			-1.092	-2.371***		-1.611***	-2.273*		0.149**	0.591
			(0.621)	(0.582)		(0.455)	(1.138)		(0.464)	(0.933)
Constraint_low X Treatment			-1.562	-0.258***		-0.343	-1.771		0.662*	0.339
			(1.006)	(0.775)		(0.945)	(1.450)		(0.347)	(0.603)
Constraint_med X Treatment			0.241	-0.653**		-0.645	-0.762***		0.130*	-0.046
			(0.875)	(0.185)		(0.713)	(0.214)		(0.637)	(1.118)
Constraint_high X Treatment			3.261**	4.068***		2.754***	3.102***		-0.884	-0.952
			(1.377)	(1.232)		(0.377)	(0.405)		(0.119)	(2.200)
Control		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	480	480	480	315	480	480	315	480	480	315
Matching approach	3-Neighbours	3-Neighbours	3-Neighbours	One-to-one	3-Neighbours	3-Neighbours	One-to-one	3-Neighbours	3-Neighbours	One-to-one

Coefficients are obtained with regression analysis estimated with Ordinary Least Squares (OLS). Robust standard errors in parenthesis. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 refers to the difference between Treatment and Control groups. Columns 3, 6, and 9 present the results obtained with a counterfactual comprising the nearest 3 neighbours for each treated firm. Columns 4, 7, and 10 present the results obtained with a counterfactual constructed with a one-to-one matching routine.

Figure 5-2 summarises our findings. The figure indicates that the type of knowledge constraints considered here, and the intensity to which firms perceive these constraints, can moderate the extent to which public financial support for R&I drives radical innovation in firms.

Figure 5-2: Summary of Findings



As discussed in Section 5.2.1, a lack of qualified employees can hamper firms' abilities to solve complex problems during the development of radical innovations (Cyert and March 1963; Chadha 2011; D'Este *et al*. 2014; Bourke and Roper 2017). Subsidising R&I activities in firms that perceive this constraint may thus, result in lower levels of radical innovation additionality (i.e. policy failure). An alternative view is that firms that perceive a lack of qualified employees may seek public financial support for R&I, as a means to develop new R&I capabilities. For example, firms may use such support to engage in R&I activities that require extending their R&I capabilities (Clarysse *et al.* 2009; Chapman and Hewitt-Dundas 2018). In this case, subsiding R&I in such firms may result in higher levels of radical innovation additionality (Wanzenböck *et al.* 2013; Nilsen *et al.* 2020).

Our findings tend to support the view, that subsidising R&I in firms with insufficient skills and capabilities (i.e. due to a lack of qualified personnel) may result in policy failure. This is because firms that perceive a lack of qualified personnel (at low or medium levels of importance) may have similar probabilities to innovate radically than unconstrained firms, when receiving public financial support for R&I. However, their radical innovations may lead to lower economic impact, as measured by the intensity of turnover generated from radical innovation. In contrast, firms that perceive a lack of qualified employees as a highly important constraint may benefit more from radical innovations, as measured by their intensity of turnover from radical innovation, when receiving public financial support for R&I. In this case, however, the probability of such firms to innovate, is significantly lower than that of unconstrained treated firms (i.e. by around 11 percent).

It is possible that perceiving a lack of qualified employees (at low and medium levels) prompts firms to seek public financial support to perform radical innovation activities, that are within their existing capabilities and expertise. For example, they may use the support to apply existing proprietary technology to enter new, but closely related, markets (Katila and Shane 2005; Radas and Božić 2009; Berends *et al.* 2014; Baptista *et al.* 2019). It is also possible that such firms underestimate the importance of their constraints, given that firms may become more aware of their constraints as they gain deeper levels of R&I capabilities (D'Este *et al.* 2012; Hölzl and Janger 2014). As a result, they may develop radical innovations which have lower commercial value, as reflected by lower levels of radical innovation turnover.

In a similar vein, firms that perceive a lack of qualified employees as a highly important constraint, and obtain public support, may focus on fewer (but more promising) radical innovation projects (Baker and Nelson 2005; Hoegl *et al.* 2008). Thus, as firms use public funding to engage in radical innovations which are well beyond their core capabilities, some firms may succeed, and enjoy superior turnover (Beck *et al.* 2016). However, many other firms may fail to innovate due to insufficient skills and capabilities (Radicic 2021). This is in line with Radas and Bozic (2012) and D'Este *et al.* (2016), who show that human capital constraints increase the likelihood of R&I projects to fail. Our results thus provide some support for Hypothesis 1a, which posits that a perceived lack of qualified employees negatively moderates the extent to which public financial support for R&I drives radical innovation in firms. We find no support for Hypothesis 1b, which states a positive moderating effect.

In addition to human capital, the development of radical innovation may require firms to access timely information on technologies and markets (McDermott and O'Connor 2002; Roper and Hewitt-Dundas 2015). As discussed in Section 5.2.2, firms that lack access to such information may be deterred from using public funding for radical innovation activities due to uncertainty (Hall *et al.* 2016). They may also be more likely to fail to innovate radically (D'Este *et al.* 2016). Alternatively, firms may use public financial support for R&I to perform

R&I activities which would not be possible without the support, as a means to improve their capabilities and absorptive capacity (Beck *et al.* 2016; Nielsen *et al.* 2020). This in turn, can result in higher radical innovation additionality. Here, our findings indicate that subsidising R&I in firms that perceive a lack sufficient information on technology and markets, may indeed result in higher levels of radical innovation additionality. However, this effect only takes place amongst firms that perceive such a constraint as highly important.

Based on our findings, firms that perceive a lack of information on technologies and markets as a constraint of low and medium importance, may (a) be less likely to innovate radically, and (b) benefit less from radical innovation. This is in comparison to unconstrained treated firms. As noted in Section 5.2.2, it is possible that the inability to obtain information on technologies and markets hinders firms' likelihood to engage in radical innovation activities, regardless of public funding. Moreover, given that firms may not be able to assess the technological and commercial advantages of their innovations (as a result of their constraint), they may be more likely to abandon, or delay, their radical innovation projects (Galia and Legros 2004, Radicic 2021). While our results cannot fully ascertain that this is indeed the case, they tend to indicate that subsidising innovation in this group of firms may lead to sub-optimal levels of radical innovation returns. These results support Hypothesis 2a, which posits that a lack of information on technologies and markets, has a negative moderating effect on the extent to which government financial support drives radical innovation in firms.

Despite the above, however, we find that firms perceiving a lack of information on technology and markets, as a highly important constraint, are more likely to innovate radically when obtaining public financial support for R&I. Moreover, such firms tend to generate more turnover from their radical innovations, as measured by the intensity of turnover per employee. This is in comparison to firms that receive support, and do not perceive such a constraint. Our findings thus suggest that public financial support for R&I may enable firms that lack sufficient information for R&I to develop absorptive capacity and obtain this information (Clarysse *et al.* 2009; Wanzenböck *et al.* 2013;Chapman and Hewitt-Dundas 2018). Moreover, as firms combine new information on technologies and markets with their existing expertise, the support may enable such firms to improve their radical innovation performance (Radicic 2021; Amara *et al.* 2016; Zahler *et al.* 2022). It is also possible that firms perceive this constraint because of their ambition to innovate radical (Amara *et al.* 2016; D'Este *et al.* 2016). In this sense, perceiving a lack of information on technologies and markets as a highly important constraint may elucidate firms' innovative orientation. These findings support Hypothesis 2b, which posits a lack of information on technologies and markets to have a positive moderating effect on the extent to which public financial support for R&I drives radical innovation in firms. Yet this only occurs in the context of firms that perceive this constraint as highly important.

Finally, our findings do not support Hypothesis 3a nor Hypothesis 3b. These hypotheses posit that a perceived difficulty in finding partners to collaborate will have a negative (i.e. H3a), and positive (H3b), moderating effect on the impact of public financial support for R&I. Here, our findings provide some evidence which suggests that firms that received public financial support for R&I, and perceived a difficulty to find R&I partners, generated higher levels of turnover from radical innovation. However, this effect is only found in the context of firms that perceived such a constraint at low and medium levels of importance, and only when the matching process was performed with a nearest neighbour approach (i.e. this finding is not corroborated by our alternative estimation, which uses a direct matching approach). Moreover, we find robust evidence which indicates that firms that perceived difficulties in finding partners to collaborate with, and received public support, were as likely as treated firms that did not perceive such a constraint, to introduce radical innovations (i.e. the perceived constraint did not affect the radical innovation additionality of the support). On balance, therefore, our findings do not support the above hypotheses.

A number of studies demonstrate that engaging in collaborative R&I activities brings about important benefits for innovating firms, such as risk-sharing, and resource complementarity (Antonioli *et al.* 2017; Jugend *et al.* 2020). In this case, our results indicate that firms may continue to develop radical innovations despite perceiving difficulties in finding partners for R&I, when in receipt of public financial support. It is possible that this takes place as a result of the support, enabling firms to enhance their internal R&I resources and capabilities (Clarysse *et al.* 2009; Wanzenböck *et al.* 2013; Szambelan *et al.* 2020).

5.5 Conclusion and implications for policy

Our paper contributes to an existing debate in the literature regarding how to best allocate public financial support for Research and Innovation (R&I), depending on firms' levels of R&I capabilities (Cantner and Kösters 2012; Haapanen *et al.* 2014; Nilsen *et al.* 2020; Mina *et al.* 2021). Given that firms R&I capabilities are unique to each firm, and difficult to measure precisely (Dosi *et al.* 2021), we focus on firms' perceived knowledge constraints. Our focus on firms' perceived knowledge constraints is important, as such constraints provide vital information regarding the specific obstacles that firms perceive to hinder their R&I activities (D'Este *et al.* 2012; Pellegrino and Savona 2017). Furthermore, the perception of constraints may indicate that firms focus on developing R&I activities that are outside their core capabilities. As a result, it is possible that subsidised firms that perceive constraints may result in higher levels of additionality (Wanzenböck *et al.* 2013; Hölzl and Janger 2014; Szambeland *et al.* 2020).

Moreover, we specifically focus on firms' radical innovation activities, as such activities can lead to high levels of social returns (Beck *et al.* 2016). To the best of our knowledge, this is the first time that the moderating effect of knowledge constraints, on the extent to which public financial support for R&I drives radical innovation in firms is critically analysed. Our paper thus makes a distinct and novel contribution the literature, with important implications for policy. Specifically, using firm-level data on firms' perceived knowledge constraints to R&I and radical innovation activities, merged with administrative data on public financial support for R&I instruments, our paper contributes to the literature in two key ways as detailed below.

Firstly, we critically examine whether allocating public support for R&I to knowledge constrained firms results in ‘policy failure’ or higher levels of additionality, specifically with regard to radical innovation activities. That is, our study addresses a key issue which has not been addressed before by previous studies. Therefore, our study extends previous studies on this topic that have compared the input and output additionality effects of public financial support for R&I between firms that, *a-priori*, have different levels of R&I capabilities, such as (a) R&D starters and R&D incumbents (Nilsen *et al.* 2020); (b) firms with different levels of R&I resources (Wanzenböck *et al.* 2013), or (c) that have focused on specific firm-size groups that are typically believed to be constrained for R&I, particularly, small and medium-sized enterprises (Cantner and Kösters 2012; Mina *et al.* 2021).

Based on our result, policy failure may arise when public financial support for R&I is allocated to: (a) firms that seek public funding but have insufficient levels of human capital resources and skills for these activities; and (b) firms that seek public funding, but perceive a lack of access to technologies and markets as being of low or medium importance for their R&I activities. In these cases, firms may be unaware of the potential risks that their constraints can have on their R&I activities (D’Este *et al.* 2012), or may specifically avoid engaging in radical innovation despite government support. As a result, such firms may fail to translate public financial support for R&I into more radical innovation and economic returns.

In contrast, allocating public financial support for R&I to firms that perceive a lack of information regarding technologies and markets as highly important, can result in higher levels of radical innovation additionality. One possible avenue driving this effect pertains to firms using public financial support to engage in R&I activities that can enable them to overcome their constraints, such as exploring new knowledge, that could not be carried out without the support (Wanzenböck *et al.* 2013; Nilsen *et al.* 2020). Another possible avenue is public financial support for R&I encouraging these firms to specifically focus on enhancing their absorptive capacity, think outside the box, and engage in new ways of value creation (Baker and Nelson 2005; Hoegl *et al.* 2008; Weiss *et al.* 2013). Allocating public financial support for R&I to firms that perceive (highly important) constraints, regarding information on technologies and markets, can thus enable more scope for the support to impact their R&I activities. This, in turn can result in higher levels of radical innovation additionality.

Secondly, our paper enhances our understanding on the extent to which public financial support for R&I can enable knowledge constrained firms to overcome their constraints. This is important as Szambelan *et al.* (2020, p. 425) have highlighted that existing studies have identified firms' barriers to innovation, but that we know relatively little about how firms can overcome these barriers. Our paper provides robust novel evidence which indicates that public financial support for R&I can indeed result in more radical innovation in knowledge constrained firms. This is despite that, in some cases, their radical innovation performance may be lower than that of unconstrained treated firms. In addition, our paper highlights that the type of knowledge constraint, and the importance that firms attached to their constraints, are crucial for determining the effectiveness of government support. In this sense, our paper supports previous studies that proposed that as firms engage more in R&I, they will be more able to assess and overcome their constraints (Galia and Legros 2004; D'Este *et al.* 2012; Pellegrino 2018; Szambelan *et al.* 2020).

The above insights can have important implications for a more effective allocation of public financial resources for R&I. As highlighted, earlier in the Introduction, Cantner and Kösters (2012) and Mina *et al.* (2021) noted that policymakers may typically focus on supporting firms which can maximise the potential returns of public investments in firm-level R&I. This is to ensure that government support contributes to employment and economic growth. An underlying assumption driving such allocation policies may relate to the view that highly R&I capable firms are better equipped for translating public financial support into more knowledge and innovation (Cowling 2016; Mina *et al.* 2021). The insights of our paper largely support such a view. However, our findings also indicate that allocating public financial support to R&I to firms that are highly constrained, in terms of access to relevant information on technologies and markets, may result in higher economic benefits and social returns.

Based on our findings, policymakers may usefully consider targeting public financial support for R&I to firms that perceive a lack of information on technologies and markets as a highly important constraint. To be effective, however, this needs to be complemented with a robust selection criteria that can efficiently identify *ex-ante,* those firms that are in most need of the support (i.e. most constrained firms). While designing and implementing such criteria may require further public resources, it may lead to significant improvements in the level of radical innovation activity of firms that may not be able to carry out such activities without the support. This in turn, may minimise potential risks of policy failure, while enlarging the pool of innovators (Pellegrino 2018), which is vital for societal and economic development (Hall *et al.* 2016).

There are some limitations pertaining to our research, which could represent new avenues for further studies. Due to sample size limitations (i.e. specifically due to firms that perceived constraints, and received public financial support for R&I), we were unable to analyse potential heterogeneous effects between different types of public financial support instruments for R&I. Following Busom *et al.* (2014), in the context of financial constraints, this is a limitation as firms' constraints may influence the type of public financial support instruments for R&I that firms may seek, and the subsequent impact of the support. Further studies could address this limitation. Our focus on firms in Ireland can provide important insights for policymakers beyond the Irish case. Indeed, it would be interesting for future research to replicate our analysis in other country-settings. Finally, it would be interesting for future research to replicate our analysis in the context of the types of R&D activities that firms engage in, such as explorative versus exploitative forms of research (Lee *et al.* 2014), which our available data did not permit. This is important given that explorative research activities are widely denoted in the literature as important drivers of radical innovation. This, in turn, will further enhance an understanding of how firms manage to develop R&I capabilities and overcome their knowledge constraints.

Despite the above limitations, the insights of our paper provide crucial new evidence to encourage debate amongst academics and policymakers alike, regarding the use of public financial support for R&I to encourage higher levels of innovation in highly knowledge constrained firms. This is especially in the context of radical innovation activities, as firms may need to extend their existing R&I capabilities and resources.

5.6 Acknowledgements

Results are based on analysis of strictly controlled Research Microdata Files provided by the Irish Central Statistics Office (CSO). The CSO does not take any responsibility for the views expressed or the outputs generated from this research.

Chapter 6: Discussion and conclusion

This final chapter concludes by discussing the contributions of my PhD research to the literature concerning firms' constraints to Research and Innovation (R&I), and public financial support for R&I. Furthermore, it outlines how the insights of the research may inform more effective Science, Technology, and Innovation (STI) policy interventions to support firms to overcome their financial and non-financial constraints. Finally, the chapter discusses some limitations affecting this research, and how the research unveils new opportunities for future studies.

6.1 Main contributions of the research to the literature

My PhD research makes two main contributions to the literature concerning firms' constraints to Research and Innovation (R&I), and the impacts of public financial support for R&I. The first main contribution is to generate a more in-depth understanding of the nature of firms' perceived financial and non-financial constraints to R&I, and how firms may overcome them. The second main contribution is to demonstrate that public financial support for R&I could be a key Science, Technology, and Innovation (STI) policy intervention to help firms to overcome their perceived financial *and* non-financial constraints.

Regarding the first main contribution, the research unravels new nuances regarding the nature of firms' perceived financial and non-financial constraints to R&I. It provides novel insights regarding how firms can overcome such constraints. Extending the focus to perceived financial *and* non-financial constraints is critical. This is because there is an established view in academic and policy domains which proposes that firms, especially *small-sized* firms, do not engage in R&I activities primarily because of financial constraints (Busom *et al.* 2014; Brancati 2015; Wilson 2015; Hall *et al.* 2016; Busom and Vélez-Ospina 2020; European Commission 2021). As the current research demonstrates, however, financial constraints only explain a small part of a much wider and complex picture. This is in the sense that financial constraints alone, do not fully explain why firms may refrain from engaging R&I activities. Therefore, to generate a deeper understanding of the underlying dynamics that hinder firms' R&I activities, it is vital to also consider perceived non-financial constraints (Hölzl and Janger 2014; Pellegrino and Savona 2017).

In light of the above, my research demonstrates that firms' perceived financial and non-financial constraints are largely endogenous, as they arise as a product of firms' R&I efforts. This is in line with Galia and Legros (2004), D'Este *et al.* (2012), and Lahr and Mina (2021), who highlight that firms may be more likely to perceive constraints, especially financial constraints, as they engage more in R&I. However, a key contribution of my research is that it demonstrates that such constraints are also dynamic, in the sense that they evolve as firms gain deeper R&I capabilities. That is, firms may overcome their initial perceived financial and non-financial constraints. However, they are likely to perceive new constraints as they engage in more knowledge and resource intensive R&I activities.

For example, specifically in the context of non-financial constraints, this research demonstrates that firms may overcome their perceived non-financial constraints by building R&I capabilities, as they engage more in R&I activities. In line with organisational learning theories of innovation (Montalvo 2006; Clarysse *et al.* 2009; Bourke and Roper 2017), by engaging in R&I, especially in R&I activities that are distant to their core capabilties, firms can develop and absorb new resources and capabilities. This takes place through a process of learning by doing and cognitive learning (Clarysse *et al.* 2009; Chadha 2011; Lopez-Vega *et al.* 2016). Moreover, as firms develop new internal R&I skills and capabilities, they can also improve their abilities to identify and absorb external knowledge (i.e. absorptive capacity) (Cohen and Levinthal 1990; Zahra and George 2002; Spithoven and Teirlinck 2015). As a result, by engaging in R&I activities, firms can upskill their human capital base, and overcome their perceived knowledge constraints. This may also result in firms being more likely to innovate. The resulting R&I outputs, in turn, can enable firms to benefit more from innovation, and overcome their perceived market constraints (Szambelan *et al.* 2020).

However, as firms continue to engage in more resource- and knowledge-intensive R&I activities, they may perceive new financial and non-financial constraints. Yet, my research shows that these new perceived constraints may no longer deter their R&I activities, as firms may have already developed sufficient levels of R&I capabilities to deal with them. For example, as highlighted in Chapter 3, firms may engage in new R&I activities by recombining their existing resources in new ways, rather than investing in the development of new resources. Moreover, as firms overcome their perceived constraints, they may innovate more efficiently, in the sense that they may focus on more radical R&I activities with higher commercial value (Musso and Schiavo 2008; Keupp and Gassmann 2013). Therefore, overcoming perceived financial and non-financial constraints to R&I may prompt firms to select R&I projects that are most beneficial to them (Keupp and Gassmann 2013; De Massis *et al.* 2018). This is in line with some related studies that focus on material resource constraints, which highlight that limited R&I resources can lead to firms innovating more radically (see, for example, Hoegl *et al.* 2008; Weiss *et al.* 2013, 2017; De Massis *et al.* 2018). Based on this, the insights of my research indicate that perceived financial and non-financial constraints to R&I are an important factor for firms' R&I activities, with potentially negative, but also positive, effects.

The above insights are critical, given that, as highlight in Chapter 2 and Chapter 4, several previous studies have identified the importance of the above perceived non-financial constraints (D'Este *et al.* 2012; Amara *et al.* 2016; D'Este *et al.* 2016; Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020). Yet, these previous studies have mainly focused on the drivers and impacts of such constraints at one point in time (D'Este *et al.* 2012; Blanchard *et al.* 2013; D'Este *et al.* 2014; Pellegrino and Savona 2017; Pellegrino 2018). To a large extent, such a focus was justified on the basis that understanding what drives firms' perceived constraints, and their effects, can inform potential policy solutions to 'lower' or 'remove' them (D'Este *et al.* 2012). However, only a few studies considered how firms can overcome such constraints (see, for example, Silva and Carreira 2012;

D'Este *et al.* 2014; Szambelan *et al.* 2020). This PhD research builds on this important limitation that prevails in the literature, to enhance an understanding of a critical issue, which, heretofore, has remained largely unexplored (Antonioli *et al.* 2017; Pellegrino and Savona 2017; Szambelan *et al.* 2020).

The insights of my research are also especially important given that firms' perceived constraints to R&I have been typically denoted in the literature as obstacles to R&I activities (Blanchard *et al.* 2013; Pellegrino and Savona 2017; Pellegrino 2018; Radicic 2021; Zahler *et al.* 2022). However, my research may signal a new perspective regarding how these new perceived financial and non-financial constraints to R&I may influence firms' R&I activities. This is because firms may learn how to become more efficient innovators, as a result of perceiving (and overcoming) constraints. Importantly, the insights of my research demonstrate that perceived financial and non-financial constraints to R&I may not be permanently 'lowered' or 'removed'. This is a crucial insight, as prevailing studies in the literature typically call for STI policy interventions to remove such constraints (see, for example, Marin *et al.* 2015; Pellegrino and Savona 2017; Pellegrino 2018). In this case, my research highlights that as firms continue to expand their technological frontier and engage in more knowledge and resources intensive R&I activities, they will likely perceive new constraints. This, in turn, poses a new challenge for policymakers when designing and implementing STI policy interventions to help firms overcome their constraints to R&I. This is because firms may face different constraints at different stages of their innovative paths.

Progressing on to the second main contribution, my PhD research sheds new light into how public financial support for R&I, as a key STI policy intervention, can enable policymakers to overcome the above challenge. This is because it demonstrates that public financial support for R&I can indeed help firms to overcome their perceived financial and non-financial constraints. As outlined above in this section, firms may overcome their perceived financial and non-financial constraints through a developmental process, which begins with firms investing more in R&I activities. Therefore, by encouraging more R&I activities in firms, such support can indirectly address firms' perceived non-financial constraints.

However, the situation is more complex than this, as not all public financial support instruments for R&I have the same effect. Here, my research identifies R&D subsidies (i.e. R&D subsidies that are paid directly to firms), as the most effective type of public financial support for R&I instrument to achieve such goals. In line with the prevailing literature, this may be due to direct R&D subsidies inducing higher levels of input additionality effects in firms, in comparison to other forms of financial support, such as R&D tax credits (see, for example, Carboni *et al.* 2013; Becker 2015; Marino *et al.* 2016; Mateut 2018). These insights are paramount, given that, as noted above, a number of studies have highlighted the need to identify STI policy interventions that can support firms to overcome their financial and non-financial constraints (D'Este *et al.* 2014; Pellegrino 2018; Szambelan *et al.* 2020).

The insights of this PhD research are especially important when considering the type of policy recommendations to address non-financial constraints as emerging from previous studies on this topic. As D' Este *et al.* (2014) and Antonioli *et al.* (2017) have highlighted, addressing non-financial constraints may require systematic policy interventions to address systemic failures. Earlier, Section 6.1 discussed how such 'systemic' policy interventions may need to be tailored to failures in the 'system' or 'environment' in which firms locate. This contrasts with policy interventions which target failures in markets, which may be similar across different systems and conditions, and may thus be easier to design and implement (Dodgson *et al.* 2011).

D'Este *et al.* (2014), for example, have demonstrated that the hiring of highly skilled human capital can enable firms to overcome their perceived knowledge and market constraints to R&I. Pellegrino (2018), in turn, has emphasised the need for policy interventions that enhance the stock of human capital available to firms. Moreover, McGuirk *et al.* (2015) and Lenihan *et al.* (2019) have posited that policy interventions that foster motivationally relevant aspects of human capital, such as enhancing employee managers' willingness to change and 'can-do' attitudes, can drive more innovation in firms. According to Szambelan *et al.* (2020), such motivational aspects are vital in the context of firms overcoming constraints to R&I. In this context, Borrás and Edquist (2015) analysed the key STI policy interventions to build firm-level capabilities for R&I used by many countries (i.e. especially by OECD countries). The authors highlighted the central importance of policy interventions focussing on regulating and funding education systems, and migration policies to support the development and retention of human capital (i.e. in line with what Pellegrino [2018] had proposed). In addition, they discussed the importance of support and incentive schemes for vocational training systems, which may include motivational aspects for R&I (i.e. in line with what Lenihan *et al*. [2019] suggested). Yet, they also point out that a lag between firms' short-term needs for specific capabilities, and the long time required to develop them, is a potential limitation of such policies.

Antonioli *et al.* (2017), in turn, have outlined that STI policy interventions to enable firms to overcome their non-financial constraints may focus on encouraging firms to engage in R&I collaborations. However, such policy interventions may not be straightforward. This is because collaborative R&I may require firms to develop specific capabilities to benefit from such collaborations (Du *et al.* 2014; Schøtt *et al.* 2016; Hewitt-Dundas *et al.* 2019). De Moraes Silva *et al.* (2020, p. 254), for example, concluded in the context of high technology firms in Brazil, that encouraging industry and universities collaborations "is not an efficient strategy for technology-based SMEs to overcome internal barriers". Similarly, Grashof (2021, p 2), has recently noted that collaborative incentives should not merely focus on increasing linkages amongst firms, but to "connect the right partners with each other".

The above examples support Wanzenböck *et al.* (2013), when proposing that the design and implementation of such systemic STI policies may be difficult for policymakers. As my research demonstrates, an additional challenge which may be considered when designing and implementing systemic policy interventions to address firms' financial and non-financial constraints pertains to the evolving nature of such constraints. This is because firms may perceive different constraints as they engage in more resource- and knowledge-intensive R&I activities. In this context, the insights of my PhD research are important, given that many countries already provide public financial support for R&I instruments, as a key part of their STI policy packages (Zúñiga-Vicente *et al.* 2014; Becker 2015; Lenihan *et al.* 2020). This means that policymakers in such countries could use existing policy tools, in the form to public financial support for R&I, to help firms overcome their non-financial constraints.

A potential drawback of providing public financial support for R&I to firms with lower levels of R&I capabilities, such as non-financially constrained firms, is that such firms may not fully realise the expected returns of public investment in R&I activities in firms (Haapanen *et al.* 2014; Nilsen *et al.* 2020; Mina *et al.* 2021). This is important, as it may deter policymakers from targeting public financial support for R&I to non-financially constrained firms. My research demonstrates that the above drawback can materialise, especially if the support is targetter to firms that have insufficient human capital resources for R&I. However, my findings also demonstrate that this is not the case when the support is allocated to highly knowledge constrained firms, with regard to a lack of access to information on technologies and markets. Here, the support can lead to higher levels of radical innovation additionality, in comparison to firms that receive support, but that do not perceive such constraints. Therefore, based on the insights of my PhD research, allocating public financial support to some non-financially constrained firms may indeed result in high economic and social returns from public investments in private R&I activities.

Collectively, the insights of my research suggest that, as firms continue to expand their technological frontier, they will inevitably perceive financial and non-financial constraints. It is likely that financial constraints can play an important role in determining firms' engagements in R&I. Yet, firms may also face important non-financial constraints related to knowledge and market dynamics. Such constraints may initially represent an obstacle to firm-level R&I, but firms can overcome them, through a process of capability building and learning, which is triggered by firms engaging more in R&I. Furthermore, by learning how to overcome their constraints, firms may innovate more efficiently. That is, by selecting R&I activities that maximise the economic returns of R&I.

Within the above evolutionary process, STI policy interventions may have a major role to play, by for example, supporting firms in specific situations where financial and non-financial constraints become insurmountable obstacles (D'Este *et al.* 2012). In this context, my research demonstrates that public financial support for R&I is an important STI policy intervention to directly address firms' perceived financial constraints, and indirectly address their perceived non-financial constraints. Therefore, my research offers novel insights that extend our knowledge in a topic that remains under-researched. This is paramount for academics and policymakers alike, given that, as highlighted by Pellegrino (2018), there is a growing interest among policymakers on this topic, but research contributions in the topic remain very limited.

6.2 Methodological contributions

In addition to the main contribution to the literature, my research makes two methodological contributions to the literature regarding firms' perceived constraints to Research and Innovation (R&I).

The first methodological contribution pertains to the novel databases used in the research. These datasets were constructed by merging several sources of publicly available data from the Irish Central Statistics Office (CSO), as outlined in Chapter 2. Publicly available data were merged with detailed administrative data on public financial support for R&I. The resulting datasets, in turn, enable this research to extend most previous studies in this vein that only used data from the Community Innovation Survey (CIS), and other similar surveys (D'Este *et al.* 2012; D'Este *et al.* 2014; Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020), in at least two main ways.

Firstly, a key strength of the above datasets is that the data include public R&I financial instruments, such as funding for industry-university collaborations, which are not typically recorded in innovation surveys (Czarnitzki and Lopes-Bento 2013; Hottenrott and Lopes-bento 2014). This enables my research to offer an in-depth understanding of how different public financial supports for R&I instruments impact the R&I activities of financially and non-financially constrained firms. As Pellegrino (2018) has highlighted, policymakers are increasingly interested in understanding the types of Science, Technology, and Innovation policy (STI) policy interventions that can assist firms in overcoming their financial and non-financial constraints. However, he also highlights that there is a paucity of contributions on this topic, which may be likely due to limitations in currently available data. In this particular case, therefore, the datasets constructed here enable my research to overcome some of the limitations as highlighted by Pellegrino (2018). This is by identifying how different forms of public financial support for R&I instruments may impact firms' perceived constraints in different ways.

Secondly, the datasets permit observing how firms perceive financial and non-financial constraints at different points in time. This is important because, as discussed in Section 6.1, such constraints may be highly dynamic. That is, firms may overcome their initial constraints, but they are likely to perceive new constraints, as they engage in more knowledge and resource intensive R&I activities (D'Este *et al.* 2012; Lahr and Mina 2021). In addition, this research highlights the importance of using data which permit identifying firms with different levels of R&I intensity. This is important for analysing how firms' perceived constraints change over time, as their perceptions of constraints may be endogenous *vis-à-vis* their levels of R&I intensity (Pellegrino and Savona 2017; Lahr and Mina 2021). By constructing such detailed datasets, therefore, my research is able to employ robust econometric techniques to control for endogeneity and omitted variable bias, such as instrumental variables and propensity score matching approaches. This is an important advantage of the research, as most previous studies focused on perceived constraints, tend to typically employ econometric models, such as probit and similar probability models, which may not fully control for these potential sources of bias (see, Silva and Carreira [2012] and Pellegrino [2018] for discussions on this issue).

Considering the above, this PhD research can serve as a roadmap of how different combinations of data can permit addressing new research questions to advance the field. In addition, it showcases the importance of using rigorous econometric methods to control for important sources of bias, such as endogeneity and omitted variables, for the study of perceived constraints to innovation. Section 6.5 (below) proposes some crucial questions that were beyond the scope of this research, but that could be the focus of future studies, by building similar datasets such as the one underpinning my research.

The second methodological contribution is that my research sets out a rationale for considering firms' perceived constraints to R&I when evaluating the impacts of public financial support for R&I. This is because the research highlights that such constraints can indeed moderate how firms use the support (i.e. and the impact of the support). However, most previous studies have typically omitted the importance of firms' perceived constraints when modelling how public financial support for R&I drives firms' R&I activities. To the best of my knowledge, only a limited number of previous studies have considered firms' constraints to R&I when analysing the impact of public financial support for R&I on firms' R&I activities, and only in the context of financial constraints (Silva and Carreira 2012; Mateut 2018; Acebo 2020). Hence, my research demonstrates that it is also vital to consider firms' perceived non-financial constraints. A possible reason that may explain why previous studies have not considered such constraints when evaluating the impacts of public financial support for R&I may be related to the endogenous nature of such constraints, as discussed in Section 6.1. In this case, this PhD research may also serve as an example for future studies regarding how to deal with such issues of endogeneity and self-selection associated with perceived variables of constraints to R&I in their empirical settings (Mohnen *et al.* 2008; Savignac 2008; Pellegrino and Savona 2017).

6.3 Implications of the research for policy

The insights of my PhD research indicate that public financial support for Research and Innovation (R&I) can indeed represent a suitable Science, Technology, and Innovation (STI) policy intervention to indirectly address firms' financial and non-financial constraints to R&I. From a policy perspective, the insights of my research are potentially very useful. This is because, as detailed in Section 2.2.2 and Section 6.1, the prevailing literature posits that addressing firms' non-financial constraints may require a combination of micro and macro-level policies to target systemic failures (see, for example, D'Este *et al.* 2014; Antonioli *et al.* 2017). While the design and implementation of such policy interventions is important, they may take time to affect firms' R&I activities (Borrás and Edquist, 2015). In addition, according to Wanzenböck *et al.* (2013) and De Moraes Silva (2020), designing and implementing such 'systemic' types of policy interventions may be difficult for policymakers. My research also shows that firms' constraints to R&I may evolve as firms gain deeper R&I capabilities, which may represent additional challenges for policymakers.

However, it is common in advanced countries, but also in some developing countries, to implement public financial support for R&I (Zúñiga-Vicente *et al.*, 2014; Becker, 2015; Jugend *et al.*, 2020). For example, as identified by the Organisation for Economic Co-operation and Development (OECD) (2021c), there are a total of 681 policy initiatives accross 61 countries that focus on providing public financial support to business R&D and innovation. Moreover, according to the OECD (2021c), most of these countries implement more than one form of public financial support for R&I instruments (e.g. R&D subsidies, R&D tax credits, R&D subsidies that require collaboration with universities and other local knowledge providers). Therefore, policymakers in such countries may be able to use public financial support for R&I instruments to enable firms to overcome their non-financial constraints and drive more R&I in firms. Such support may not substitute the above 'systemic' types of policies, but it can prove useful as a temporary measure, or as a complement, to such interventions.

Despite the above, it is possible that policymalkers may be deterred from providing public financial support for R&I to non-financially constrained firms. This is because policymakers typically allocate public financial support for R&I by following an economic rationale, which primarily focuses on maximising the economic benefits of public investments in firm-level R&I (Cantner and Kösters 2012; Mina *et al.* 2021). In this context, a potential risk of allocating public financial support for R&I to non-financially constrained firms, is that such firms may not be able to fully realise the expected economic returns of public R&I investment. This is because, such firms may not have sufficient levels of skills and expertise to translate the public funding into more research and innovation (Cowling *et al.* 2012; Haapanen *et al.* 2014; Mina *et al.* 2021). Underpinning this view is the fact that firms' R&I capabilities are intrinsically related to their levels of R&I productivity (Xue *et al.* 2021). As a result, allocating public financial support for R&I to non-financially constrained firms may be incompatible, *a-priori*, with the above economic rationales.

My research demonstrates, that allocating public financial support for R&I to non-financially constrained firms, does not necessarily mean that the output additionality effects of the support will be reduced. In fact, in some cases, such as firms that perceive a lack of information on technologies and markets as a highly important constraint, the support may result in high levels of innovation. This is especially so in terms of goods and services that are new to the market (i.e. radical innovation). As a result, allocating public financial support for R&I to non-financially constrained firms may bring important economic and social benefits, while it can also enhance the pool of innovating firms. This is key, as a number of studies have highlighted that enhancing the pool of innovators is vital for achieving societal and economic goals (see, for a review, Hall *et al.* 2016; Jugend *et al.* 2020). My research, therefore, generates crucial novel evidence which may be useful for policymakers as a form of rationale, for using scarce public financial resources to support R&I activities in non-financially constrained firms.

As noted above, most countries that implement public financial support for R&I in firms typically have more than one form of public financial support instrument. In addition, Lenihan *et al* (2020) studied the different forms of innovation and science policy instruments in Ireland, Germany, the United Kingdom, Belgium, Denmark, Israel, Singapore, and Norway. They find some commonalities in the types of instruments used. However, they noted that even if some of these instruments may appear similar on the surface (i.e. R&D tax credits and R&D subsidies), "there can be subtle, but important differences that alter the manner in which firms engage with the instruments" (Lenihan *et al.* 2020, p. 2). In this context, if public financial support for R&I were to be used to help firms to overcome their non-financial constraints, policymakers may need to critically evaluate which public support instruments would be more suitable to achieve this goal.

Here, my research offers important insights for policymakers, as it identifies direct R&D subsidies, in the form of subsidies that are paid directly to firms, as the most suitable instruments to help firms overcome non-financial constraints. A likely reason underpinning the effectiveness of this type of public financial support, which emerges from my research, is that firms may use the additional liquidity made available by the support to engage in more distant forms of R&I activities. This is in the form of generating new scientific and technical knowledge, and the development of radical innovation. Such insights are in a similar vein to previous studies on related topics, such as Busom *et al.* (2014)*;* Beck *et al.* (2016), and Nilsen *et al.* (2020), which propose that direct forms of R&D support may enable firms to engage in R&I activities that would not be possible without the support.

Another potential challenge for using public financial support for R&I as a means to help firms to overcome their non-financial constraints, pertains to how policymakers can identify and target such firms. While in the context of my research such identification was possible by using innovation survey data, identifying non-financially constrained firms may be challenging for programme officials on the ground. Based on the insights of this research, however, potential target firms may include small-sized firms that are R&D starters, and small-sized firms operating at the technological frontier. Linking back to the prevailing literature, small-sized firms are widely regarded in the literature as the most likely group of firms to face financial and non-financial resource constraints (Hall *et al.* 2016). R&D starters, in turn, may be most likely to perceive financial and non-financial constraints to R&I as highly important factors deterring their R&I activities (D'Este *et al.* 2012; Szambelan *et al.* 2020). Moreover, as demonstrated by Hölzl and Janger (2014), firms operating at the technological frontier may face important non-financial constraints, especially knowledge constraints. This is because innovation in such a context, may require firms to extend the frontier of existing scientific and technological knowledge.

Finally, based on the insights of the current research, policymakers may usefully consider allocating public financial support to firms which intend to engage in distant R&I activities (i.e. the generation of new knowledge and radical innovation). This is because such R&I activities can maximise the economic and social returns of public financial support for R&I (Beck *et al.* 2016; Mazzucato and Semieniuk 2017). In addition, as highlighted by my research, they can also maximise the learning effects that such support induces in firms, and enable firms to overcome their non-financial constraints.

Collectively, therefore, the insights of my research have the potential to guide policymakers when using public financial support for R&I, as a means to address firms' financial and non-financial constraints.

6.4 Limitations of the research

While my PhD research builds on robust theoretical and methodological underpinnings and makes a number of significant contributions, there are some limitations affecting the research. This section discusses these limitations.

The first limitation affecting the research pertains to the novel data used in Chapter 4 and Chapter 5. As discussed in each specific chapter (including Chapter 2), addressing the research questions driving this research requires highly detailed data of firms' research and innovation (R&I) activities, and the constraints that firms perceive when carrying out such activities. In addition, the research requires detailed administrative data on public financial support for R&I instruments available to firms. The empirical approaches used for addressing the research questions also require specific data structures, which necessitate firms to be featured in the dataset in at least two time periods. This enables the research to draw on rich and detailed data, but it also entails working with limited samples, in terms of the numbers of observations used. This can be a potential limitation because it can affect the representativeness of the samples used.

To mitigate this limitation Chapters 4 and 5 discus how, the sub-samples used largely retain the representativeness of the original samples (i.e. which pertain to the Innovation in Irish Enterprises Survey). This is in terms of key firm characteristics, such as firm-size, sector and level of R&I activities. However, these sub-samples are not an exact match of the original samples. In particular, the sub-samples used slightly over-represented large-sized firms, but as discussed in Chapters 4 and 5, this was not deemed to represent an important problem in the context of my research.

Another limitation of the research relates to the nature of firms' perceived constraints to R&I. As several studies have highlighted (see, for example, Savignac 2008; D'Este *et al.* 2012; Pellegrino and Savona 2017; Lahr and Mina 2021), the variables used to measure firms' constraints to R&I are subjective in nature, and may suffer from issues of endogeneity due to reverse causality. To mitigate such issues, rigorous econometric techniques were employed. Despite these efforts, however, it is impossible to effectively ascertain whether perceived constraints pertain to a lack of resources for R&I, or if they relate to other factors affecting the subjective appraisal of the survey respondents. This is an issue affecting most studies focussing on firms' perceived constraints to R&I, as acknowledged by a plethora of authors, such as Baldwin and Lin (2002), Tourigny and Le (2004), Savignac (2006), D'Este *et al.* (2012), and Pellegrino and Savona (2017).

Finally, the administrative data available to this research includes data on the amount of public funding paid to firms for some, but not all, of the public financial support for R&I instruments considered. For example, while data on euro amount were available for R&D subsidies, this was not the case for collaborative R&D subsidies. This is because, as discussed in Section 2.5.2, such R&D collaborative subsidies are not allocated directly to firms, but to local knowledge providers, such as universities and research centres, to collaborate with firms (i.e. the data shows the firms that have collaborated with these local knowledge providers). As a result, the research faces a trade-off, between: (a) including all of the available public financial instruments, but not using the data on euro amount paid to firms; or (b) only selecting those instruments which include the euro amount of funding paid to firms. Given that the analyses employed are already highly data-demanding, which reduce the size of the effective sample, the research focuses on specific analyses that maximised the number of observations. That is, the analyses are performed on data which contain all public financial support instruments, but without information on specific euro amount paid to firms.

Despite the above limitations, the research makes several distinct and important contributions to understanding the nature of financial and non-financial constraints to R&I. In particular, the research advances an understanding on how public financial support for R&I can help firms to overcome their constraints to R&I.

6.5 Opportunities for future research

Given the findings and contributions of my PhD research, this section considers how the research opens new avenues for future studies.

My research interprets firms' self-assessments of the obstacles hampering their research and innovation (R&I) activities as measures of perceived constraints. As noted earlier, in Table 3-1 in Section 2, and Chapters 4 and 5, this interpretation is consistent with most studies in the literature (Baldwin and Lin 2002; Tourigny and Le 2004; Savignac 2006; D'Este *et al.* 2012; Pellegrino and Savona 2017; Pellegrino 2018; Szambelan *et al.* 2020). However, this does not necessarily mean that firms had low levels of specific resources and/or capabilities for R&I. As noted in Section 6.2, firms may perceive constraints as they develop more R&I capabilities. A comprehensive assessment of the relationship between firms' levels of resources, and their likelihood to perceive constraints, was beyond the scope of this research. Yet, the current research identifies that while an established literature has focused on the drivers of firms' perceived constraints (Baldwin and Lin 2002; Tourigny and Le 2004; Mohnen *et al.* 2008; D'Este *et al.* 2012; Marin *et al.* 2015), the extent to which firms' levels of resources impact the types of constraints perceived by firms remains largely unexplored. Future research might focus on providing a more comprehensive account of how the financial and non-financial resources available to firms, can influence their perceptions of constraints. This may involve in-depth qualitative interviews with firms' managers and owners, and other similar approaches, which extend beyond the focus of this research.

Furthermore, the research primarily focuses on unveiling key mechanisms internal to firms, which explain how public financial support for R&I can enable firms to overcome their non-financial constraints. However, there may be other additional mechanisms at play, which may take place externally to firms, that were beyond the scope of this research. For example, the receipt of public financial support has been shown to generate 'signalling' or 'certification effects', which, as discussed in Chapter 4, can enable firms to attract highly skilled human capital (Söderblom *et al.* 2015; Carboni 2017). Therefore, it would be interesting if future research focus on whether such certification effects play a role in enabling firms to overcome their financial and non-financial constraints.

Finally, future research might usefully focus on building on the insights of this PhD research by exploring how firms' constraints to R&I moderate the impact of public financial support for R&I in more detail. This could be achieved by considering further constraints, which were not available to this study, such as constraints related to employee managers' willingness to change and managerial capabilities. As Wanzenböck *et al.* (2013) and Chapman and Hewitt-Dundas (2018) have demonstrated, public financial support for R&I can have an indirect impact on firms' managerial capabilities. Moreover, such support can also indirectly lead to more positive attitudes for R&I amongst firms' employee managers, and firms' owners (Colclough *et al.* 2019). This is important because as Lenihan *et al.* (2019) have outlined, in the specific context of employee managers, such attitudinal factors can drive firms R&I in firms. In addition, as Szambelan *et al.* (2020) have noted, attitudinal factors can be vital for firms overcoming their constraints to R&I. This, in turn, may enhance the impact of such support on firms' R&I activities, and future studies may explore these mechanisms in more detail.

6.6 Conclusion

This chapter has summarised the objectives and empirical findings of my PhD research. Furthermore, it has discussed the contributions of the research to the literature regarding firms' constraints to research and innovation (R&I), and public support for such activities. The chapter has progressed by outlining the insights for the design, implementation and improvement of associated Science, Technology, and Innovation (STI) policy interventions. Finally, it presented a discussion on the limitations affecting the research, and how future studies may build on the research to advance an understanding of the nature and impact of firms' constraints to R&I, and how such constraints may be overcome.

My research enhances our knowledge of three key intricacies that, up to now, remain contested in the literature regarding the nature and impact of firms' constraints to R&I. By drawing on novel datasets, which were constructed specifically for the purpose of this research, the research offers critical insights that enhance an understanding of these three intricacies.

Firstly, the research focuses on the relationship between firms' levels of internal financial resources and their R&I activities. While there is an established literature indicating that more money typically leads to more R&I (Cyert and March 1963; Jissink *et al.* 2019; González-Bravo *et al.* 2021), the extent to which this is indeed the case, remains unclear (Hoegl *et al.* 2008; Keupp and Gassmann 2013; Weiss *et al.* 2013, 2017; Teirlinck 2020). My research thus contributes to this literature, by demonstrating that the relationship between firms' levels of financial resources and firms' R&I activities is highly heterogeneous across different types of R&I activities, and across firms of different sizes. The insights of my research contribute to the formulation of a more detailed theory of the importance of financial resources for R&I, which heretofore, remained much needed (Hoegl *et al.* 2008; Teirlinck 2020).

Secondly, while previous research has identified several constraints that can hinder firms' R&I activities (Blanchard *et al.* 2013; Pellegrino and Savona 2017; Pellegrino 2018), how firms overcome these constraints remains largely unexplored (Antonioli *et al.* 2017; Szambelan *et al.* 2020). Here, my research provides novel insights into how public financial support for R&I can enable firms to overcome their financial constraints, and indirectly overcome two forms of non-financial constraints. These non-financial constraints are related to firms' lack of knowledge and demand for R&I (i.e. knowledge and market constraints). Such insights are crucial for academics and policymakers alike, as they demonstrate that firms can indeed overcome their non-financial constraints to R&I by engaging more in R&I activities.

Finally, my research demonstrates that allocating public financial support for R&I to knowledge-constrained firms may be desirable for policymakers. This is because the support can have important positive externalities in the recipient firms, such as enabling firms to overcome non-financial constraints to R&I. Furthermore, public financial support for R&I can enable firms that perceive knowledge constraints to engage in R&I activities that were not possible without the support. As a result, my research demonstrates that, in some cases, the input and output additionality effects of public financial support for R&I can be higher in knowledge-constrained firms, in comparison to firms that do perceive such constraints. This is especially true for firms perceiving a lack of information on technologies and markets as highly important constraints. This means that public financial support for R&I can have effects in firms that extend beyond what the support was initially intended for (i.e. addressing market failures and firms' financial constraints). Such insights are vital for our understanding of firms' constraints to R&I. In addition, they are potentially very important for policymakers, as they unravel a potential new way through which policymakers can support firms to overcome such constraints. This is by means of public financial support for R&I.

The research concludes by highlighting how, by addressing the above three key issues, it makes two main distinct and novel contributions to the literature concerning firms' financial and non-financial constraints, and the impacts of public financial support for R&I. This is achieved by generating a deeper understanding of the nature and role that such constraints play on firms' R&I activities. Furthermore, the research provides novel evidence which demonstrates that public financial support for R&I can represent an effective policy intervention to help firms overcome such constraints.

7. References

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Appendix 3-A: Dependent and independent variables

Panel A Dependent Variables	Construction	Activities Includes	Source
Scientific Research	Binary variable = 1 if expenditure on Basic and Applied Research > 0	**Basic Research:** Experimental or theoretical work undertaken primarily to acquire new knowledge, without any particular application or use in view. **Applied Research:.** Original investigation undertaken to acquire new knowledge, primarily directed towards a specific practical aim or objective.	BERD
Development	Binary variable = 1 if expenditure on Experimental Development > 0	**Experimental Development:.** Systematic work, drawing on existing knowledge gained from research and practical experience that is directed to producing new materials, products, and devices, to installing new processes, systems, and services, or to improving substantially those already produced or installed.	BERD
Process Innovation	Binary variable = 1 if the firm introduced significantly improved processes in the last 3 years, otherwise 0	New or significantly improved: a) methods of manufacturing of goods or services; b) methods of logistics, delivery or distribution of inputs, goods or services; c) supporting activities for processes, such as maintenance systems or operations for purchasing, accounting or computing	IIE
Product Innovation	Binary variable = 1 if the firm introduced incremental product innovation in the last 3 years, otherwise 0	New to the firm or significantly improved goods	IIE
Service Innovation	Binary variable = 1 if the firm introduced significantly improved or new services in the last 3 years, otherwise 0	New to the firm or significantly improved services.	IIE
Radical Innovation	Binary variable = 1 if the firm introduced product and/or service innovations that are new to the market in the last 3 years, otherwise 0	Goods and Services that are new to the market.	IIE
Organisational Innovation	Binary variable = 1 if the firm introduced any of the activities in the adjacent column in the last 3 years, otherwise 0	New: a) business practices for organising procedures b) methods of organising work responsibilities and decision-making c) methods of organising external relations with other firms or public institutions	

Panel B: Independent Variables	Definitions	Source
Employees (R&D)	% Employees engaged in R&D activities	BERD
Age	Survey wave year - Registration Date	Business Register
Irish Owned	Binary variable = 1 if the firm is Irish owned	IIE
Size (Ln Employees)	Natural Logarithm of the total number of employees	BERD
Export	Binary variable = 1 if firm exports	IIE
Enterprise Group	Binary variable = 1 if the firm is part of an enterprise group	IIE
Fund EU	Binary variable = 1 if the firm receives financial support for R&D from EU	IIE
Fund National	Binary variable = 1 if the firm receives financial support for R&D from National Government	IIE
Other Funding Sources (IRL)	Binary variable = 1 if the firm used external financial resources from (i) other firms; (ii) other public funding; (iii) higher education institutes; (iv) private non-profit institutes; and (v) other sources, from Ireland	BERD
Other Funding Sources (Outside IRL).	Binary variable = 1 if the firm used external financial resources from (i) other firms; (ii) other public funding; (iii) higher education institutes; (iv) private non-profit institutes; and (v) other sources, from outside of Ireland	BERD
Cooperation Clients	Binary variable = 1 if the firm cooperates with clients	IIE
Cooperation Suppliers	Binary variable = 1 if the firm cooperates with suppliers	IIE
Cooperation Other Firms	Binary variable = 1 if the firm cooperates with other firms	IIE
Cooperation Public	Binary variable = 1 if the firm cooperates with University/Research Centre	IIE

Appendix 3-B: Robustness checks by excluding some variables of our main model (in average marginal effects)

	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ.. Innov.	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ. Innov.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	dy/dx	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**	**dy/dx**
VARIABLES /ESTIMATOR	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IV Probit**	**IVProbit**	**IV Probit**	**IV Probit**	**IV Probit**
Firm Characteristics														
Internal Financial Resources	0.189***	0.033	0.107**	0.022	-0.007**	-0.035	-0.003	0.113**	0.087	0.068	0.029	-0.004**	-0.070	-0.035
	(0.048)	(0.049)	(0.051)	(0.049)	(0.003)	(0.050)	(0.052)	(0.045)	(0.057)	(0.049)	(0.048)	(0.002)	(0.048)	(0.050)
Size (Ln Employees)	0.082***	0.086***	0.093***	0.038***	0.027***	0.062***	0.082***	0.068***	0.074***	0.080***	0.023***	0.022***	0.050***	0.070***
	(0.007)	(0.007)	(0.008)	(0.008)	(0.007)	(0.008)	(0.009)	(0.007)	(0.007)	(0.008)	(0.008)	(0.007)	(0.008)	(0.009)
Employees (R&D)	0.009***	0.013***	0.002***	0.005***	0.002***	0.006***	0.002***	0.008***	0.011***	0.001**	0.003***	0.002***	0.005***	0.008
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)
Age	-0.001*	-0.001**	-0.003***	-0.001**	-0.001**	-0.001*	-0.002***	-0.001	-0.001**	-0.003***	-0.001	-0.001**	-0.000	-0.002**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
Irish Owned	0.064***	0.005	0.025	0.053**	-0.001	0.019	-0.007	0.055***	-0.001	0.017	0.044**	-0.004	0.012	-0.014
	(0.019)	(0.018)	(0.021)	(0.020)	(0.017)	(0.020)	(0.021)	(0.051)	(0.017)	(0.021)	(0.020)	(0.017)	(0.020)	(0.021)
Export	0.115***	0.122***	0.148***	0.249***	0.069***	0.160***	0.155***	0.073***	0.090***	0.110***	0.204***	0.056***	0.128***	0.117***
	(0.023)	(0.022)	(0.024)	(0.023)	(0.021)	(0.024)	(0.024)	(0.022)	(0.021)	(0.024)	(0.023)	(0.021)	(0.024)	(0.024)
Enterprise Group	0.016	0.048**	-0.026	0.039*	-0.016	0.002	0.009	0.019	0.048**	-0.024	0.042**	-0.013	0.005	0.011
	(0.020)	(0.019)	(0.022)	(0.021)	(0.017)	(0.021)	(0.022)	(0.019	(0.018)	(0.022)	(0.020)	(0.017)	(0.021)	(0.022)
Support/Finance														
Fund EU								0.055	-0.111***	0.049	0.078	0.101**	0.136**	0.143***
								(0.051)	(0.054)	(0.057)	(0.051)	(0.039)	(0.055)	(0.063)
Fund National								0.163***	0.138***	0.049	0.234***	0.092***	0.202***	0.242***
								(0.022)	(0.054)	(0.025)	(0.023)	(0.020)	(0.024)	(0.026)
Other Funding Sources (IRL)								0.057	-0.009	0.038*	0.041	-0.017	0.073	0.023
								(0.052)	(0.052)	(0.051)	(0.049)	(0.039)	(0.048)	(0.051)
Other Funding Sources (Outside IRL).								-0.414***	-0.380***	-0.175***	-0.271***	-0.002	-0.132***	-0.146***
								(0.063)	(0.058)	(0.058)	(0.053)	(0.450)	(0.055)	(0.058)
Cooperation														
Cooperation Clients														
Cooperation Suppliers														
Cooperation Other Firms														
Cooperation Public														
Industry Control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Survey wave control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	0.371***	0.441***	0.511***	0.485***	0.232***	0.397***	0.568***	0.372***	0.443***	0.511***	0.485***	0.233***	0.397***	0.568***
Constant	(0.007)	(0.007)	(0.009)	(0.008)	(0.007)	(0.009)	(0.009)	(0.008)	(0.007)	(0.009)	(0.008)	(0.007)	(0.008)	(0.009)
Observations	2531	2531	2531	2531	2531	2531	2531	2531	2531	2531	2531	2531	2531	2531
McFadden Pseudo R^2	0.341	0.352	0.401	0.322	0.377	0.451	0.372	0.411	0.398	0.362	0.315	0.423	0.399	0.390
Wald Test Exogeneity (null = yes)	1.69	0.61	0.55	088	0.40	0.0	0.01	5.18***	0.203	0.10	0.66	6.65***	8.26***	0.10

Results presented in average marginal effects. Robust standard errors clustered at the industry level in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 3-C: Robustness check with panel data random effect probit model for panel data (in average marginal effects)

	Panel A: Small-sized Firms (> =10 & < 50 Employees)							Panel B: Larger-sized firms (>=50 Employees)						
	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ. Innov.	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Organ. Innov.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES/ESTIMATOR	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**
Internal Financial Resources	0.007	0.011	-0.028	-0.050	-0.066**	0.014	-0.073**	0.192***	0.117	0.143**	0.106*	-0.060	-0.027	0.064
	(0.055)	(0.054)	(0.063)	(-0.047)	(0.027)	(0.055)	(0.042)	(0.068)	(-0.166)	(0.069)	(0.063)	(0.061)	(0.073)	(0.070)
Size (Ln Employees)	0.103***	0.099***	0.039	-0.040	-0.010	-0.005	0.102***	0.029*	0.060***	0.075***	0.021	0.006	0.037**	0.053***
	(0.027)	(0.028)	(0.031)	(0.030)	(0.024)	(0.030)	(0.032)	(0.016)	(0.015)	(0.017)	(0.017)	(0.013)	(0.017)	(0.018)
Employees (R&D)	0.007***	0.011***	0.001	0.004***	0.002***	0.004***	-0.000	0.007***	0.011***	0.002*	0.002	0.002***	0.006***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Age	0.001	-0.000	-0.002	0.001	0.002	0.001	-0.000	-0.002*	-0.003**	-0.003**	-0.002	-0.004***	-0.002*	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Irish Owned	0.041	-0.002	-0.060*	-0.005	-0.029	0.001	-0.039	0.081***	0.003	0.075**	0.081***	0.012	0.025	-0.014
	(0.028)	(0.029)	(0.035)	(0.033)	(0.026)	(0.031)	(0.036)	(0.029)	(0.028)	(0.029)	(0.031)	(0.026)	(0.031)	(0.028)
Export	0.016	0.075***	0.083**	0.206***	0.047*	0.117***	0.099***	0.070*	0.063*	0.097***	0.138***	0.033	0.081*	0.062*
	(0.027)	(0.028)	(0.032)	(0.031)	(0.028)	(0.031)	(0.033)	(0.038)	(0.035)	(0.037)	(0.040)	(0.032)	(0.043)	(0.037)
Enterprise Group	-0.000	-0.006	-0.036	0.026	-0.021	0.009	0.024	0.007	0.094***	-0.030	0.051	-0.025	-0.008	-0.021
	(0.031)	(0.034)	(0.038)	(0.034)	(0.029)	(0.034)	(0.037)	(0.030)	(0.028)	(0.031)	(0.032)	(0.026)	(0.032)	(0.029)
Fund EU	-0.017	-0.049	-0.009	0.072	0.008	0.035	0.139	0.012	-0.130**	-0.037	-0.062	0.058	0.085	-0.016
	(0.056)	(0.074)	(0.081)	(0.073)	(0.052)	(0.069)	(0.085)	(0.071)	(0.064)	(0.088)	(0.064)	(0.052)	(0.078)	(0.081)
Fund National	0.070**	0.071**	0.248***	0.216***	0.076***	0.201***	0.219***	0.150***	0.139***	0.156***	0.166***	0.067**	0.140***	0.162***
	(0.030)	(0.031)	(0.039)	(0.034)	(0.027)	(0.034)	(0.040)	(0.034)	(0.032)	(0.036)	(0.033)	(0.029)	(0.038)	(0.036)
Other Funding Sources (IRL)	0.131	-0.119	0.147	0.016	0.008	0.197*	0.007	-0.123	-0.054	-0.088	0.051	0.053	-0.009	-0.029
	(0.099)	(0.119)	(0.124)	(0.093)	(0.070)	(0.114)	(0.103)	(0.134)	(0.105)	(0.087)	(0.092)	(0.079)	(0.112)	(0.127)
Other Funding Sources (Outside IRL).	-0.473***	-0.321***	-0.234*	-0.117	0.006	-0.145	-0.104	-0.393**	-0.538***	0.002	-0.216**	-0.070	-0.126	-0.060
	(0.107)	(0.117)	(0.131)	(0.103)	(0.080)	(0.121)	(0.115)	(0.179)	(0.148)	(0.091)	(0.102)	(0.089)	(0.118)	(0.129)
Cooperation Clients	0.010	0.116**	0.105	0.103*	0.170***	0.061	0.069	-0.072	0.123**	0.116*	0.155**	0.035	0.050	0.125**
	(0.049)	(0.056)	(0.071)	(0.062)	(0.049)	(0.059)	(0.073)	(0.050)	(0.048)	(0.061)	(0.061)	(0.041)	(0.055)	(0.059)
Cooperation Suppliers	-0.049	-0.012	0.220***	0.103	0.012	0.090*	0.191***	0.069*	-0.062*	0.210***	0.110***	0.031	0.095**	0.214***
	(0.052)	(0.047)	(0.063)	(0.063)	(0.043)	(0.053)	(0.069)	(0.042)	(0.036)	(0.044)	(0.040)	(0.032)	(0.040)	(0.049)
Cooperation Other Firms	0.127**	-0.021	0.169*	0.202**	0.078	0.060	0.247**	0.023	0.025	0.132	0.018	0.159***	-0.001	0.098
	(0.057)	(0.068)	(0.097)	(0.096)	(0.058)	(0.077)	(0.098)	(0.072)	(0.073)	(0.097)	(0.098)	(0.058)	(0.077)	(0.120)
Cooperation Public	0.152***	0.057	0.139***	0.207***	0.065*	0.113**	0.091*	0.147***	0.060*	0.132***	0.109***	0.060*	0.078*	0.152***
	(0.033)	(0.043)	(0.051)	(0.048)	(0.035)	(0.044)	(0.054)	(0.035)	(0.036)	(0.041)	(0.038)	(0.031)	(0.040)	(0.041)
Industry Control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Survey wave control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	0.511***	0.435***	0.533***	0.432***	0.394***	0.542**	0.533***	0.443	0.544*	0.436***	0.411**	0.388***	0.510***	0.561
Constant	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0..001)	(0.002)	(0.002)	(0.002)	(0.003)
Observations	1,169	1,139	1,169	1,169	1,158	1,169	1,169	1,362	1,362	1,362	1,362	1,347	1,362	1,362
	.132	.326	-.969	-.592	-.333	-.775	-.805	-.395	.272	.852	.116	-.002	-.234	-.728
Panel variance (Log)	(393)	(.243)	(.425)	(.393)	(.371)	(.434)	(.378)	(.245)	(.234)	(.107)	(.214)	(.274)	(.224)	(.274)
	.53	.508	.274	.355	.471	.315	,308	.402	.567	.421	.529	.499	.441	.325
Rho	(.393)	(.100)	(.084)	(.090)	(.090)	(.093)	(.080)	(.059)	(.057)	(.061)	(.053)	(.068)	(.055)	(.060)
McFadden Pseudo R^2	0.341	0.295	0.339	0.410	0.281	0.411	0.398	0.411	0.437	0.399	0.441	0.373	0.410	0.399

Results presented in average marginal effect: Robust standard errors in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included. Rho refers to interclass-correlation, which is the variance that can be explained by differences across panels. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 3-D: Robustness check with a multivariate probit model (in log likelihoods)

	Panel A: Small-sized Firms (> =10 & < 50 Employees)							Panel B: Larger-sized firms (>=50 Employees)						
	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Org. Innov.	Scientific Research	Dev.	Process Innov.	Product Innov.	Service Innov.	Radical Innov.	Org. Innov.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**	**MVProbit**
Internal Financial Resources	-0.013	-0.012	-0.046	-0.149	-0.404***	0.023	-0.184***	0.594***	0.298	0.423*	0.381**	-0.101	0.022	0.119
	(0.367)	(0.248)	(0.183)	(0.111)	(0.097)	(0.086)	(0.051)	(0.144)	(0.204)	(0.221)	(0.194)	(0.247)	(0.126)	(0.124)
Size (Ln Employees)	0.517	0.474***	0.159***	-0.059	0.067	0.088**	0.316**	0.095***	0.200***	0.246***	0.028	0.038	0.064	0.160**
	(0.319)	(0.171)	(0.034)	(0.079)	(0.064)	(0.035)	(0.037)	(0.021)	(0.064)	(0.066)	(0.072)	(0.027)	(0.075)	(0.063)
Employees (R&D)	0.029***	0.040***	0.002	0.012***	0.009**	0.014***	0.000	0.026***	0.036***	0.005***	0.008***	0.012***	0.014***	0.003***
	(0.008)	(0.005)	(0.001)	(0.003)	(0.002)	(0.002)	(0.001)	(0.007)	(0.011)	(0.002)	(0.002)	(0.004)	(0.002)	(0.001)
Age	0.004	0.00	-0.007*	0.001	0.005*	0.001	-0.001	-0.009***	-0.007***	-0.010***	-0.006***	-0.018***	-0.008***	-0.008***
	(0.002)	(0002)	(0.004)	(0.004)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
Irish Owned	0.150	-0.017	-0.146*	-0.014	-0.142*	0.003	-0.125	0.248***	-0.037	0.226***	0.220	0.071	0.027	-0.026
	(0.094)	(0.226)	(0.076)	(0.050)	(0.079)	(0.086)	0.135)	(0.061)	(0.078)	(0.059)	(0.237)	(0.109)	(0.113)	(0.081)
Export	0.082	0.379***	0.247**	0.732***	0.296***	0.449***	0.293***	0.301**	0.285**	0.325***	0.477***	0.035	0.253***	0.216**
	(0.189)	(0.072)	(0.071)	(0.115)	(0.110)	(0.080)	(0.075)	(0.148)	(0.136)	(0.128)	(0.086)	(0.116)	(0.087)	(0.085)
Enterprise Group	-0.074	-0.109	-0.108	0.130	-0.065	0.036	0.085	0.037	0.296**	-0.120***	0.162***	-0.096	-0.040	-0.0730
	(0.052)	(0.102)	(0.081)	(0.116)	(0.140)	(0.088)	0.077)	(0.068)	(0.116)	(0.035)	(0.044)	(0.074)	(0.053)	(0.060)
Fund EU	-0.103	-0.217	-0.040	0.303***	0.162	0.340***	0.416**	-0.042	-0.627**	-0.144	-0.289	0.368	0.162	-0.013
	(0.176)	(0.139)	(0.090)	(0.096)	(0.137)	(0.096)	0.163)	(0.184)	(0.306)	(0.174)	(0.201)	(0.277)	(0.221)	(0.185)
Fund National	0.293***	0.354**	0.564***	0.642***	0.329**	0.066***	0.631***	0.504***	0.638***	0.439***	0.558***	0.139***	0.380***	0.510***
	(0.095)	(0.071)	(0.027)	(0.244)	(0.133)	(0.092)	0.102)	(0.082)	(0.065)	(0.133)	(0.020)	(0.057)	(0.050)	(0.074)
Other Funding Sources (IRL)	0.505	-0.418	0.565**	0.120	0.195	0.464**	0.051	-0.412***	-0.338***	-0.336***	0.332***	0.162	0.201***	0.004
	(0.320)	(0.418)	(0280)	(0.098)	(0.238)	(0.080)	(0.244)	(0.097)	(0.306)	(0.109)	(0.051)	(0.122)	(0.040)	(0.110)
Other Funding Sources (Outside IRL).	-0.238	-0.346**	-0.508*	-0.439***	0.195	-0.446***	-0.351*	-1.187***	-1.600***	0.048	-0.843***	-0.195	-0.735***	-0.349***
	(0.329)	(0.097)	(0.280)	(0.089)	(0.386)	(0.084)	(0.198)	(0.229)	(0.237)	(0.233)	(0.093)	(0.274)	(0.110)	(0.101)
Cooperation Clients	0.139	0.230	0.518***	0.287	0.845***	0.429***	0.249**	-0.253**	0.455***	0.509***	0.633***	0.300***	0.275**	0.419***
	(1.133)	(0.174)	(0.121)	(0.180)	(0.235)	(0.146)	(0.107)	(0.114)	(0.130)	(0.077)	(0.099)	(0.086)	(0.136)	(0.107)
Cooperation Suppliers	-0.252	-0.145	0.534***	0.365***	-0.070	0.224*	0.473***	0.207**	-0.194*	0.671***	0.160	0.111	0.121	0.626***
	(0.210)	(0.119)	(0.162)	(0.089)	(0.378)	(0.135)	(0.092)	(0.104)	(0.116)	(0.059)	(0.136)	(0.212)	(0.119)	(0.079)
Cooperation Other Firms	0.377	-0.361	0.437	0.408**	0.331***	0.041	0.704***	0.083	0.083	0.338	0.194	0.724***	0.317	0.352*
	(0.263)	(0.338)	(0.276)	(0.196)	(0.113)	(0.067)	(0.170)	(0.137)	(0.255)	(0.264)	(0.147)	(0.181)	(0.235)	(0.212)
Cooperation Public	0.727***	0.422**	0.387***	0.528***	0.188	0.237*	0.287***	0.496***	0.264*	0.307***	0.365***	0.199**	0.242***	0.482***
	(0.098)	(0.190)	(0.106)	(0.134)	(0.117)	(0.130)	(0.086)	(0.063)	(0.135)	(0.056)	(0.063)	(0.101)	(0.044)	(0.053)
Industry Control/ Survey wave control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	149.9**	252.2**	19.1	169.2***	-14.6	80.5	16.977	295.8***	241.7***	69.5	141.6***	-40.1	69.5***	54.8
	(61.3)	(73.1)	(40.6)	(39.3)	(22.4)	(54.2)	(30.242)	(10.3)	(40.3)	(65.4)	(49.4)	(49..5)	(26.7)	(41.5)
Observations	1,169	1,139	1,169	1,169	1,158	1,169	1,169	1,362	1,362	1,362	1,362	1,347	1,362	1,362
Rho 2	0.371**	1						0.362***	1					
Rho 3	0.079	0.137***	1					0.089**	0.080	1				
Rho 4	0.257***	0.244***	0.408***	1				0.121***	0.206***	0.312***	1			
Rho 5	0.045	0.176**	0.439***	0.410***	1			-0.005	-0.038	0.375***	0.300***	1		
Rho 6	0.178***	0.268***	0.417***	0.853***	0.615***	1		0.085***	0.159**	0.360***	0.813***	0.458***	1	
Rho 7	0.122***	0.086**	0.533***	0.533***	0.312***	0.344***	1	0.0450	0.043	0.511***	0.920***	0.163***	0.168***	1
McFadden Pseudo R^2	0.322	0.293	0.298	0.222	0.301	0.230	0.300	0.371	0.301	0.310	0.332	0.266	0.300	0.371

Results presented in log likelihoods: Robust standard errors in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included Rho (2 to 7) refers to the correlation of the panels' residuals for each pairwise comparison. Statistically significant Rho coefficients support the simultaneous estimations of the probit models by means of a multivariate approach. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 3-E: Robustness check with random effect probit model with an interaction term (in average marginal effects)

	Scientific Research	Development	Process Innovation	Product Innovation	Service Innovation	Radical Innovation	Org. Innovation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	dy/dx RE Probit	**dy/dx RE Probi t**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**	**dy/dx RE Probit**
VARIABLES							
Internal Financial Resources	0.210***	0.149**	0.177***	0.111*	-0.067	0.007	0.098
	(0.062)	(0.061)	(0.073)	(0.060)	(0.056)	(0.068)	(0.072)
Small (< 50 Employees)	-.097***	-0.102***	-0.77***	-0.003	-0.059**	-0.096***	-0.076***
	(0.062)	(0.022)	(0.024)	(0.023)	(0.019)	(0.023)	(0.023)
Financial Resource X Small	-0.224***	-0.162***	-0.226***	-0.157*	0.004	0.022	-0.169*
	(0.080)	(0.080)	(0.093)	(0.089)	(0.074)	(0.089)	(0.091)
Employees (R&D)	0.007***	0.010***	0.000	0.002***	0.001***	0.004***	0.001
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)
Age	-0.006	-0.001	-0.001**	-0.005	-0.001*	-0.006	-0.008
	(0.008)	(0.008)	(0.000)	(0/008)	(0.000)	(0.008)	(0.009)
Irish Owned	0.053**	-0.016	0.001	0.038*	-0.001	0.004	-0.031
	(0.020)	(0.019)	(0.023)	(0.022)	(0.018)	(0.021)	(0.022)
Export	0.065**	0.092***	0.104***	0.188***	0.050**	0.116***	0.100***
	(0.0232)	(0.021)	(0.024)	(0.024)	(0.021)	(0.025)	(0.024)
Enterprise Group	0.027	0.074***	-0.015	0.031	-0.023	0.003	0.018
	(0.020)	(0.021)	(0.023)	(0.022)	(0.019)	(0.022)	(0.023)
Fund EU	0.003	-0.069	-0.018	0.008	0.037	0.070	0.064
	(0.048)	(0.049)	(0.061)	(0.050)	(0.036)	(0.052)	(0.060)
Fund National	0.128***	0.120***	0.202***	0.190***	0.072***	0.178***	0.196***
	(0.022)	(0.022)	(0.026)	(0.024)	(0.199)	(0.025)	(0.026)
Other Funding Sources (IRL)	-0.003	-0.091	0.046	0.029	0.012	0.085	-0.009
	(0.087)	(0.082)	(0.077)	(0.065)	(0.059)	(0.077)	(0.082)
Other Funding Sources (Outside IRL).	-0.437***	-0.433***	-0.123	-0.160**	0.010	-0.135	-0.094
	(0.118)	(0.097)	(0.084)	(0.072)	(0.059)	(0.082)	(0.082)
Cooperation Clients	-0.030	0.114***	0.108**	0.151***	0.100***	0.067*	0.098**
	(0.035)	(0.039)	(0.046)	(0.045)	(0.031)	(0.040)	(0.046)
Cooperation Suppliers	0.204	-0.036	0.217***	0.101***	0.021	0.0856***	0.211***
	(0.031)	(0.029)	(0.036)	(0,033)	(0.025)	(0.031)	(0.039)
Cooperation Other Firms	0.079	-0.010	0.176***	0.097	0.130***	0.052	0.184**
	(0.048)	(0.058)	(0.066)	(0.071)	(0.040)	(0.055)	(0.076)
Cooperation Public	0.155***	0.064**	0.144***	0.145***	0.057***	0.097***	0.137***
	(0.025)	(0.026)	(0.032)	(0.029)	(0.230)	(0.029)	(0.033)
Industry Control	yes	yes	yes	yes	yes	Yes	yes
Survey wave control	yes	yes	yes	yes	yes	yes	yes
Constant	0.373***	0.443	0.510***	0.485***	0.233**	0.397***	0.568
	(0.007)	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)	(0.008)
Observations	2531	2531	2531	2531	2531	2531	2531
Panel variance (Log)	-0.296	0.180	-0.475	-0.218	-0.083	-0.460	-0.723
	(0.192)	(0.195)	(0.195)	(0.079)	(0.207)	(0.189)	(0.215)
Rho	0.426	0.545	0.383	0.445	0.470	0.386	0.326
	(0.048)	(0.048)	(0.046)	(0.043)	(0.051)	(0.045)	(0.047)
McFadden Pseudo R^2	0.322	0.291	0.289	0.330	0.223	0.389	.0323

Results presented in average marginal effect: Robust standard errors in parentheses. One-digit NACE Rev.2 codes and survey wave control variables included. Rho refers to interclass-correlation, which is the variance that can be explained by differences across panels. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 4-A: Comparison between full sample of firms in the Innovation in Irish Enterprises survey with the effective sub-sample used in the analysis

Variables	Innovation in Irish Enterprises Survey 2010 (n = 3,245)		Innovation in Irish Enterprises Survey 2016 (n = 2,576)		Effective Sample (n = 1,296)	
	(n)	(%)	(n)	(%)	(n)	(%)
Irish Owned firms (Yes = 1)	2278	70.231	1570	60.952	919	70.910
Small-sized firms (Yes = 1)	2216	68.232	1681	65.269	832	64.211
Medium-size firms (Yes = 1)	802	24.711	726	28.181	366	28.244
Large-sized firms (Yes = 1)	227	7.010	169	6.558	98	7.559
Part of Enterprise Group (Yes = 1)	689	35.682	960	39.272	492	36.223
Sector B (Mining and Quarrying)	30	0.921	25	0.961	14	1.079
Sector C (Manufacturing)	1138	35.068	933	36.190	483	37.272
Sector D (Electricity, Gas, etc.)	12	0.371	7	0.291	3	0.232
Sector E (Water Supply, etc.)	64	1.966	46	1.831	24	1.845
Sector G (Wholesale and retail)	812	25.010	650	25.231	347	26.768
Sector H (Transport and Storage)	369	11.371	289	11.199	139	10.733
Sector J (Information and Comm.).	314	9.683	247	9.598	124	9.573
Sector K (Financial Services)	352	10.852	223	8.671	98	7.562
Sector M (Scientific and Technical act.)	154	4.745	124	4.823	64	4.942
Product Innovation (Yes = 1)	2226	68.532	1607	62.382	844	65.196
Process Innovation (Yes = 1)	2084	64.210	1600	62.111	787	60.734
Organisational Innovation (Yes = 1)	1964	60.521	1638	63.596	731	66.421
Received Public Financial Support for R&I (Yes = 1)	N/A*		329	12.777	150	11.572

Note: Table produced by the author using data from the IIE survey. * The 2010 IIE survey wave did not include questions regarding the receipt of public financial support for R&I.

Appendix 4-B: Sample of firms that received financial support for research and innovation between IIE Survey and Administrative data.

Variables	Received Public Financial Support as reported in IIE survey (i.e. 2012, 2014, and 2016 waves) (n = 1,296)		Received Public Financial Support as Matched with the Administrative Data (i.e. 2011 to 2015)	
	(n)	(%)	(n)	(%)
Irish Owned firms (Yes = 1)	208	71.232	156	69.962
Small-sized firms (Yes = 1)	147	50.341	109	48.881
Medium-size firms (Yes = 1)	104	36.621	86	38.574
Large-sized firms (Yes = 1)	41	14.040	28	12.561
Part of Enterprise Group (Yes = 1)	159	54.452	122	54.711
Sector B (Mining and Quarrying)	4	1.373	1	0.442
Sector C (Manufacturing)	186	63.691	150	67.711
Sector D (Electricity, Gas, etc.)	1	0.34	1	0.454
Sector E (Water Supply, etc.)	1	0.342	2	0.899
Sector G (Wholesale and retail)	34	11.644	19	8.522
Sector H (Transport and Storage)	7	2.441	4	2.212
Sector J (Information and Comm.).	40	13.691	31	13.939
Sector K (Financial Services)	7	2.411	6	2.691
Sector M (Scientific and Technical act.)	12	4.112	9	4.040
Product Innovation (Yes = 1)	192	65.753	151	67.714
Process Innovation (Yes = 1)	174	59.594	130	58.332
Organisational Innovation (Yes = 1)	182	62.332	135	59.951
Observations		n = 292		n = 223

Note: Table prepared by the author using IIE survey data, and administrative data from Ireland's three main funding agencies for R&I, and R&D tax credit data from the Revenue Commissioners. The period covered by the IIE survey data pertains to 2010 to 2016. However, the period covered by the administrative data is from 2011 to 2015.

Appendix 4-C: Questions pertaining to perceived constraints to innovation activities included in 2010 and 2016 IIE survey waves

Panel A: 2010 Survey Wave

Question 7.1 During the three years 2008 to 2010, how important were the following factors in preventing your enterprise from innovating or in hampering your innovation activities?		High	Medium	Low	Factor not experienced
Cost Factors	Lack of funds within your enterprise or group				
	Lack of finance from sources outside your enterprise				
	Innovation costs too high				
Knowledge Factors	Lack of qualified personnel				
	Lack of information on technology				
	Lack of information on markets				
	Difficulty in finding cooperation partners for innovation				
Market Factors	Market dominated by established enterprise				
	Uncertain demand for innovative goods or service				
Reasons not to innovate	No need due to prior innovations by your enterprise				
	No need because of no demand for innovation				

Panel B: 2016 Survey Wave

Question 9.1 During the three years 2014 to 2016, how important were the following factors in hampering your innovation activities?		High	Medium	Low	Not important
Cost Factors	Lack of internal finance for innovation				
	Lack of credit or private equity				
	Innovation costs too high				
Knowledge Factors	Lack of skilled employees within your enterprise				
	Lack of collaboration partners				
	Difficulties in obtaining government grants or subsidies for innovation				
Market Factors	Uncertain market demand for your ideas for innovations				
	Too much competition in your market				

Appendix 4-D: Constraints to innovation variables

Heading Constraint	Sub-constraints	Heading constraints (any level)	Heading Constraints (high)
Financial Constraints	Lack of Internal Funding Lack of Credit Cost too High	Financial constraints =1 if a firm experienced any of these constraints at any level of importance (low=1, medium=2 and high=3), otherwise 0.	Financial constraint high = 1 if a firm experienced any of these constraints to be of high importance (i.e. high=3), otherwise 0.
Market Constraints	Lack of Qualified Personnel Lack of Partners	Knowledge constraints =1 if a firm experienced any of these constraints at any level of importance (low=1, medium=2 and high=3), otherwise 0.	Knowledge constraints high = 1 if a firm experienced any of these constraints to be of high importance (i.e. high=3), otherwise 0.
Market Constraints	Lack of Demand	Lack of demand = 1 if a firm experienced a lack of demand at any level of importance (low=1, medium=2 and high=3), otherwise 0.	Lack of demand high = 1 if a firm experienced a lack of demand to be of high importance (i.e. high=3), otherwise 0

Appendix 4-E: Public financial instruments used in the analysis

Instrument	Agency	Classification
Panel A		
Company R&D Support	IDA/EI	Direct R&D Subsidy
R&D innovation	IDA	Direct R&D Subsidy
R&D Funding	IDA/EI	Direct R&D Subsidy
Panel B		
Innovation Voucher	IDA/EI	Collaborative R&D Subsidy
Innovation Partnerships	IDA/EI	Collaborative R&D Subsidy
Technical Feasibility/RD&I Feasibility	IDA	Collaborative R&D Subsidy
Tech centre collaboration	IDA/EI	Collaborative R&D Subsidy
Technology Gateway	EI	Collaborative R&D Subsidy
Research Centre Award	SFI	Collaborative R&D Subsidy
Panel C		
R&D Tax Credits	Revenue Commissioner	R&D Tax Credit (indirect)

Appendix 4-F: Impact of public financial support on firms' likelihood to perceive new (sub) constraints.

Experienced (sub-Constraint)	Treated ATT (1)	Tax Credit ATT (2)	Direct Subsidies ATT (3)	Collaborative Subsidies ATT (4)
Lack Internal Funding	0.296**	0.445*	0.124	0.135
	(0.136)	(0.251)	(0.251)	(0.207)
Lack of Credit	0.336**	0.368	0.209	0.303*
	(0.119)	(0.225)	(0.228)	(0.173)
Cost too High	0.186	0.292	0.235	0.251
	(0.140)	(0.264)	(0.279)	(.184)
Lack of Qualified Personnel	0.122	0.369*	0.139	0.088
	(0.158)	(0.209)	(0.304)	(0.198)
Lack of Partners	-0.045	0.004	0.012	0.201
	(0.158)	(0.236)	(0.290)	(0.196)
Lack of Demand	0.359**	0.222	0.460*	0.259
	(0.138)	(0.204)	(.251)	(0.182)
Observations	186	67	52	49

Coefficients are Average Treatment Effects with robust standard errors in parenthesis. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 refers to the receipt of any type of public financial support instrument for R&I, Column 2 to the receipt of R&D tax credits only, Column 3 to the receipt of R&D subsidies only, and Column 4 for the receipt of R&D subsidies that require collaboration between firms and public knowledge providers only.

Appendix 5-A: Variables Description

	Total Sample							
	Treated				Untreated			
Outcome Variables (i.e. in 2016)	Mean	SD	Min	Max	Mean	SD	Min	Max
Introduction of new to market good or service (1 = Yes)	0.406	0.492	0	1	0.212	0.412	0	1
Ln Turnover from radical innovation per Employee	4.049	5.194	0	13.707	1.999	4.118	0	13.411
Control Variables (i.e. in 2010)								
Irish Owned (1=Yes)	0.696	0.463	0	1	0.711	0.449	0	1
Enterprise Group (1= Yes)	1.547	0.498	0	1	1.677	0.572	0	1
Export (1= Yes)	0.904	0.293	0	1	0.253	0.432	0	1
Financial Constraints High (1 = Yes)	0.276	0.448	0	1	0.325	0.467	0	1
Financial Constraints Med (1 = Yes)	0.52	0.521	0	1	0.276	0.457	0	1
Financial Constraints Low (1 = Yes)	0.425	0.495	0	1	0.425	0.514	0	1
Knowledge Constraints High (1 = Yes)	0.095	0.293	0	1	0.064	0.241	0	1
Knowledge Constraints Med (1 = Yes)	0.285	0.452	0	1	0.215	0.415	0	1
Knowledge Constraints Low (1 = Yes)	0.506	0.501	0	1	0.324	0.473	0	1
Market Constraints High (1 = Yes)	0.18	0.385	0	1	0.19	0.391	0	1
Market Constraints Med (1 = Yes)	0.438	0.452	0	1	0.312	0.463	0	1
Market Constraints Low (1 = Yes)	0.371	0.484	0	1	0.324	0.469	0	1
Breath of Cooperation Partners (0 to 4)	0.574	0.943	0	4	0.199	0.646	0	4
Breath of Innovation (0 to 4)	2.44	1.801	0	4	1.355	1.61	0	4
Intensity of turnover from Innovation (Ln per employee)	9.54	6.891	0	20.31	3.853	6.442	0	19.821
New to market good or service (1 = Yes)	0.472	0.500	0	1	0.165	0.373	0	1

Appendix 5-B: Public financial instruments used in the analysis

Instrument	Funding Agency	Number of Firms Supported
Company R&D Support	IDA/EI	27
Innovation Voucher	IDA/EI	21
Innovation Partnerships	IDA/EI	12
Technical Feasibility/RD&I Feasibility	IDA	8
Tech centre collaboration	IDA/EI	5
Technology Gateway	EI	8
Research Centre Award	SFI	5
R&D Tax Credits	Revenue Commissioners	135
Total		**221**

Appendix 5-C: Questions pertaining to perceived constraints to innovation activities included in 2010 Innovation in Irish Enterprises (IIE) survey wave

Question 7.1 During the three years 2008 to 2010, how important were the following factors in preventing your enterprise from innovating or in hampering your innovation activities?		High	Medium	Low	Factor not experienced
Cost Factors	Lack of funds within your enterprise or group				
	Lack of finance from sources outside your enterprise				
	Innovation costs too high				
Knowledge Factors	Lack of qualified personnel				
	Lack of information on technology				
	Lack of information on markets				
	Difficulty in finding cooperation partners for innovation				
Market Factors	Market dominated by established enterprise				
	Uncertain demand for innovative goods or service				
Reasons not to innovate	No need due to prior innovations by your enterprise				
	No need because of no demand for innovation				

Appendix 5-D: Constraints to R&I variables, and their distribution in the effective sample (Nearest Neighbour)

Constraints	Treatment		
	Treated =0	Treated = 1	Total
Lack of Qualified employees within the enterprise = 0	116	167	
Lack of qualified employees within the enterprise = 1	63	134	
Total	179	301	480
Lack of qualified employees within the enterprise Low=1	85	55	
Lack of qualified employees within the enterprise Medium=1	32	31	
Lack of qualified employees within the enterprise High=1	26	27	
	Treated =0	Treated = 1	Total
Lack of Information Tech. and Markets = 0	109	174	
Lack of Information Tech. and Markets = 0	59	138	
Total	168	312	480
Lack of Information Tech. and Markets Low=1	92	85	
Lack of Information Tech. and Markets Medium=1	69	62	
Lack of Information Tech. and Markets High=1	27	29	
	Treated =0	Treated = 1	Total
Difficulty finding partners = 0	156	127	
Difficulty finding partners = 1	101	96	
Total	257	223	480
Difficulty finding partners Low=1	85	55	
Difficulty finding partners Medium=1	32	31	
Difficulty finding partners High=1	26	27	

Appendix 5-E: Probit analysis of likelihood to receive public financial support for research and innovation

Independent Variables	Probability of Treatment (1 = Yes) Probit
Irish Owned (1=Yes)	0.188
	(0.114)
Enterprise Group (1= Yes)	-0.003
	(0.112)
Export (1= Yes)	0.748***
	(0.133)
Breath of cooperation partners (0 to 4)	0.094*
	(0.045)
Intensity turnover from Innovation (Baseline)	0.032***
	(0.010)
Breath of Innovation (0 to 4)	-0.041
	(0.041)
Introduction of new to market good or service (Baseline)	-0.322**
	(0.143)
Financial Constraints High (1 = Yes in 2010)	-0.032
	(0.122)
Financial Constraints Med (1 = Yes in 2010)	0.148
	(0.112)
Financial Constraints Low (1 = Yes in 2010)	0.145
	(0.111)
Knowledge Constraints High (1 = Yes in 2010)	0.323*
	(.184)
Knowledge Constraints Med (1 = Yes in 2010)	-0.063
	(0.123)
Knowledge Constraints Low (1 = Yes in 2010)	0.201*
	(0.117)
Market Constraints High (1 = Yes in 2010)	-0.181
	(0.136)
Market Constraints Med (1 = Yes in 2010)	-0.104
	(0.111)
Market Constraints Low (1 = Yes in 2010)	-0.071
	(0.121)
Size = 2 (i.e. Medium)	0.164
	(0.113)
Size = 3 (i.e. Large)	0.119
	(0.184)
Sector B (Mining and Quarrying)	0.718
	(0.616)
Sector C (Manufacturing)	0.978***
	(0.342)
Sector D (Electricity, Gas, etc.)	0.354
	(0.729)
Sector E (Water Supply, etc.)	-0.164
	(0.624)
Sector G (Wholesale and retail)	0.492
	(0.627)
Sector H (Transport and Storage)	-0.295
	(0.650)
Sector J (Information and Comm.).	0.270*
	(0.111)
Sector K (Financial Services)	0.164
	(0.113)
Sector M (Scientific and Technical act.)	0.119*
	(0.066)
Constant	-2.389***
	(0.665)
Observations	1,296
Log Likelihood -433.126 Lr chi2(25) 257.67 Prob > chi2 = 0.000 Pseudo R2 = 0.229	
Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1.	

Appendix 5-F: Balance check Stage 1 (Nearest 3 Neighbours)

Matching Variables	Treated	Control	Difference (T – C)	P-Value (T- C)
Irish Owned (1=Yes)	0.675	0.684	-0.009	0.844
Enterprise Group (1= Yes)	1.565	1.529	0.036	0.501
Export (1= Yes)	0.893	0.922	-0.029	0.325
Breath of cooperation partners (0 to 4)	0.532	0.555	-0.023	0.814
Intensity turnover from Innovation (2010)	9.191	8.982	0.208	0.771
Breath of Innovation (0 to 4)	2.442	2.373	0.067	0.676
New to market good or service (2010)	0.446	0.404	0.042	0.397
Size	1.619	1.619	0	1
Financial Constraints High (1 = Yes in 2010)	0.284	0.285	-0.001	0.97
Financial Constraints Med (1 = Yes in 2010)	0.522	0.496	0.026	0.604
Financial Constraints Low (1 = Yes in 2010)	0.406	0.444	-0.038	0.446
Knowledge Constraints High (1 = Yes in 2010)	0.081	0.105	-0.024	0.404
Knowledge Constraints Med (1 = Yes in 2010)	0.299	0.341	-0.042	0.308
Knowledge Constraints Low (1 = Yes in 2010)	0.492	0.466	0.026	0.603
Market Constraints High (1 = Yes in 2010)	0.187	0.175	0.012	0.761
Market Constraints Med (1 = Yes in 2010)	0.441	0.463	-0.022	0.662
Market Constraints Low (1 = Yes in 2010)	0.373	0.367	0.003	0.446

Rubin’s B = 20.6. Mean Bias =2.9 ; Median Bias = 3.5. R = 0.92
*** Denotes significance at the 99% level, ** 95% level and * 90% level. Following Rubin (2001), a Rubin’s B coefficient below 25 indicates that the standardised difference of the means of the propensity score in the treated and control groups lies between .5 and 2, which is sufficient for ascertaining sufficient overall balance.

Appendix 5-G: Balance check Stage 1 (One to One Matching)

Matching Variables	Treated	Control	Difference (T – C)	P-Value (T- C)
Irish Owned (1=Yes)	0.666	0.677	-0.011	0.827
Enterprise Group (1= Yes)	1.561	0.1545	1.4055	0.757
Export (1= Yes)	0.888	0.904	-0.016	0.613
Breath of cooperation partners (0 to 4)	0.554	0.486	0.064	0.524
Intensity turnover from Innovation (2010)	9.236	9.182	0.048	0.952
New to market good or service (2010)	0.449	0.396	0.053	0.299
Size	1.597	1.603	-0.006	0.938
Financial Constraints High (1 = Yes in 2010)	0.282	0.243	0.037	0.694
Financial Constraints Med (1 = Yes in 2010)	0.523	0.462	0.063	0.218
Financial Constraints Low (1 = Yes in 2010)	0.412	0.475	-0.058	0.256
Knowledge Constraints High (1 = Yes in 2010)	0.195	0.179	0.016	0.694
Knowledge Constraints Med (1 = Yes in 2010)	0.444	0.412	0.032	0.534
Knowledge Constraints Low (1 = Yes in 2010)	0.37	0.343	0.027	0.593
Market Constraints High (1 = Yes in 2010)	0.195	0.179	0.016	0.694
Market Constraints Med (1 = Yes in 2010)	0.444	0.412	0.032	0.534
Market Constraints Low (1 = Yes in 2010)	0.376	0.343	0.027	0.256

Rubin's B = 23.1. Mean Bias =3.9 ; Median Bias = 3.3. R = 0.98

*** Denotes significance at the 99% level, ** 95% level and * 90% level. Following Rubin (2001), a Rubin's B coefficient below 25 indicates that the standardised difference of the means of the propensity score in the treated and control groups lies between .5 and 2, which is sufficient for ascertaining sufficient overall balance.