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DISCUSSION PAPER

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Subsidising Innovation Outside or Within Firms' Existing Knowledge Base: Which Is Best for Radical Innovation?

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Subsidising Innovation Outside or Within Firms' Existing Knowledge Base: Which is Best for Radical Innovation?

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Abstract

Public financial support for firm-level Research and Innovation (R&I) can generate important socio-economic returns. This is especially true if firms use this support to develop radical innovation, defined as new-to-market goods and services. However, radical innovation is risky, and prone to failure. Therefore, subsidising radical innovation can also generate sub-optimal socio-economic returns (i.e. policy failure). Understanding how public funding for R&I can be allocated in a way that encourages radical innovation, while avoiding policy failure, is crucial. Our paper investigates, for the first time, whether public funding for R&I generates more radical innovation in firms seeking to innovate by engaging in knowledge areas that are new to them, versus firms seeking to exploit their existing knowledge base. We make this distinction by using a novel approach, based on the knowledge challenges that firms face when innovating. By merging firm-level survey data with administrative data on public funding for R&I in Ireland, we find that subsidising firms seeking to engage in new knowledge areas, can result in more radical innovation and turnover from radical innovation, compared to firms seeking to exploit their existing knowledge base. These are critical insights from theoretical and policymaking perspectives, regarding the allocation of public funding for R&I.

JEL: D32, D83, O31, O32, O33

Keywords: radical innovation, public financial support, knowledge base, policy failure, additionality

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1. Introduction

Governments in many countries provide firms with public financial support for their research and innovation (R&I) activities (Link and Scott 2013; OECD 2023). Subsidising firm-level R&I can generate socio-economic returns, including improved economic performance, and high-quality employment (Choi and Lee 2021; Cerulli et al. 2022). Academics and policymakers increasingly recognise that such returns are more likely to arise when public financial support for R&I results in radical innovation in firms (Beck et al. 2016; Laplane and Mazzucato 2020; OECD 2021). Defined as products and services that are new to the market, radical innovation can increase firms' turnover, improve their performance in the market, and generate important knowledge spillovers (Autio et al. 2008; Beck et al. 2016; Berrutti and Bianchi 2020). However, there is only limited empirical evidence on how policymakers can successfully deliver R&I support in a way that translates into radical innovation in firms (Berrutti and Bianchi 2020; OECD 2021; Mina et al. 2021). This is a critical knowledge gap that prevails in the literature concerned with ensuring a more impactful allocation of public funding for R&I. As articulated by Criscuolo et al. (2022, p. 3) "best practices for designing and modulating R&D incentives continue to be an open question".

Public support for R&I can serve various policy goals, and policymakers face several policy options when allocating this support to firms (Okamuro and Nishimura 2015; Pereira and Suárez 2018). For example, policymakers have to decide whether to target the support at specific technologies (e.g. renewable energies), specific types of firms (e.g. start-ups, SMEs), and/or certain types of R&D activities (e.g. R&I within firms, industry-academic collaborations). In this paper, we analyse one key policy option that policymakers typically face, when allocating public financial support for R&I to firms. That is, whether to focus support on: (1) Firms seeking to innovate by exploiting their existing knowledge base; or (2) Firms seeking to innovate by engaging in knowledge areas that are new to them.

Our focus on the above groups of firms is important, in the context of using public financial support for R&I to generate more radical innovation. On the one hand, focusing support on firms seeking to engage in new knowledge areas can enable such firms to generate new knowledge and innovate radically (Yang et al. 2014; Mina et al. 2021). This, in turn, can result in firms opening new markets and/or developing new business models (Colombo et al. 2017; Radicic 2021). However, focusing support on such firms is risky (D'Este et al. 2016), and more likely to result in failed innovation projects, than focussing support on firms seeking to innovate by exploiting their existing knowledge base (Fiorentin et al. 2019). Therefore, it can lead to so-called 'policy failure', which refers to the mis-allocation of public funding resulting in sub-optimal (or no) socio-economic returns (Haapanen et al. 2014; Kärnä et al. 2022). On the other hand, focussing support on firms seeking to exploit their existing knowledge base can clearly reduce such risks, but the innovation activities of these firms may be less likely to be radical, and thus, have lower levels of socio-economic returns (Colombo et al. 2017; Berrutti and Bianchi 2020). There is also a risk of deadweight spending effects, as such firms may use public financial support to carry out R&I activities that they would have carried out anyway (Lenihan 2004; Pereira and Suárez 2018; Mina et al. 2021). Investigating whether public financial support for R&I results in radical innovation when focused on these two groups of firms is thus vital, as it can usefully inform a more impactful allocation of public financial support for R&I (Fiorentin et al. 2019; Berrutti and Bianchi 2020; Cerulli et al. 2022).

To identify the above two groups of firms, we use a new approach, based on information regarding the knowledge challenges that firms can face when innovating (D' Este et al. 2012; Coad et al. 2015; Zahler et al. 2022). Firms seeking to engage in new knowledge areas will need to generate or absorb new knowledge (Dasí et al. 2015; Ryan et al. 2018). In doing so, they are likely to face knowledge challenges related to a lack of knowledge about the technologies and markets they aim to enter, as these are new to them (Gibbert and Scranton

2009; Keupp and Gassmann 2013). Several studies support this, by outlining that firms are likely to face such knowledge challenges as they become more innovative and reach their knowledge frontiers (D'Este et al. 2012; Hölzl and Janger 2014; Coad et al. 2015; Santiago et al. 2017; Radicic 2021). Based on this, we identify firms facing a lack of information on technologies and markets for their desired R&I activities as firms seeking to innovate by engaging in knowledge areas that are new to them. Firms that do not experience such knowledge challenges are considered to innovate by exploiting their existing knowledge base. Using these definitions, we analyse whether public financial support for R&I results in a higher probability of radical innovation if allocated to the former or the latter group of firms. Moreover, to maximise socio-economic returns, radical innovation needs to generate economic benefits to firms (Cowling 2016; Nilsen et al. 2020). Therefore, we also analyse the percentage of turnover that the two groups of firms generate from radical innovation, as a result of receiving public financial support. As outlined by Hewitt-Dundas et al. (2019, p. 1315), this is a standard measure of the "initial market success of firms' NTM [new to-market] innovation activity", which is how we define radical innovation in the current paper.

Our paper makes a novel contribution to the literature concerned with a more impactful allocation of public financial support for R&I to firms. Existing studies on this topic, have mainly focused on analysing the impact of public financial support for R&I when allocated to firms with limited innovative capacity (e.g. R&D starters), *vis-à-vis* more established innovative firms (Wanzenböck et al. 2013; Nilsen et al. 2020; Berrutti and Bianchi 2020). Other studies have focused on the impact of the support on the 'Research' and 'Development' components of firm-level R&D (Beck et al. 2016; Hottenrott et al. 2017). In addition, existing literature does not specifically focus on radical innovation. To the best of our knowledge, ours is the first study to empirically analyse whether public financial support for R&I is more effective at generating radical innovation when targeted at: (1) Firms seeking to engage in new

knowledge areas, or; (2) Firms seeking to exploit their existing knowledge base. From a policy perspective, Mina et al. (2021, p. 3) note that public financial support for R&I needs to be allocated with "a greater degree of selectivity in order to address the funding gaps of firms with growth opportunities". The insights of our paper can usefully contribute to this key policy challenge.

Our analysis uses a novel and detailed database with information on firms in Ireland. We combine two waves of the Innovation in Irish Enterprises Survey (IIE, 2008-2010 and 2014-2016), with administrative data on public financial R&I support from all of the main funding agencies in Ireland (i.e. Enterprise Ireland, IDA Ireland, and Science Foundation Ireland) and data on R&D tax credits (from Ireland's Revenue Commissioners). Based on propensity score matching (Vanino et al. 2019), we build a sample of firms that received public financial support for R&I and firms which did not receive this support (i.e. treated and control firms). The control firms have the same characteristics as treated firms, especially in terms of past innovation activities, knowledge challenges, and other firm-level characteristics (e.g. firm sizes, sectors, etc.). We then use the balanced sample to estimate innovation production functions (Nilsen et al. 2020), using radical innovation as the output measure. The model includes a variable for public financial support for R&I, variables for the importance of knowledge challenges, and interaction terms for R&I support and knowledge challenges. This setting allows us to investigate whether treated firms that face knowledge challenges are more or less likely to produce radical innovation outputs, compared to treated firms not facing such challenges.

The remainder of the paper is organised as follows. Section 2 discusses the conceptual framework that guides our empirical research. Section 3 presents the data and the empirical approach. Section 4 discusses our main findings. Section 5 concludes with some implications for innovation policy and suggested avenues for future research.

2. Conceptual framework

2.1 Public support financial support and radical innovation

Public financial support for research and innovation (R&I) primarly focuses on addressing market failures resulting from knowledge spillovers (Arrow 1962; Choi and Lee 2017). Since knowledge spillovers limit the appropriation of returns from R&I investment, the returns of many R&I activities may be too low for firms to justify investing in them (Hall et al. 2015). Because of this, firms may refrain from investing in R&I activities, limiting the generation of new knowledge (Link and Scott 2021). Subsidising firm-level R&I can enable firms to perform additional R&I activities, create new knowledge spillovers, and improve innovation and productivity, beyond the supported firms (Autio and Rannikko 2016; Mina et al. 2021).

Given the importance of public financial support for R&I in driving firm-level R&D, policymakers typically face a critical decision when allocating this support to firms. On the one hand, they want to maximise the socio-economic returns of public investments (Haapanen et al. 2014; Mina et al. 2021). In the case of public financial support for R&I, this is most likely to occur when the support stimulates radical innovation in firms, defined here as new-to-market goods and services (Caggese 2019; Grashof and Kopka 2022). Radical innovation can enable firms to gain new customers, enter new markets and achieve growth (Hewitt-Dundas et al. 2019; Dean et al. 2020; Choi and Lee 2021). Moreover, radical innovation is most likely to maximise knowledge spillovers (Autio and Rannikko 2016; Colombo et al. 2017; Caggese 2019).

On the other hand, policymakers also need to avoid public financial support being provided for R&I activities that are likely to fail (Haapanen et al. 2014; Cerulli et al. 2022; Kärnä et al. 2022). As Haapanen et al. (2014) and Kärnä et al. (2022) note, this is important so as avoid 'policy failure', which refers to the misallocation of public financial support for R&I resulting in sub-optimal (or no) socio-economic returns. Supporting radical R&I activities in firms can result in

policy failure, because generating and successfully implementing radical innovation is challenging (Radas and Bozic 2009; D'Este et al. 2016). A key reason for this is that firms need to generate new knowledge, and/or combine different types of existing knowledge to come up with new solutions and/or technologies (Gibbert and Scranton 2009; Radas and Bozic 2009; Colombo et al. 2017). Moreover, firms need to convince users to adopt these new solutions and/or technologies, and/or create new markets for them (McDermott and O'Connor 2002; Colombo et al. 2017; Jugend et al. 2018; Perez-Alaniz et al. 2023).

To minimise the above risks, policymakers may focus public financial support for R&I on firms that are capable of successfully developing and implementing radical innovation (Hottenrott et al. 2016; Mina et al. 2021). There are two groups of firms that fulfil this policy requirement. The first group comprises firms that have well-developed knowledge stocks, and that seek to innovate based on technologies and competencies already available to them (Kapoor and Adner 2012; Roy and Sarkar 2016). As such firms exploit their existing knowledge base, targeting support at this group of firms is likely result in high innovation outputs. However, it can also result in low additionality since these firms are likely to achieve high levels of innovation output regardless of public financial support for R&I (Aschhoff 2010; Wanzenböck et al. 2013; Berrutti and Bianchi 2020). This, in turn, can lead to policy failure due to deadweight spending effects (Haapanen et al. 2014; Mina et al. 2021).

To avoid low additionality, policymakers may focus on supporting a second group of firms. This group of firms pertains to innovative firms seeking to innovate by engaging in knowledge areas that are new to them (Lee et al. 2014; Ryan et al. 2018; Rigg et al. 2021). Targeting support at this group of firms can potentially generate high additionality, especially in terms of radical innovation. This is because the support can enable such firms to carry out R&I activities that they would not carry out (or carry out to a lesser extent) without support (Lee 2011; Beck et al. 2016; Woschke et al. 2017; Caggese 2019). However, such firms may not have all of the

necessary knowledge and technology to successfully achieve their desired radical innovation projects. Therefore, some risk of project failure remains, especially if the firms are unable to obtain all the necessary knowledge to go beyond their existing technological frontiers (Gibbert and Scranton 2009; Colombo et al. 2017).

Allocating public financial support for R&I to the above two groups of firms, in view of realising more radical innovation, presents a challenge for policymakers. They need to strike a balance between the likelihood of the support resulting in radical innovation, while at the same time minimising the likelihood of policy failure. In this context, whether to target public financial support for R&I at firms seeking to engage in new knowledge areas, or at firms that exploit their existing knowledge base, remains the focus of academic and policy debates (Berrutti and Bianchi 2020; Fiorentin et al. 2023; OECD 2023).

2.2 Public financial support and knowledge challenges

As noted earlier (Section 2.1), allocating public financial support for R&I to drive radical innovation is risky. This is because radical innovation typically requires firms to generate new knowledge, and combine this new knoweldge with existing knowledge in order to go beyond existing technological frontiers (Gibbert and Scranton 2009; Colombo et al. 2017; Douglas et al. 2018). Firms can usually follow two different avenues to do this. The first avenue is to rely on their existing knowledge and established links to external knowledge sources. Radical innovation is based on exploiting these knowledge sources in a way that shifts the technological frontier within a given field of technology (D'Este et al. 2016; Antonelli et al. 2023). Moreover, firms can use their existing in-depth knowledge about markets and customer requirements to develop new ways to address existing user needs, or to identify new user needs (Colombo et al. 2017). A second avenue through which firms can achieve radical innovation is by engaging in knowledge areas and markets that are new to them (Gimenez 2006; Hottenrott et al. 2017;

Antonelli and Fusillo 2023). This strategy is likely to require more effort by firms when generating, absorbing and recombining knowledge, compared to exploiting their existing knowledge base. However, when compared to the first avenue, the second one has the potential to result in more novel and impactful radical innovations (McDermott and O'Connor 2002; Inauen and Schenker-Wicki 2012; Colombo et al. 2017; Grashof and Kopka 2022).

Regarding both of the above avenues, firms will need to perform internal R&D in addition to identifying and absorbing relevant external knowledge (Roper and Hewitt-Dundas 2015; Douglas et al. 2018). The key difference between these two avenues is that firms seeking to exploit their existing knowledge base will likely face fewer knowledge challenges, compared to firms seeking to innovate by engaging in new knowledge areas and markets. Therefore, the extent to which public financial support for R&I translates into radical innovation in such firms depends on the firms' abilities to overcome knowledge challenges (Inauen and Schenker-Wicki 2012; Colombo et al. 2017; Radicic 2021).

A key knowledge challenge that firms are most likely to face when engaging in new knowledge areas is a lack of information on technologies and markets. As D'Este et al. (2012, 2014, 2016), Keupp and Gassmann (2013) and Zahler et al. (2022) have stressed, firms are likely to face a lack of information on technologies and markets in two key instances along their innovation paths. The first instance pertains to situations where firms have low levels of R&I knowledge and experience. In this context, a lack of information of technologies and markets can result in firms stopping R&I activities, or refraining from conducting such activities. The second instance, which is the focus of this paper, is when innovative firms seek to expand their knowledge frontiers (Galia and Legros 2004; D'Este et al. 2012; Galia et al. 2012; Keupp and Gassmann 2013; Zahler et al. 2022). In this latter case, a lack of information on technologies and markets does not deter firms from innovating. Instead, it reveals the level of firms' R&I efforts (D'Este et. al. 2012; Coad et al. 2015; Zahler et al. 2022). More specifically, it can

indicate that such firms are seeking to generate innovations that require them to extend beyond their existing knowledge base.

Public financial support for R&I can result in radical innovation in both types of firms as presented above. In the case of firms seeking to innovate by exploiting their existing knowledge base, the support can enable such firms to conduct R&I activities faster, at a larger scale, or with a larger scope (Aschhoff and Fier 2005; Roper and Hewitt-Dundas 2015). This, in turn, can help such firms to achieve a higher level of novelty, and to bring their innovations to the market faster, and/or to address a larger group of potential users. As a result, public financial support for R&I can enable these firms to improve their radical innovation outcomes (Beck et al. 2016). In the case of firms engaging in new knowledge areas, public financial support for R&I can help them to overcome their lack of information on technologies and markets. This can take place by providing firms with the financial means to engage in new thematic areas, or to find new sources of external knowledge (Lee 2011; Hottenrott and Lopes-Bento 2014; Hottenrott et al. 2017). If successful, these R&I activities can result in radical innovation, with the potential to disrupt markets and gain commercial success.

Considering the above, we focus on understanding the extent to which public financial support for R&I is more impactful, in terms of radical innovation outcomes, when focused on: (1) Firms seeking to exploit their existing knowledge base; and (2) Firms seeking to engage in new knowledge areas. We achieve this by focusing on firms that face, or do not face, knowledge challenges relating to a lack of information on technologies and markets for their desired R&I activities. The next sub-section discusses the data and the approach used in our empirical analysis.

3. Data and empirical approach

3.1 Data

Our analysis uses a novel dataset with information on the knowledge challenges and research and innovation (R&I) activities of firms that responded to both the 2010 and the 2016 waves of the Innovation in Irish Enterprises survey (IIE, which is the Irish contribution to the European Union's Community Innovation Survey [CIS]). The IIE is a biennial survey focused on the R&I activities of firms with at least 10 employees.[1] The 2010 IIE survey wave includes information for the period 2008 to 2010. The 2016 IIE survey wave covers innovation activities during the period 2014 to 2016.

The survey data were merged with detailed administrative data on public financial support instruments for R&I from the three main funding agencies for R&I in Ireland, covering the period between the two IIE survey waves, 2011-2014. The three main funding agencies are: (1) Enterprise Ireland (EI); (2) the Industrial Development Agency Ireland (IDA Ireland), and (3) Science Foundation Ireland (SFI). EI provides a range of policy supports for Irish-owned firms from start-up to maturity, with a particular focus on innovation and exporting activities (Enterprise Ireland 2023). IDA Ireland mainly focuses on attracting and supporting investments into Ireland, by foreign-owned multinational corporations (IDA 2023). We only consider financial support instruments that focus on firm-level R&I. SFI primarily funds scientific research in higher education institutions. However, SFI funded institutions can also provide cutting edge knowledge to firms through co-funded collaborative research projects (SFI 2023).

[1] 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.

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.[2] Appendix A lists all the types of public financial support instruments considered.

3.2 Empirical approach

Evaluating the extent to which public financial support for research and innovation (R&I) results in radical innovation in firms necessitates considering the well-known issue of selection bias (Hottenrott and Lopes-Bento 2014; Nilsen et al. 2020). This is because firms seeking to develop radical innovation may be more likely to try to obtain public financial R&I support, given that they may require more financial means for their innovation efforts (compared to firms aiming at a lower level of novelty). At the same time, firms seeking support for radical innovation are likely to command capabilities and resources that facilitate the generation of radical innovation. This means that firms using financial R&I support can be intrinsically different from firms that do not receive such support (Mina et al. 2021; Lenihan et al. 2023). To address this issue, we employ a control-group approach based on propensity-score matching (PSM), following the recommendations of Czarnitzki and Lopes-Bento (2013), Vanino et al. (2019) and Lenihan et al. (2023).

To operationalise our analysis, we construct a panel dataset of firms with R&I activities that covers three periods (*t-1, t, t+1*). In period *t*, we observe whether firms receive public financial support for R&I (*PS*) or not. Using PSM, we balance the sample in a way that firms not receiving public financial support for R&I are statistically similar to supported firms, before

[2] 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).

receiving such support (in period *t-1*). This is with respect to several firm and innovation characteristics, which we discuss in detail in Section 3.4. Finally, in the third period (*t+1*), we observe whether public financial support for R&I has resulted in firms introducing radical innovation (*RI*), and firms generating a higher percentage of turnover from this type of innovation (see Section 3.3).

We achieve the above by following two steps. In the first step, we estimate the determinants of receiving public financial support for R&I (*PS*) with Equation (1):

$$PS_{i,t} = \alpha_i + \boldsymbol{\beta}_X \mathbf{X'}_{i,t-1} + u_{i,t} \quad (1)$$

Where $PS_{i,t}$ denotes whether firm *i* receives public financial support for R&I in period *t,* and X is a vector of variables that measure firms' key characteristics affecting their probability to obtain support in *t-1* (as discussed in Section 3.4). The terms α and u represent the intercept and the error term, respectively. We estimate Equation (1) with a probit regression model. Appendix B presents the results of this estimation, which we use to derive the propensity scores to carry out our Propensity Score Matching (PSM) routine.

In line with Hottenrott and Lopes-Bento (2014) and Mina et al. (2021), we match treated firms with up to three control firms, by employing a nearest neighbour approach. To ensure that the matching is carried out correctly, we use a narrow calliper of 0.2 points of the standard deviation of the propensity score (Austin 2011). Moreover, we only allow matches between firms of the same size-group (i.e. 1 = small, 2 = medium, and 3 = large-sized firms), and one-digit NACE Rev 2 Sectors (Vanino et al. 2019; Lenihan et al. 2023). As a robustness check, we repeat the matching routine with one-to-one matching, which yields almost identical results.

The second step consists of estimating the following innovation production function, using our matched sample:

$$RI_{i,t+1} = \alpha_i + \mathbf{\beta}_X \mathbf{X'}_{i,t-1} + \beta_{KC} KC_{i,t-1} + \beta_{PS} PS_{i,t} + \beta_{PSKC} PS_{i,t} * KC_{i,t-1} + u_{i,t+1} \quad (2)$$

In Equation (2), α is a constant, β are parameters to be estimated, and u is an error-term. As in Equation (1), X is a vector of control variables, which we discuss in Section 3.4. $PS_{i,t}$ represents whether a firm obtained public support for R&I in period *t*, while $KC_{i,t-1}$ represents whether a firm faced knowledge challenges related to a lack of information on technologies and markets in *t-1*. Importantly, $PS_{i,t} * KC_{i,t-1}$is an interaction term, measuring whether a firm that faced knowledge challenges related to a lack of information on technologies and markets in *t-1,* received public financial support for R&I (PS) in period *t*. The key coefficient of interest is β_{PSKC}, which indicates whether public support results in significantly higher (lower) radical innovation outputs in *t+1*, when provided to firms facing knowledge challenges (in *t-1*). The coefficient is interpreted relative to the coefficient β_{PS}, which indicates the impact of public financial support for R&I when provided to firms not facing knowledge challenges. As noted earlier, firms facing knowledge challenges are considered to be seeking to innovate by engaging in new knowledge areas. In turn, firms not facing such challenges are considered to be firms seeking to innovate by exploiting their existing knowledge base.

As discussed in detail below (Section 3.3), we have two measures of radical innovation (*RI*). Therefore, we estimate Equation (2) using both a probit regression model (for a binary measure of *RI*) and an ordinary least squares (OLS) regression (for a continuous measure of *RI*). When using our binary measure of radical innovation (*RI*), marginal effects of the interaction terms are calculated as the difference of the marginal effects between firms that received public financial support for R&I and faced knowledge challenges, and treated firms that did not face such challenges. That is, by holding all other control variables constant, we calculate the discrete change of the average marginal effects of treated firms, depending on whether they faced knowledge challenges in *t-1*. This is important because, as noted 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.

3.3 Definition of key variables

We measure radical innovation (*RI*) in two ways. Following Hewitt-Dundas et al. (2019) and Perez-Alaniz et al. (2023), our first indicator is a binary measure that takes the value of 1 if firms introduce goods or services that are new to the market, otherwise the value is 0. For our second measure, we use the percentage of total turnover that firms obtain from radical innovation (Beck et al. 2016; Hewitt-Dundas et al. 2019). Using this second measure is important, as the socio-economic returns of financial support for R&I may only be fully realised if firms generate economic benefits from their radical innovations (Grashof and Kopka 2022).

To measure the receipt of public financial support for R&I (*PS*), we construct a binary variable that takes the value of 1 if firms receive public financial support for R&I. Otherwise, the value is 0. Using an aggregated measure of public financial support for R&I is common in the literature (Czarnitzki and Lopes-Bento 2014; Hottenrott et al. 2017; Berrutti and Bianchi 2020). As discussed in Section 3.1, some of the public financial support instruments considered are not directly allocated to firms, but the funding is provided to Higher Education Institutions and research centres (e.g. SFI funded collaborations). However, as Scandura (2016), Vanino et al. (2019) and Mulligan et al. (2021) demonstrate, firms benefit financially from such instruments, as they lower the cost of access to external knowledge.

In terms of firms' knowledge challenges (*KC*), we obtain this information from specific questions in the 2010 IIE survey wave, regarding the factors hampering firms' R&I activities. This is in line with a plethora of previous studies on this topic (see, for example, D'Este et al. 2012; Antonioli et al. 2017; Pellegrino and Savona 2017). The specific question used includes eleven items or hampering factors. Firms evaluate the importance of each of these items, by

using a four-point scale (high, medium, low, not relevant). Appendix C shows the framing of the specific questions used. Our key variable of interest Knowledge Challenge (*KC*) specifically pertains to a lack of information on technology and the lack of information on markets. As noted in Section 2.2, this is because firms that seek to innovate by entering into knowledge areas that are new to them are highly likely to face these challenges. The questionnaire includes these challenges as two separate items, as outlined in Appendix C (i.e. a lack of information on technology, and a lack of information on markets). In our analysis, they are operationalised as one variable (i.e. lack of information on technologies and markets) due to a high correlation betweern the two individual challenges (i.e. correlation coefficient = 0.87).[3]

Using the combined variable pertaining to a lack of information on technologies and markets, as explained above, we generate four new variables. The first variable Knowledge Challenge (*KC*) equals 1 if firms experience these knoweldge challenges at any level of importance (i.e. high, medium or low levels); otherwise 0. We use this variable as our main headline variable.

The remaining three variables ($KC_{1,\,2\text{ and }3}$), do the same as above, but now consider the different levels of importance that firms attach to their knowledge challenges. More specifically, KC_3 takes the value 1 if a firm reported facing a lack of information on technologies and markets at a high level of importance, and otherwise 0. KC_2 and KC_1 do the same for medium and low levels of importance, respectively. The construction of these variables is in line with a cannon of earlier studies focused on analysing the drivers and impact of obtacles to innovation in firms (see, for example, Galia and Legros 2004; Iammarino et al. 2009; Pellegrino and Savona 2017; Pellegrino 2018). As proposed by these studies, the importance that firms attach to their obstacles can indicate the extent to which they seek to expand their R&D and innovation

[3] We repeated our analysis with each individual variable, yielding almost identical results, to when the two variables are grouped into one single variable. An advantage of grouping the variables is that it enables more observations in the categories pertaining to 'encounter/did not encounter' the challenge. Such an approach improves the precision of our findings.

portfolio. As an ilustrative example, D'Este et al. (2012) show that, as firms become more innovative and engage in more novel R&D projects, they are more likely to experience financial and knowedge challenges at a high level of importance. Based on this, we consider the level of importance that firms attach to their knowledge challenges as an indication of the extent to which such firms seek to expand their knowledge base when innovating. Table 1 shows the distribution of the four Knowledge Challenge (*KC*) variables, differentiated by whether firms received and did not receive public firnancial support for R&I.

Table 1 Here

3.4 Matching and control variables

Our main analysis is carried out using our matched sample, by using the propensity scores estimated with Equation (1) in a probit regression model. In estimating Equation (1), we include the following variables:

(i) firm sizes, as measured by three binary variables according to their number of employees (i.e. small-sized, medium-sized, and large-sized firms)[4];

(ii) whether firms are Irish or foreign owned, in binary form

(iii) whether firms are part of an enterprise group, in binary form

(iv) whether firms are exporters, in binary form

(v) a count variable (0 to 4) measuring the breadth of innovation partners. Following the recommendation of Roper et al. (2008), we include links with clients, suppliers, other firms, and Higher Education Institutions (e.g. universities and research centres), as measures of forward, backward, horizontal, and public links, respectively;

[4] 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.

(vi) a count variable measuring the number of types of innovation (product innovation, process innovation, service innovation, and organisational innovation) that firms performed (0 to 4) in 2010

(vii) whether firms introduced radical innovation in 2010, in binary form

(viii) a continuous variable measuring the percentage of turnover generated from radical innovation in 2010 (Becket et. al. 2016; Hewitt-Dundas et al. 2019); and

(ix) a set of binary variables measuring whether firms faced financial or non-financial challenges in 2010 (i.e. including a lack of information of technologies and markets), at low, medium, and high levels of importance (Mateut 2018). Including these variables enables matching firms that experienced the same set of challenges, before firms received public financial support for R&I. To obtain these variables, we grouped each of the challenges that firms face, into three headline variables (i.e. financial, knowledge and market), as organised in Appendix B. For example, the variable *Financial* high equals 1 if a firm declares any of the factors hampering their R&I activities to be of high importance. In a similar way, *Financial Medium* equals 1 if a firm declare any of the factors under this financial category to be of medium importance. This is carried out in a mutually exclusive way, meaning that firms that have been assigned the value of 1 for *Financial High*, are not considered for *Financial Medium*. The same process is followed for *Financial Low*, and for the other items listed in Appendix B as knowledge and market factors (i.e. *Knowledge* and *Market*).

Finally, we include indicator variables for the industry a firm belongs to, based on one-digit NACE rev. 2 classes.

Our main analysis is based on estimating the innovation production function presented in Equation (2). In this case, we use the same set of control variables as described above in the context of Equation (1). As our analysis is carried out by using the matched samples, our model

enables us to capture the effect of public support for R&I (received in period *t*), by comparing firms' levels of innovation output in period *t+1*. Therefore, any differences in the radical innovation outputs of treated and control firms can be interpreted as resulting from public support for R&I.

3.5 Descriptive statistics and balance tests

Our dataset comprises 1,296 firms. From these, 221 firms received public financial support (*PS*) for R&I in period *t*. A total of 138 firms in the sample faced Knowledge Challenges pertaining to a lack of information on technologies and markets (*KC*) in period *t-1*. The top panel of Table 2 presents the descriptive statistics for the outcome variables (in *t+1*), while the bottom panel does the same for the variables used in our matching approach (in *t-1*). In the top panel, the table shows that 40 percent of firms that received public financial support for R&I in *t* (i.e. treated firms) introduced radical innovations to the market, in *t+1*. However, this was only the case for approximately 20 percent of untreated firms. Moreover, treated firms generated, on average, 7.7 percent of their total turnover from radical innovation in *t+1*, with untreated firms only generating an average of 2.2 percent of turnover form such innovations in the same period.

Table 2 Here

Focusing on the comparison between treated versus untreated firms in the period before treatment (i.e. *t-1*), the bottom panel of Table 2 shows that treated firms outperformed untreated firms in terms of their probability to innovate radically, and the turnover that they generated from radical innovation. We also observe that a larger proportion of the sample of treated firms faced challenges to innovation in *t-1* at all levels of importance (i.e. low, medium, and high), in comparison to untreated firms. Our descriptive statistics thus support our decision to use PSM as a means of dealing with differences between treated and untreated firms at the time of treatment assignment. Appendices D and E show the standard tests for our 1:3 and 1:1 matching

routines performed. The tables indicate that the matching process resulted in control groups of firms being statistically indistinguishable to the treated firms in period *t-1*. This suggest that our matching process was carried out successfully.

4. Results and discussion

Table 3 presents the impact of public financial support for research and innovation (R&I) on firms' probabilities to innovate radically (in period *t+1*), for firms that faced and did not face knowledge challenges due to a lack of information on technologies and markets (in period *t-1*). In Column 1 and Column 2, the variable *Public Financial Support (PS)* presents the impact of public financial support for R&I on firms not facing knowledge challenges, when obtained with a 1:3 and 1:1 nearest neighbour matching approach, respectively. Here, we observe that public financial support for R&I has a positive and significant effect on such firms' probabilities to introduce radical innovation. This impact is between 13 to 18 percentage points ($p < 0.01$), depending on the matching specification used. The interaction variables *Support x Challenge (PS x KC)* in the same columns capture the impact of public financial support for R&I, when allocated to firms facing knowledge challenges due to a lack of information on technologies and markets. The insignificant coefficients indicate that public financial support has a similar effect on firms with and without knowledge challenges.

Columns 3 and 4 of Table 3 reveal that the results change significantly, when the importance that firms attach to their knowledge challenges is considered. In these columns, we observe that public financial support for R&I results in firms without knowledge challenges, being between 13 to 19 percentage points more likely to innovate radically ($p < 0.01$). However, when public support is allocated to firms for which a lack of information on technologies and markets is of high importance, as captured by the variable *Support x Challenge High (PS x KC_3)*, the impact of such support is substantially higher (circa 27 percentage points higher). This is in comparison

to the impact of the support on firms not facing knowledge challenges ($P < 0.01$). Moreover, in the case of the one-to-one matching specification in Column 4, we find significant negative effects for the variables *Support x Challenge Low (PS x KC_1)* and *Support x Challenge Med. (PS x KC_2)*. This suggests that public funding when allocated to firms with some knowledge challenges (i.e. at low and medium levels of importance) can be less effective at increasing firms' probabilities of generating radical innovations. Again, this is in comparison to the impact that the support has on firms not facing knowledge challenges.

Table 3 Here

Table 4 presents the impact of public financial support for R&I on the percentage of turnover that firms generate from radical innovation. Columns 1 and 2 show that public financial support for R&I increases radical innovation turnover in firms without knowledge challenges. These firms, on average, generate between 1.9 to 2.3 percentage points more turnover from radical innovation (as percentage of total turnover) than untreated firms ($p < 0.01$), depending on the model specification used. The insignificant effect for our interaction variable *Support x Challenge (PS x KC)* indicates that the effect of public financial support does not differ between firms with and without, knowledge challenges. This is consistent with our findings from Table 3. Also consistent with Table 3, we find a significant positive effect for the interaction term *Support x Challenge High (PS x KC_3)* in Columns 3 and 4. This suggests that supporting firms that experience knowledge challenges at high levels of importance, results in a higher percentage of turnover from radical innovation. The magnitude of the effect is substantial, at around 9 percentage points more, than treated firms not experiencing such challenges (total impact is between 11 to 13 percentage points).

Table 4 Here

Unlike the case of Table 3, we do not find a significant negative effect for the variable *Support x Challenge Low (PS x KC_1)* in Table 4. This means that treated firms facing knowledge challenges at low levels of importance generate a similar percentage of turnover from radical innovation, as treated firms not experiencing knowledge challenges. However, our results from Column 4 of Table 4 support the results in Table 3 for the variable *Support x Challenge Med. (PS x KC_2)*, which is negative and significant ($p < 0.01$). This indicates that public financial support for R&I can result in a lower percentage of turnover from radical innovation, when targeted at firms facing knowledge challenges at medium levels of importance. This is when compared to treated firms not facing knowledge challenges. The magnitude of the coefficient is also larger than the coefficient for the variable *Public Financial Support (PS)*, suggesting that the support may not result in more radical innovation turnover in these firms.

Based on the above, our combined findings indicate that, on average, public financial support for R&I has similar impacts on the radical innovation activities of the two groups of firms considered. These findings concur with Beck et al. (2016), in the sense that public financial support for R&I can result in firms generating radical innovation, and additional turnover from radical innovation. Moreover, our findings support those of Lee et al. (2014) who propose that the increasing availability of firm-level financial resources (in our case due to public financial support for R&I) can drive firms to generate new knowledge and radical innovation. We extend the insights of these previous studies by showing that, on average, public financial support for R&I results in similar levels of radical innovation, when targeted at firms seeking to innovate outside or within their existing knowledge base.

Importantly, however, our findings reveal key additional insights, when the importance that firms attach to their knowledge challenges is considered. As discussed in Section 3.3, we conceptualise the importance that innovative firms attach to their knowledge challenges to indicate the extent to which firms seek to expand their knowledge frontiers. This is in line with

a plethora of studies focused on the challenges that firms face when innovating (see, for example, Galia and Legros 2004; D'Este et al. 2012; Galia et al. 2012; Keupp and Gassmann 2013; Zahler et al. 2022). Our results thus highlight the importance of not only considering whether firms seek to engage in new knowledge areas, but also considering the extent to which firms intend to do this.

In this context, we find that targeting public financial support at firms facing knowledge challenges at low or medium levels of importance, can lead to sub-optimal socio-economic returns (i.e. policy failure). This is because such firms are less likely to translate public financial support for R&I into more radical innovation outcomes, in comparison to treated firms without knowledge challenges. It is possible that firms facing knowledge challenges at a low or medium level of importance may only make small incremental efforts to go beyond their existing knowledge base, which do not result in radical innovation (Lee et al 2014; Zahler et al. 2022). An alternative explanation relates to such firms using public funding to carry out explorative research activities, which may not necessarily focus on developing specific products and services (Wanzenböck et al. 2013; Mina et al. 2021).

Moreover, and importantly, our findings indicate that allocating support to firms facing knowledge challenges at a high level of importance, is much more likely to result in radical innovation, and higher levels of turnover from radical innovation. This is in comparison to firms that do not face knowledge challenges. Based on our conceptualisation of knowledge challenges, this means that public financial support for R&I is most impactful, in terms of radical outcomes, when targeted at firms seeking to significantly extent their knowledge frontiers. This concurs with Yang et al. (2014), when proposing that radical innovation requires firms to 'unlearn' existing ways of innovating, and develop new ones. It is also consistent with some studies that outline firms' innovative strategies as key determinants of the impact that public financial support for R&I has on firms (Wanzenböck et al. 2013; Nilsen et al. 2020).

Finally, our findings elucidate that public financial support for R&I can indeed help firms engaging in new knowledge to overcome knowledge challenges and innovate radically. This, in turn, lends support to studies highlighting the impacts that public financial support for R&I can have on improving organisational learning and R&I capabilities in firms (Clarysse et al. 2009; Wanzenböck et al. 2013; Fiorentin et al. 2019; Nilsen et al. 2020).

5. Conclusion and implications for policy

In this paper, we have addressed a critical knowledge gap that prevails in the literature regarding the allocation of public financial support for Research and Innovation (R&I). We achieved this by analysing how policymakers may successfully target public support for R&I to stimulate radical innovation in firms (Laplane and Mazzucato 2020; OECD 2021; Mina et al. 2021; Cerulli et al. 2022). This is important because radical innovation is best placed for translating such public support for R&I into high socio-economic returns (Colombo et al. 2017; Berrutti and Bianchi 2020). However, radical innovation is risky, and public financial support for R&I can result in sub-optimal or no returns (i.e. policy failure) if firms fail to bring their radical innovations to the market, and/or fail to benefit from introducing radical innovations to the market (Haapanen et al. 2014). Despite this, the question of how policymakers can best allocate public financial support for R&I in a way that drives more radical innovation in firms, while avoiding policy failure, remains unanswered (Berrutti and Bianchi 2020; OECD 2021).

Our paper directly addressed this question, by investigating whether public financial support for R&I results in more radical innovation when focused on two distinct groups of firms. These are: (1) Firms seeking to engage in knowledge areas that are new to them, and hence, face knowledge challenges; and (2) Firms seeking to innovate by exploiting their existing knowledge base, and hence, do not face knowledge challenges. To identify these firms, we used a novel approach, focused on one key knowledge challenge that firms are most likely to face when

seeking to engage in knowledge areas that are new to them. That is, a lack of information on technologies and markets. Using matched administrative and survey panel data on firms in Ireland, we find that supporting firms experiencing knowledge challenges (at a high level of importance) results in a higher probability of radical innovation, and is associated with a higher percentage of turnover from radical innovation. This is in comparison to firms not facing such challenges. For firms facing knowledge challenges at low levels of importance, we find that public financial support for R&I has a lower impact on firms' probabilities to develop radical innovation, than when targeted at firms not facing knowledge challenges. However, we do not find that this affects the percentage of turnover that firms generate from radical innovation. Moreover, we find some evidence suggesting that public financial support for R&I becomes less effective, in terms of firms' probabilities to innovate radically and generate turnover from such innovations, when targeted at firms experiencing knowledge challenges at a medium level of importance. This is in comparison to supporting firms without knowledge challenges. Our findings thus highlight that, in the context of public financial support for R&I driving radical innovation in firms, the issue is not simply whether firms engage in knowledge areas, but the extent to which they do so.

Our paper contributes to the literature in several ways. To the best of our knowledge, this is the first time that the effectiveness of public financial support for R&I on firms seeking to innovate outside of (or within) their existing knowledge areas is empirically analysed. In this context, our results indicate that firms' knowledge strategies, in terms of whether they seek to engage in new knowledge areas or not, play a key role in determining the impact that the support has on firms. Hence, such strategies should be considered, when allocating public financial support for R&I to firms, and when evaluating the impact that such support has on firms. Moreover, our specific focus on radical innovation is important, because "although the effect of public R&D subsidies on private R&D has been examined extensively, we know little about the quality of

technologies that private firms produced using public R&D subsidies" (Choi and Lee 2021, p. 3). In a similar vein, our focus on the potential risks of policy failure associated with the allocation of public financial support is important. As Kärnä et al. (2022, p. 1037) have noted, previous studies focused on the allocation of public financial support for R&I "have often been lacking considerations to the risks of political failures, meaning that policies fail to achieve their stated goals in a systematic manner". Finally, our paper enhances our understanding of the extent to which public financial support for R&I enables firms to overcome key challenges affecting their R&I activities. This is with a focus on stimulating radical innovation in firms. In this vein, our paper offers important insights which extend earlier studies focused on using public financial support for R&I to improve organisational learning and R&I capabilities in firms (Clarysse et al. 2009; Wanzenböck et al. 2013; Fiorentin et al. 2019; Nilsen et al. 2020).

From a policy perspective, our results provide evidence which can usefully inform a more effective allocation of public financial resources for R&I. As discussed earlier, policymakers typically need to focus support on R&I projects that can maximise socio-economic returns. At the same time, they also need to avoid a misallocation of supports to R&I projects that are likely to fail, and/or result in low levels of additionality (Haapanen et al. 2014; Mina et al. 2021). Our findings suggest that allocating public financial support for R&I to firms seeking to innovate by engaging in knowledge areas that are new to them, can result in more radical innovation, provided that these firms aim high in terms of advancing into new knowledge areas. These findings suggest that more attention might usefully be paid by policymakers at project appraisal stage when deciding what types of firms might be best to support in terms of public financial support for R&I, so as to ensure the greatest socio-economic returns.

There are some limitations pertaining to our paper, which could represent new avenues for future research. Due to sample size limitations (specifically regarding treated firms that face knowledge challenges), 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' knowledge challenges could also influence the type of public financial support instruments for R&I that they seek. Further studies could address this limitation. Our focus on firms in Ireland can provide important insights for policymakers beyond the Irish case. It would be interesting therefore, for future research to replicate our analysis in other country-settings. Finally, it would be fruitful 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 knowledge capabilities and overcome their knowledge challenges. Despite these limitations, our paper offers important insights, which can usefully inform an understanding of the effectiveness of public financial support for R&I, when it comes to generating more radical innovation in firms.

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Table 1: Challenges to R&I variables, and their distribution in the matched sample

Knowledge challenges	Treatment =0	Treatment = 1	Total
Lack of information technologies and markets = 0	109	174	283
Lack of information technologies and markets = 1	59	138	197
Total	**168**	**312**	**480**
Lack of information technologies and markets low=1	92	85	177
Lack of information technologies and markets medium=1	69	62	131
Lack of information technologies and markets high=1	27	29	56
Total	**188**	**176**	**364**

Table 2: Descriptive statistics by treated and untreated firms

	Treated				**Untreated**			
Outcome Variables (i.e. in 2016)	Mean	SD	Min	Max	Mean	SD	Min	Max
Introduced Radical Innovation (1 = Yes)	0.406	0.492	0	1	0.212	0.412	0	1
Turnover from Radical Innovation (% Turnover)	7.746	16.423	0	100	2.222	9.851	0	100
Control Variables (i.e. in 2010)								
Small-sized firm (< 50 employees)	0.484	0.500	0	1	0.675	0.468	0	1
Medium-sized firm (50 to 249 employees)	0.389	0.488	0	1	0.260	0.439	0	1
Large-sized firm (250 or more employees)	0.126	0.333	0	1	0.065	0.246	0	1
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
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
Introduced of Radical Innovation in 2010	0.472	0.500	0	1	0.165	0.373	0	1
Turnover from Radical Innovation 2010 (% Turnover)	9.54	6.891	0	20.31	3.853	6.442	0	19.821
Knowledge challenges high (1 = Yes)	0.095	0.293	0	1	0.064	0.241	0	1
Knowledge challenges medium (1 = Yes)	0.285	0.452	0	1	0.215	0.415	0	1
Knowledge challenges low (1 = Yes)	0.506	0.501	0	1	0.324	0.473	0	1
Financial challenges high (1 = Yes)	0.276	0.448	0	1	0.325	0.467	0	1
Financial challenges medium (1 = Yes)	0.52	0.521	0	1	0.276	0.457	0	1
Financial challenges low (1 = Yes)	0.425	0.495	0	1	0.425	0.514	0	1
Market challenges high (1 = Yes)	0.18	0.385	0	1	0.19	0.391	0	1
Market challenges medium (1 = Yes)	0.438	0.452	0	1	0.312	0.463	0	1
Market challenges low (1 = Yes)	0.371	0.484	0	1	0.324	0.469	0	1

Table 3: Knowledge challenges influencing how public financial support drives radical innovation in firms

	Dependent variable: Introduction of radical innovation(1= yes) in Average Marginal Effects (dy/dx)			
	(1)	(2)	(3)	(4)
Public Financial Support (*PS*)	0.132***	0.189***	0.138***	0.194***
	(0.040)	(0.025)	(0.044)	(0.022)
Knowledge Challenge (*KC)*	0.047	0.057		
	(0.063)	(0.056)		
Support x Challenge *(PS x KC)*	0.035	0.109		
	(0.110)	(0.072)		
Knowledge Challenge Low (KC_1)			-0.059	-0.058
			(0.054)	(0.066)
Knowledge Challenge Med. (KC_2)			0.045	0.041
			(0.036)	(0.089)
Knowledge Challenge High (KC_3)			-0.043*	-0.015
			(.025)	(0.062)
Support x Challenge Low ($PS \times KC_1$)			-0.061	-0.251**
			(0.061)	(0.017)
Support x Challenge Med. ($PS \times KC_2$)			-0.036	-0.063***
			(0.082)	(0.016)
Support x Challenge High ($PS \times KC_3$)			0.281***	0.272***
			(0.024)	(0.043)
Control	Yes	Yes	Yes	Yes
Observations	480	370	480	370
Matching approach	3-Neighbours	One-to-one	3-Neighbours	One-to-one

Notes: Treatment effects 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 facing and not facing challenges. *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 and Column 2 refer to the difference between Treatment and Control groups using a counterfactual comprising the nearest 3 neighbours for each treated firm. Column 2 and Column 4 presents the results obtained with a one-to-one matching routine. This explains the difference in number of observations relative to the other columns in the table.

Table 4: The impact of public financial support and knowledge challenges on turnover from radical innovation

	Dependent variable: Ln of total turnover from radical innovation			
	(1)	**(2)**	**(3)**	**(4)**
Public Financial Support (PS)	1.916***	2.271***	2.150***	1.986***
	(0.740)	(0.107)	(0.964)	(0.737)
Knowledge Challenge (*KC)*	1.538	1.724		
	(3.594)	(0.111)		
Support x Challenge *(PS x KC)*	-0.675	-2.680		
	(2.513)	(2.880)		
Knowledge Challenge Low (KC_1)			-0.308	1.000
			(2.830)	(4.097)
Knowledge Challenge Med. (KC_2)			-2.818	3.233
			(1.902)	(3.583)
Knowledge Challenge High (KC_3)			-1.754	-3.132
			(1.879)	(3.763)
Support x Challenge Low ($PS \times KC_1$			-2.183	-3.193
			(2.666)	(4.200)
Support x Challenge Med. ($PS \times KC_2$)			-1.781	-2.229***
			(1.460)	(0.783)
Support x Challenge High. ($PS \times KC_3$)			9.137***	9.089***
			(3.376)	(3.076)
Control	Yes		Yes	Yes
Observations	488	315	488	315
Matching approach	3-Neighbours	One-to-one	3-Neighbours	One-to-one

Notes: Treatment effects are obtained with regression analysis estimated with Ordinary Least Squares (OLS). *** denotes significance at the 99% level, ** 95% level and * 90% level. Column 1 and Column 2 refer to the difference between Treatment and Control groups using a counterfactual comprising the nearest 3 neighbours for each treated firm. Column 2 and Column 4 presents the results obtained with a one-to-one matching routine. This explains the difference in number of observations relative to the other columns in the table.

Appendix A: Public financial instruments used in the analysis

Instrument	Funding Agency	Number of Firms Supported
Company R&D Support	IDA/EI	27
Innovation Vouchers	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 B: Probability of receiving public financial support for R&I

Independent Variables	Probability of Treatment (1 = Yes)
Medium-sized firm (1 = Yes, 50 to 249 employees)	0.164 (0.113)
Large-sized firm (1 = Yes, 250 or more employees)	0.119 (0.184)
Irish owned (1=Yes)	0.188 (0.114)
Enterprise group (1= Yes)	-0.003 (0.112)
Export (1= Yes)	0.748*** (0.133)
Breadth of cooperation partners (0 to 4)	0.094* (0.045)
Breadth of Innovation (0 to 4)	-0.041 (0.041)
Introduced Radical Innovation in 2010 (1 = Yes)	-0.322** (0.143)
Turnover from Radical Innovation in 2010 (% Turnover)	0.032*** (0.010)
Knowledge challenges high (1 = Yes in 2010)	0.323* (.184)
Knowledge challenges medium (1 = Yes in 2010)	-0.063 (0.123)
Knowledge challenges low (1 = Yes in 2010)	0.201* (0.117)
Financial challenges high (1 = Yes in 2010)	-0.032 (0.122)
Financial challenges medium (1 = Yes in 2010)	0.148 (0.112)
Financial challenges low (1 = Yes in 2010)	0.145 (0.111)
Market challenges high (1 = Yes in 2010)	-0.181 (0.136)
Market challenges medium (1 = Yes in 2010)	-0.104 (0.111)
Market challenges low (1 = Yes in 2010)	-0.071 (0.121)
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 chi^2 (25)	257.67***
Pseudo R^2	0.229

Notes: Results of Probit model estimation. Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

Appendix C: Questions pertaining to hampering factors 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	Not relevant
Cost Factors	Lack of funds within your enterprise or group	o	o	o	o
	Lack of finance from sources outside your enterprise	o	o	o	o
	Innovation costs too high	o	o	o	o
Knowledge Factors	Lack of qualified personnel	o	o	o	o
	Lack of information on technology	o	o	o	o
	Lack of information on markets	o	o	o	o
	Difficulty in finding cooperation partners for innovation	o	o	o	o
Market Factors	Market dominated by established enterprise	o	o	o	o
	Uncertain demand for innovative goods or service	o	o	o	o
Reasons not to innovate	No need due to prior innovations by your enterprise	o	o	o	o
	No need because of no demand for innovation	o	o	o	o

Appendix D: Balance check Stage 1 (Nearest 3 Neighbours)

Matching Variables	Treated	Control	Difference (T – C)	P-Value (T- C)
Small-sized firm (1 = Yes, < 50 employees)	0.487	0.436	0.051	0.294
Medium-sized firm (1 = Yes, 50 to 249 employees)	0.386	0.417	-0.031	0.527
Large-sized firm (1 = Yes, 250 or more employees)	0.125	0.146	-0.021	0.536
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
Breath of Innovation (0 to 4)	2.442	2.373	0.067	0.676
Introduced Radical Innovation in 2010 (1 = Yes)	0.446	0.404	0.042	0.397
Turnover Radical Innovation in 2010 (% Turnover)	8.787	8.697	0.09	0.960
Knowledge challenges high (1 = Yes)	0.081	0.105	-0.024	0.404
Knowledge challenges medium (1 = Yes)	0.299	0.341	-0.042	0.308
Knowledge challenges low (1 = Yes)	0.492	0.466	0.026	0.603
Financial challenges high (1 = Yes)	0.284	0.285	-0.001	0.97
Financial challenges medium (1 = Yes)	0.522	0.496	0.026	0.604
Financial challenges low (1 = Yes)	0.406	0.444	-0.038	0.446
Market challenges high (1 = Yes)	0.187	0.175	0.012	0.761
Market challenges medium (1 = Yes)	0.441	0.463	-0.022	0.662
Market challenges low (1 = Yes)	0.373	0.367	0.003	0.446
Rubin's B = 20.6. Mean Bias =2.9; Median Bias = 3.5. R = 0.92				

Notes: *** Denotes significance at the 99% level, ** 95% level and * 90% level. The Rubin's B score represents the standardised difference of means of a linear index of the propensity score in treated and control firms. The Rubin's R is the ratio of treated to matched non-treated variances of the propensity score index. Values of below 25 for Rubin's B, and between 0.5 and 2 for Rubin's R, are usually accepted as indicating a sufficiently balanced sample, as per the guidelines of Rubin (2001).

Appendix E: Balance check Stage 1 (One to One Matching)

Matching Variables	Treated	Control	Difference (T – C)	P-Value (T- C)
Small-sized firm (1 = Yes, < 50 employees)	0.497	0.502	-0.005	0.919
Medium-sized firm (1 = Yes, 50 to 249 employees)	0.409	0.393	0.016	0.756
Large-sized firm (1 = Yes, 250 or more employees)	0.093	0.103	-0.01	0.733
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
Breath of Innovation (0 to 4)	0.449	0.396	0.053	0.299
Introduced Radical Innovation in 2010 (1 = Yes)	0.450	0.398	0.052	0.304
Turnover Radical Innovation in 2010 (% Turnover)	9.492	8.921	0.571	0.437
Knowledge challenges high (1 = Yes)	0.444	0.412	0.032	0.534
Knowledge challenges medium (1 = Yes)	0.37	0.343	0.027	0.593
Knowledge challenges low (1 = Yes)	0.195	0.179	0.016	0.694
Financial challenges high (1 = Yes)	0.523	0.462	0.063	0.218
Financial challenges medium (1 = Yes)	0.412	0.475	-0.058	0.256
Financial challenges low (1 = Yes)	0.195	0.179	0.016	0.694
Market challenges high (1 = Yes)	0.444	0.412	0.032	0.534
Market challenges medium (1 = Yes)	0.376	0.343	0.027	0.256
Rubin's B = 23.1. Mean Bias =3.9; Median Bias = 3.3. R = 0.98				

Notes: *** Denotes significance at the 99% level, ** 95% level and * 90% level. The Rubin's B score represents the standardised difference of means of a linear index of the propensity score in treated and control firms. The Rubin's R is the ratio of treated to matched non-treated variances of the propensity score index. Values of below 25 for Rubin's B, and between 0.5 and 2 for Rubin's R, are usually accepted as indicating a sufficiently balanced sample, as per the guidelines of Rubin (2001).

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