The Economic and Social Review, Vol. 51, No. 1, Spring 2020, pp. 105-131

POLICY PAPER

Respect Your Elders: Evidence from Ireland's R&D Tax Credit Reform

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Abstract: This paper exploits a unique reform in Irish corporation tax policy to evaluate the effect of tax incentives on research and development (R&D) investment. Using administrative panel data from the Revenue Commissioners, we establish for the first time the additional R&D investment that arises from the provision of the tax credit and we examine the associated firm characteristics. We find that the tax incentive helped to increase R&D investment by firms; however, the estimated effect is driven by older firms rather than younger firms. The latter result challenges a common narrative on the role of R&D tax incentives which increase cashflow for young firms: it suggests that their barriers to innovation may not necessarily be financial, and that age-targeted tax incentives could carry large deadweight.

I INTRODUCTION

Research and Development (R&D) tax incentives have rapidly increased in popularity in recent decades. As of 2017, 30 of the 35 OECD countries, 21 of 28 EU countries and several non-OECD economies provide tax relief on R&D investment. The theoretical justification is that a tax credit for R&D investment

Acknowledgements: The authors thank colleagues who provided assistance with data and helpful comments, in particular Jackie Mahon and Gavin Murphy. They also thank Barra Roantree and Enda Hargaden for useful feedback on earlier drafts. Valuable comments from an anonymous referee motivated revisions that markedly improved the paper. Any views expressed in this paper are solely those of the authors and should not be regarded as an official position of the Department of Finance or the Office of the Revenue Commissioners. The authors are solely responsible for the content and the views expressed.

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represents a non-discretionary way of increasing inefficiently low levels of R&D (Hall and Van Reenan, 2000). Although not a foregone conclusion empirically, many economic studies show their effectiveness for a variety of different countries (Bloom *et al*., 2002).

The primary purpose of this paper is to establish for the first time whether the Irish R&D tax credit results in additional R&D on the intensive margin. The secondary purpose of the paper, arising specifically out of the 2009 tax reform which introduced a refundable credit, is to assess whether such credits, which increase firm cashflow, result in heterogeneous outcomes at the firm-level.

Our results suggest, first, that the refundable tax credit results in both statistically and economically significant increases in R&D investment by firms. Second, we find that this 'additionality' is wholly associated with older firms, rather than younger firms. This suggests that financial constraints may not be a key explanation for the relatively lower level of R&D investment observed in young firms.

The paper makes three main contributions to the existing literature on R&D fiscal incentives. It presents for the first time research that is based on a refundable credit, which has relevance for debates on tax credit design. Second, it provides a new and unexpected assessment of whether tax incentives which have a cashflow element influence the behaviour of young firms. Third, it directly relates to research on the impact of R&D tax credits at the firm level but does so using a large administrative dataset which links corporation tax records to employment records, thereby overcoming challenges related to accurately reflecting the choices and characteristics of R&D-active firms.

The rest of the paper is structured as follows. Section II reviews the relevant literature. Section III provides an overview of the Irish R&D tax credit scheme and tax incentives in the OECD more generally. Section IV and Section V describe our empirical approach and data. Section VI presents the results and Section VII concludes.

II LITERATURE REVIEW

2.1 Young Innovative Companies

There is an extensive literature on innovation and market structure, dating back to the 'creative destruction' of Schumpeter (1934), which emphasises new entrants; and the alternative 'creative accumulation' of Schumpeter (1942), which emphasises incumbents' market power. An increasing number of studies underscore the role played by young innovative companies (YICs) in innovation, in line with the 'creative destruction' hypothesis (Veugelers, 2008). Small, young and highly innovative companies are characterised in the public policy literature as a key source of economic growth (see, for example, O'Sullivan, 2007) although, notably, the empirical evidence is stronger for US than European firms. Cincera and Veugelers (2014) observe that, unlike equivalent US firms, young European firms engaged in innovation activity fail to generate significant rates of return to R&D relative to the average firm. The authors argue there is a need for a greater understanding of the barriers facing young firms.

A large strand of the literature on YICs looks at financial barriers, and mainly focuses on US firms. Hall and Lerner (2010) note that small and young firms are more likely to be financially constrained, due to the lack of internal funds, collateral and reputation. Hao and Jaffe (1993) find evidence that small-firm R&D investments respond to changes in liquidity, whereas large firms do not. Brown *et al*. (2009) find financial constraints for young, but not mature, R&D investing high-tech firms. One recent study covering European firms finds evidence of a relationship for young and small firms (and no evidence for mature and large firms), once firms' use of cash buffers (i.e. R&D smoothing) and external equity finance is controlled for (Brown *et al*., 2012).

Although access to finance is one of the most discussed barriers for young innovating firms, other factors also play a role. Firms will conduct more or less R&D due to differing economies of scale and scope, access to skilled staff, and factors such as the strength of intellectual property protection and the stage in the industry life cycle (see Audretsch *et al*., 2014, for a recent survey). Large incumbent firms may be better placed to appropriate the benefits from innovation and to control complementary downstream assets to commercialise their innovation (Teece, 1986). In a study of UK firms, D'Este *et al*. (2012) identify market barriers as an important determinant of the feasibility of innovation activity by new, smaller firms. In a similar vein, Baldwin and Lin (2002) find that the more competition a firm faces, the higher the possibility it will face challenges related to costs, labour (for example, skill shortages) and information deficits (for example, lack of scientific and technical information).

In summary, the 'creative destruction' literature suggests that young firms will respond positively to the refundable R&D tax credit, with liquidity constraints being a primary motivation for this. However, the 'creative accumulation' literature suggests that other, non-financial barriers to R&D growth may hinder this response.

2.2 Public Support for R&D

While generally agreed that R&D can provide an important contribution to economic growth (Aghion and Howitt, 1998), this in and of itself does not justify public support for R&D. However, there is strong consensus in the empirical literature that the social returns to R&D are greater than the private returns (Hall *et al*., 2009), and that there are notable correlations between tax incentives and increased R&D investment (Hall and Van Reenan, 2000).

Looking specifically at R&D and firm characteristics, we note the evidence is relatively limited regarding firm age. One paper finds a relatively lower degree of persistence in R&D conducted by young firms in Spain's manufacturing sector, which could reflect the relative inexperience of such firms, resulting in a more erratic implementation of R&D projects (García-Quevedo *et al*., 2014). In terms of fiscal incentives, Guceri and Liu (2019) observe that younger firms respond differentially more than older firms to the UK's R&D tax credit. On the other hand, Schneider and Veugelers (2010) find that R&D subsidies in Germany are not associated with a relatively higher innovative performance of YICs as compared to other subsidy recipients.

It is likely due to the literature on YICs and financial barriers that international organisations advise that refundable R&D tax credits are more effective for new firms or start-ups (see IMF, 2016, for a recent example). However, there appears to be no specific empirical basis for this policy advice. The OECD is currently conducting a research project that involves analysing tax credit design features and their impact, but the results of this are not yet publicly available.[1] As far as we are aware, our paper is the first public contribution specifically on the topic of refundable R&D tax credits.

2.3 Empirical Methods

The present study is the first evaluation of the Irish R&D tax credit that uses a treatment evaluation methodology. Treatment evaluations of R&D fiscal supports have become more popular in recent years due to the expansion of administrative panel data (see, for example, Lach, 2002, for Israel; Cornet and Vroomen, 2005, for the Netherlands; Hægeland and Møen, 2007, for Norway; Bronzini and Iachini, 2014, for Italy).[2] We are aware of only one published study of Irish R&D grants that relies on treatment evaluation: Görg and Strobl (2007) find that small grants provided to Irish-owned manufacturing firms result in additional R&D, but additionality disappears once the grant size becomes large, indicating crowding out. They find no evidence of additionality for grants (of any size) provided to foreign manufacturing firms.

Görg and Strobl (2007) rely on survey data, while our study utilises comprehensive administrative data that reflect the behaviour of the overall population of R&D-active firms in Ireland. The use of administrative data represents a very recent strand of the literature on R&D, innovation and public supports. The advantages of administrative data over survey data, particularly for evaluating public policy, include the larger number of observations and the inherent

[1] http://www.oecd.org/sti/microberd.htm, accessed 25 January 2019.

[2] Structural modelling is the other main empirical approach but in practice has many data challenges including: calculating the stock of R&D capital; finding exogenous variation in the user cost of capital; capturing capital market imperfections; and correctly specifying the degree of risk. See Hall and Van Reenan (2000) for a full discussion.

panel structure of the data. Our paper adds to a small but growing set of other country examples (see, for example, Hægeland and Møen, 2007, for Norway; Agrawal *et al*., 2014, for Canada; Rao, 2016, for the US).

III BACKGROUND

3.1 The Irish R&D Tax Credit

The Irish government introduced an R&D tax credit in the 2004 Finance Act. Initially, the tax credit equalled 20 per cent of eligible R&D investment and was applied to a firm's corporation tax liability. If the tax credit was not exhausted in one year, it could be carried forward to the next year.

In an important policy reform, introduced in 2009, the tax credit became refundable. From 1 January of that year onward, a firm could request a cash payment, to be paid in three instalments over 33 months, if their corporation tax liability was less than the claim submitted for the R&D tax credit. There were no other restrictions placed on receiving the cash payment and the first instalment could be received in the same year that the claim was made. The intention of the 2009 reform was to enhance the scheme's attractiveness to the enterprise sector and protect R&D investment during a recession. The refund is limited each year to the greater of the aggregate corporation tax paid by the firm in the preceding ten years or the aggregate payroll liabilities for the current and preceding year.

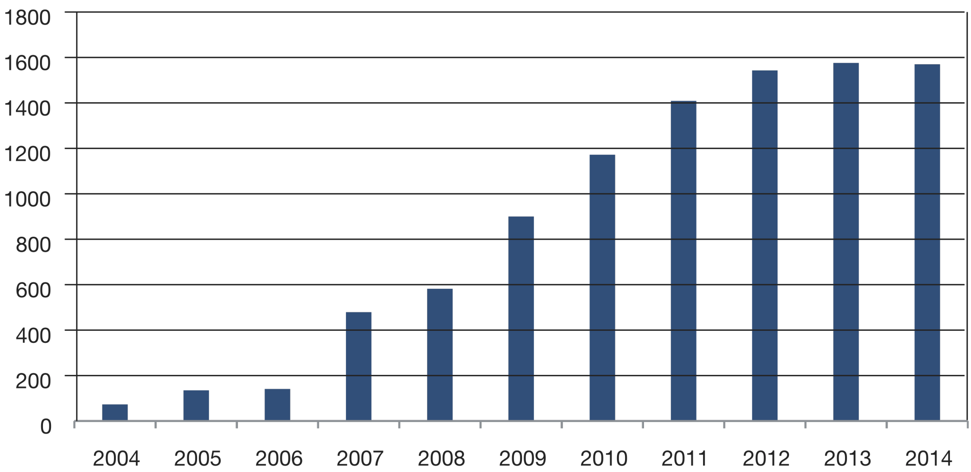
The Irish R&D tax credit is a relatively straightforward scheme, as the credit simply equals 25 per cent of all qualifying expenditure, and the Office of the Revenue Commissioners (Revenue) regularly produces updated and user-friendly guidelines and holds consultations on its use.[3] This suggests that any analysis of the tax credit is less likely to suffer from salience or complexity issues related to firms' understanding of the scheme.

Indeed, the tax credit scheme has proven to be very popular. Since its introduction, the number of claims has increased rapidly, with a more than tenfold rise between 2004 and 2014 (Figure 1). Most of this expansion in uptake happened between 2008 and 2012, with the number of claims having stabilised since then.

By 2014, the refundable element of the tax credit accounted for half of total public support for business enterprise expenditure on R&D (BERD) in Ireland (Figure 2). The tax credit as applied to positive tax liabilities accounted for 35 per cent and R&D grants for the remaining 15 per cent of public support.

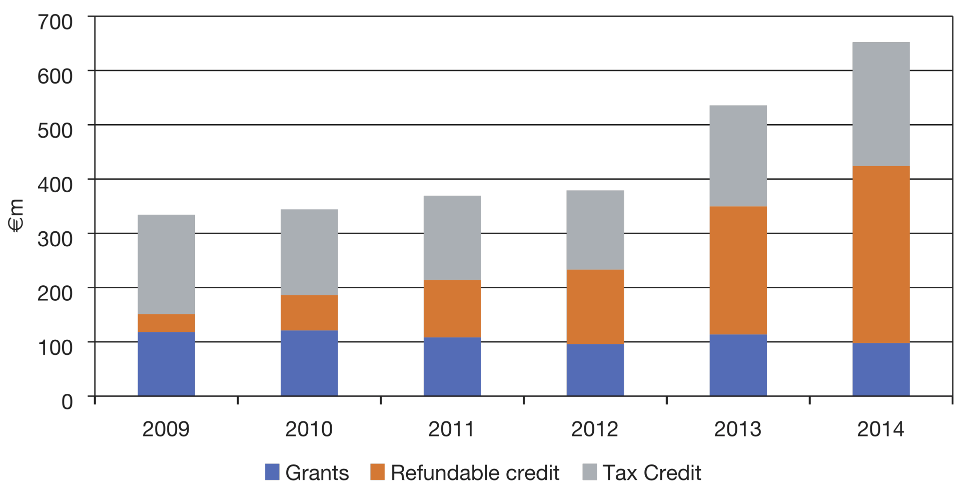
[3] The proportion of eligible R&D investment changed from 20 per cent to 25 per cent, also in 2009.

Figure 1: Total Number of R&D Tax Credit Claims, 2004-2014



Source: Office of the Revenue Commissioners.

Figure 2: Public Support for BERD in Ireland, € million



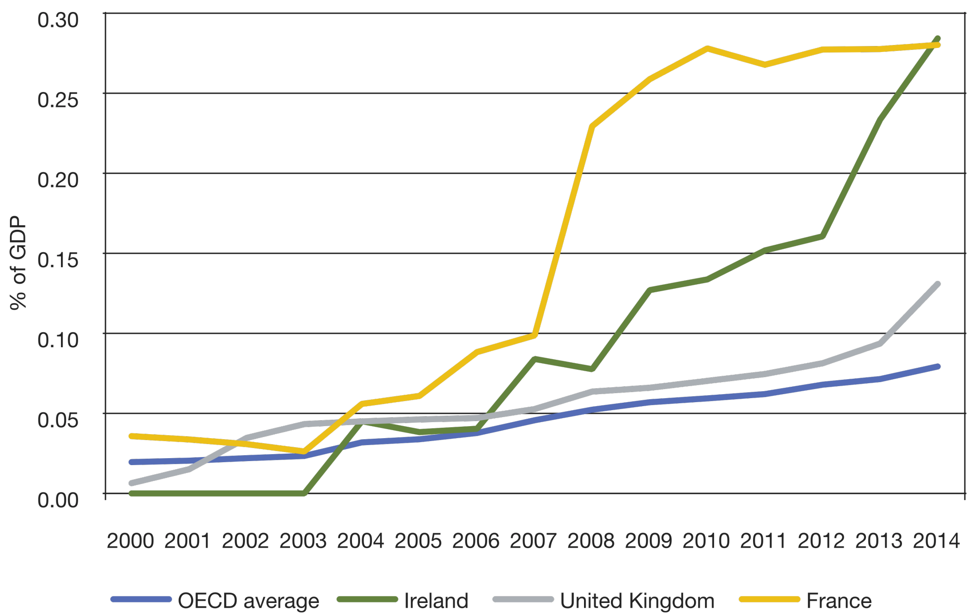
Source: Office of the Revenue Commissioners, Industrial Development Agency (IDA), Enterprise Ireland (EI).

3.2 International Comparisons and Trends

R&D tax incentives have become increasingly popular in other countries too (Figure 3). However, Ireland's support has increased more rapidly than the OECD average, and, as highlighted by Figure 2, the refundable tax credit is a primary driver of this.

Although R&D tax incentives are an important policy tool to stimulate BERD in many countries, it is not automatically the case that the higher the public support, the greater the R&D by private firms. Finland and Germany, for example, provide relatively low levels of public support (and almost exclusively through R&D grants), yet their firms have some of the highest levels of BERD in Europe (Figure 4). By contrast, Ireland provides a relatively high level of public support for BERD but BERD levels here are below the EU28 average level. France and the UK, which respectively have similar and lower tax support than Ireland, perform better than Ireland in terms of BERD (Figures 3 and 4). This highlights the point that there are many factors that will determine the success of a tax credit, ranging from its design to general macroeconomic framework conditions like the level of competition and market size.

Figure 3: R&D Tax Incentives, % of GDP

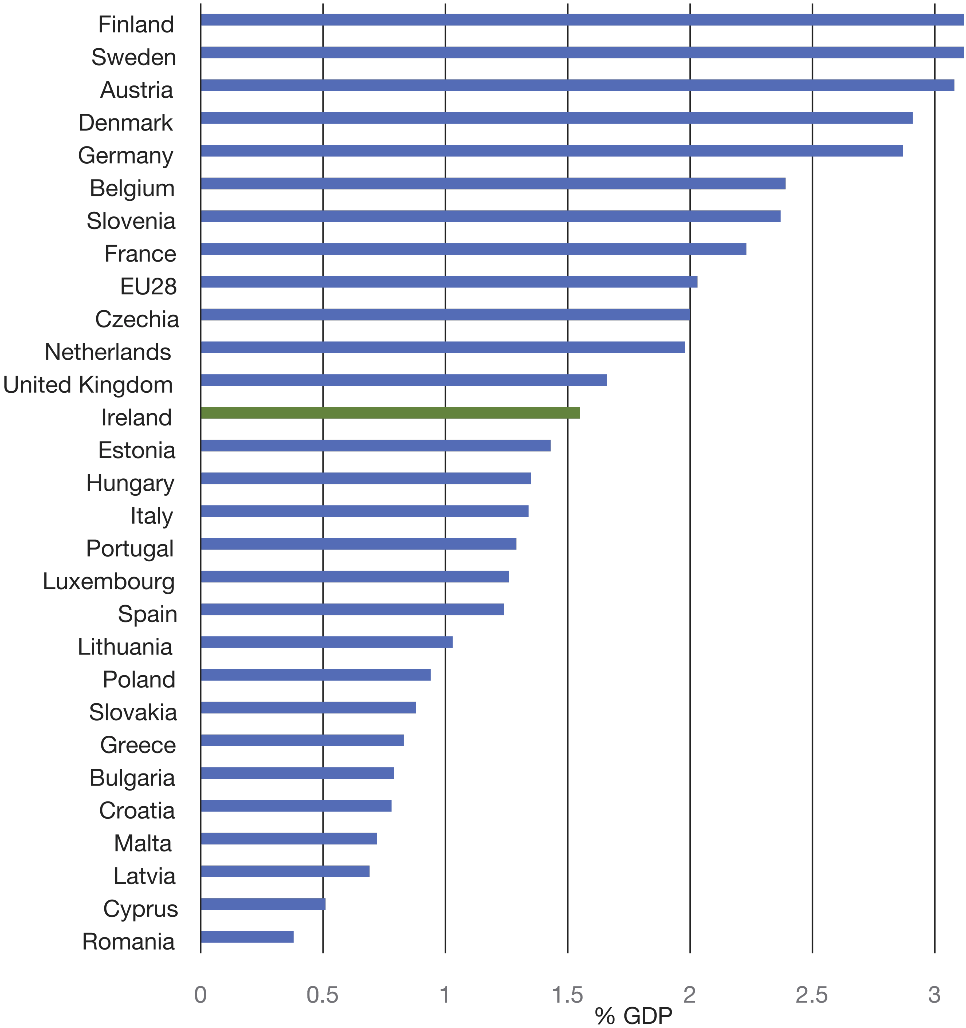


Source: OECD R&D tax incentive database, accessed on 25 January 2019.

3.3 Refundable Tax Credits

Providing any excess tax credit as a refund to firms is relatively uncommon in the OECD. To the best of our knowledge, the countries outlined in Table 1 are the only ones which currently offer a refundable tax credit and, of these, only Austria, Ireland, Netherlands, Norway and the UK could be characterised as quasi-unrestricted in the sense that all firm types can immediately avail of a refund.

Figure 4: Business Expenditure on R&D as a Percentage of GDP, 2014



Source: Eurostat.

Table 1: Refundable Tax Credits in the OECD (2017)

County	*Coverage*	*Refundability features*
Australia	SMEs	43.5 per cent of first AU$100 million of qualifying expenditure
Austria	All	12 per cent of qualifying expenditure
Belgium	All (after 5 years)	4.57 per cent of qualifying expenditure
Canada	Canadian-owned SMEs	35 per cent of qualifying expenditure Refund capped at CA$3 million
France	SMEs, New, YICs Large (after 3 years)	30 per cent of first €100 million of qualifying expenditure
Ireland	All	25 per cent of qualifying expenditure Refund capped at the greater of CIT liabilities in previous ten years or payroll liabilities in current and preceding year
Netherlands	All	30 per cent of first €350,000 of qualifying expenditure, 16 per cent thereafter
Norway	All	18-20 per cent of qualifying expenditure
Spain	All (after 1 year)	25 per cent of qualifying expenditure Refund capped at €3 million *Refund to be reinvested in R&D; average R&D staff headcount to be maintained over a 24-month period
UK	SMEs Large	*33.35 per cent of qualifying expenditure 11 per cent of qualifying expenditure

Source: OECD (2017), *Deloitte (2018).
Note: Small and Medium-sized Enterprise (SME); Young Innovative Company (YIC).

IV EMPIRICAL APPROACH

In this section we outline our empirical model. We estimate the causal effect of the R&D tax credit on R&D investment using a difference-in-difference approach by exploiting the differential change in R&D tax incentives which arose because of the 2009 policy reform.

The 2009 policy reform creates two groups for comparison. First, a treated group of R&D-conducting firms that began to receive a financial benefit from the tax credit scheme for the first time (i.e. the refundable credit), as they previously had not generated sufficient tax liabilities to do so. Second, a control group of R&D-conducting firms for whom the introduction of the refundable credit was irrelevant as they already gained financial benefit via reduced corporation tax liabilities. As we observe the same firms within a group both before and after the treatment, the average change in outcomes (R&D investment) in the control group can be subtracted from the average change in outcomes in the treatment group to establish the average treatment effect.[4]

Firms are assigned to the treatment and control group based on their ex ante behaviour in 2007 and 2008. In practical terms, they are given a treatment assignment if they had a nil tax liability in either or both years. This approach ensures that the intention to treat (ITT) has been randomly assigned (and that we will estimate reduced form effects, which will estimate directly the actual effect of the policy). ITT analysis is widely accepted as the correct standard to apply rather than treatment on the treated (TOT) (Blundell and Costa Diaz, 2000; YHEC, 2016). A TOT estimate will suffer from bias if group cross-overs are not random i.e. cross-overs directly related to the existence of the refundable credit itself which may cause firms to manipulate their tax liability. We deem this a likely scenario, due to the generosity of the tax credit and the accounting treatment of the refund as 'above the line'.[5]

A difference-in-difference approach relies on the parallel trend assumption: in the absence of the policy reform, the difference in R&D investment by the treatment and control group would be constant over time. There is no statistical test for this, as it is unobservable by definition. Instead, the assumption is tested in the econometric model using group-specific linear trends (discussed in Section VI Results).

To further support our argument of random assignment, we note that this policy reform was introduced at very short notice. The Minister for Finance's Budget 2009 speech, given in October 2008, made no reference to the introduction of a refundable credit.[6] It was first publicly suggested in a Tax Strategy Group paper on the Department of Finance's website in November 2008, and subsequently took legal effect in the Finance (No 2) Bill from January 1 2009. Therefore, firms did not have much time to adjust or manipulate their R&D investments in response to this event. In addition, even if the policy had been announced much further in advance, it is difficult for most firms to adjust their R&D quickly as projects and upfront financing tends to be determined on a multi-year basis (for example, executive boards typically approve new research projects on a scheduled basis).

[4] A difference-in-difference approach is particularly important in the Irish case as the share of qualifying expenditure for the tax credit also increased in 2009, from 20 per cent to 25 per cent, which would be of benefit to firms in the control group.

[5] The accounting treatment of the refundable credit as 'above the line' improves financial indicators in firms' financial accounts, such as their EBITA (Earnings before interest, tax and amortisation), which can be of interest to potential investors.

[6] http://www.budget.gov.ie/Budgets/2009/FinancialStatement.aspx#18, accessed on 25 January 2019.

As part of our strategy, we assume that R&D growth is not systematically related to tax liability levels. While it may be common to assume that corporation tax liabilities are synonymous with profit levels, we stress that the two can differ considerably due to losses carried forward from a previous year, charges, capital expenditure allowances, and foreign income in the Irish case. Nevertheless, it is not a completely innocuous assumption, as it is not obvious that firms with different tax liabilities have the same expected R&D growth rates in the absence of the tax credit. Furthermore, R&D growth rates in both groups may be influenced by regression-to-the-mean. To the extent possible, fixed effects, time dummies and other control variables and robustness checks deal with these issues.

The difference-in-difference regression framework we use relies on the insights of Hall and Van Reenan (2000), who survey the impact of fiscal incentives on R&D investments. They outline a structural model as follows:

$$ln(R\&D)_{it} = \alpha_0 + \beta\rho_{it} + \gamma ln(output)_{it} + \eta_i + u_{it} \quad (1)$$

where ρ represents the user cost of capital and η represents firm-level fixed effects.

We can take Equation 1 as the starting point for our model but replace the user cost of capital with an indicator of whether a firm is in the treatment group. We will also replace the output control variable by an employee control variable, which, like output, can be interpreted as a proxy for firm size. As we are conducting difference-in-difference estimation, we also add period and group fixed effects.

The general model for difference-in-difference estimation is as follows:

$$Y_{it} = \beta_0 + \beta_1 Treat_i + \beta_2 Post\text{-}treatment_t + \vartheta\ Treat_i .\ Post\text{-}treatment_t + u_{it} \quad (2)$$

β_1 is the coefficient on the group fixed effects and β_2 is the coefficient on the period fixed effects. ϑ is the coefficient of interest and is interpretable as the average treatment effect.

The model we run is as follows:

$$ln(R\&D)_{it} = \alpha_0 + \eta_i + \sum_{t=1}^{t=T} \delta_t D^{year\ t} + \vartheta\ D^{year\ post\text{-}treatment} .\ D^{treatment} + \gamma ln(employees)_{it} + u_{it} \quad (3)$$

Following Bertrand *et al*. (2004), we adjust the standard errors u_{it} in the model by clustering them on the individual firm's unique identifier, which allows for arbitrary correlation of the residuals among individual time series but assumes the errors are independent across firms. This approach corrects for both autocorrelation and heteroscedasticity.

One of the challenges we face is distinguishing between the effect of the refundable tax credit and other potential changes in the macroeconomic environment that affect R&D outcomes in the treated and control group differently.

This is particularly important given the severe recession in Ireland at the time of the policy change. The role of the year dummies as period fixed effects highlights this problem – a year dummy can pick up a macroeconomic shock, but we are assuming the effect on R&D is the same, on average, for all firms in the sample.

In addition to the year dummies, we include a size control (employee headcount) in all regressions.[7] This does vary over time and can be thought of as aiding the interpretation of the coefficients on the year dummies: we estimate an average response to macroeconomic shocks similar for firms in both groups that is conditional on their individual firm size (and also on unobserved permanent differences between the two groups). The size control is also important to account for the possibility that the absolute size of the R&D tax credit claimed by firms may influence the observed treatment response; given firm size is itself strongly correlated with a firm's level of R&D investment, any treatment effect observed over and above this can then be more confidently attributed to the policy reform rather than the absolute size of a firm's R&D investment.

We also employ firm-level fixed effects to control for unobserved permanent characteristics that may be correlated with treatment status.[8] A firm-level fixed effect can refer, for example, to the firm's industry, its foreign ownership status or its subsidiary status. To illustrate, one can envisage that multinational status is a firm-level fixed effect which would influence the response to an R&D price shock. By employing firm-level fixed effects, we reduce the possibility that multinational status drives any observed results.

V DATA AND DESCRIPTIVE STATISTICS

The data we use come primarily from the Revenue Commissioners' administrative data on corporation tax returns.[9] A specific database was built for this study which consisted of the full population of firms who ever availed of the R&D tax credit between 2007 and 2014. As such, the data are only suitable for examining the intensive margin.[10] In addition, employee numbers were merged into the dataset using other tax returns filed by tax-registered employers.

Other data came from the enterprise development agencies, Enterprise Ireland (EI) and the Industrial Development Agency (IDA). The former provides R&D

[7] One reason to use employee headcount rather than turnover as the size variable is due to the potentially distorting effect of multinational balance sheets and financial data in the Irish context (Connolly, 2018).

[8] Note that as we specify firm-level fixed effects in the regression, the group-level fixed effects ($\beta 1$ in Equation 1) will drop out of the results.

[9] Each observation refers to a corporation tax-liable entity. Entities may have affiliates or subsidiaries, and these file separate tax returns. However, groups are identifiable in the data through a manual marker which is built and maintained by Revenue.

[10] A broader panel dataset which included firms who do not claim the credit would be required to study the extensive margin.

grants to domestic-owned firms and the latter to foreign-owned firms. They provided the grant data aggregated to NACE Rev. 2 section-level.

The sample for determining additionality is restricted to firms who conducted R&D (i.e. had a positive tax credit claim) in either or both of the years prior to the treatment year and who were potentially affected by the policy change (i.e. they had a positive tax credit claim in 2009).[11] Firms with an R&D investment level greater than €250 million were categorised as outliers and excluded from the analysis. We use the full time period in the data available to us, in order to estimate additionality for R&D over the long-run. We note this is typically higher than that of the short-run due to adjustment costs for R&D (Bloom *et al*., 2002; Lokshin and Mohnen, 2012). Table 2 provides a summary of the sample data and the treatment assignment for reference.

Table 2: Summary of Sample and Treatment Assignment

Regression Sample	*Treatment Assignment*
R&D < €250 million in all years	Tax liability = 0 in pre-treatment period
R&D > 0 in pre-treatment period	
R&D > 0 in year of policy change (2009)	

Source: Authors' analysis based on Revenue data.

Table 3 provides descriptive statistics on R&D growth to motivate our identification strategy. We construct the growth rate for R&D from the period just before the treatment to just after the treatment i.e. growth between 2008 and 2010. We use a weighted growth formula (see Equation 4) to reduce the influence of extremely large values in either period, and we only apply it to the sample of firms that we will subsequently use in our regression analysis.

$$(R\&D_{2010} - R\&D_{2008}) / (0.5 * R\&D_{2008} + 0.5 * R\&D_{2010}) \quad (4)$$

We compare these growth rates for our treated and control group and observe a positive difference between the two at various points on the distribution of growth rates. The statistical significance of this difference is checked via a t test, which indicates that the mean growth rates for the treated and control group are different from each other. This table offers the first suggestion that the tax credit scheme does provide additionality.

The definition of age used in this study is based on the firm's date of incorporation (this is when the firm registers with the Companies Registration Office). This age variable will be accurate for all domestic firms, but care must be

[11] As Figure 1 shows, the number of firms claiming the credit before 2007 was very small so we focus on the two years prior to the introduction of the refundable credit.

Table 3: R&D Growth for Regression Sample

	Growth in R&D from 2008 to 2010 (%)		*Difference (in % points)*
	Treated group: firms with zero tax liability in pre-treatment period	*Control group: firms with positive tax liability in pre-treatment period*	
25th percentile	–0.62	–0.95	0.33
Median	0.00	0.00	0.00
75th percentile	0.71	0.61	0.10
Mean	0.00	–0.10	0.10**
Standard error	1.26	1.26	

Source: Authors' analysis based on Revenue data.
Note: **Difference in mean growth is significant at the 5 per cent level.

taken when interpreting 'young' multinationals, as the age will be the age of the subsidiary and not the parent company. Robustness checks are employed in Section VI to explore this issue. The BERD survey data published by the CSO do not have an age variable and, to the best of our knowledge, this is the first time that R&D activity by age has been publicly examined using an Irish data source. BERD data show that total R&D has increased in Ireland since 2007, a trend which the Revenue administrative data mirror, but the latter data source suggests that the majority of the growth is due to the oldest firms.[12] Analysing Revenue data, we find that over half of R&D growth between 2007 and 2012 is due to firms aged over 15 years, roughly a third is due to firms aged 0-5 years, and the remainder is due to firms aged 6-10 years.[13]

Table 4 shows the characteristics of the firms in our sample. While the treatment and control groups are similar in terms of foreign multinational status, firms in the control group are more likely to be older and employ more people.[14]

[12] Unlike firm size, there is no convention for age brackets in empirical work. We adopt 0-5, 6-10, 11-15, 16-20, 21-25 and 25+ years here.
[13] A shorter period is used here for the sake of demonstration, as the oldest age bracket had untypical R&D investment in 2013 and 2014.
[14] Tax records do not provide a complete record of the nationality of firms operating in Ireland. To address this, Revenue has compiled a marker for firms that are tax resident in Ireland to distinguish them by multinational status. The marker is updated as firms restructure, or new firms register for tax, but Revenue notes that it is a manually compiled statistic and therefore subject to potential error and incomplete coverage.

Table 4: Firm Characteristics (as Share of Each Group)

	Treatment group %	*Control group* %
Foreign Multinationals	28	28
of which: 0-5 years	1	2
0-5 years	28	17
6-10 years	27	25
11-15 years	11	20
16-20 years	9	11
21-25 years	9	10
25+ years	15	17
0-9 employees	26	12
10-49 employees	27	50
50-249 employees	27	22
250+ employees	15	11

Source: Authors' analysis based on Revenue data.
Note: Firms change age and size category over time. The shares above refer to their status in 2009.

VI RESULTS

6.1 Firm Characteristics which Influence R&D

Prior to examining the impact of the tax credit, this section briefly discusses the type of firm characteristics which influence R&D investment. Using the same sample as will be under study in the next section, Table 5 highlights how age is associated with higher levels of investment: the very oldest firms (25+ years) typically do over 5 per cent more R&D than the very youngest firms (0-5 years). Likewise, increasing firm size is associated with increased investment. Interestingly, foreign multinationals invest more in R&D as their profit gap with other firm types grows, but the magnitude and statistical significance of the effect is more limited than for the other firm characteristics of size and age.[15]

Table 5 illustrates both the need to account for firm-level fixed effects in the main regressions, but also the importance of employing control variables to account for characteristics that do not have time-invariant effects. For example, economies of scale from conducting large or increasing amounts of R&D would not be accounted for by solely employing fixed effects.

[15] The log of foreign multinational profit is constructed by interacting the foreign multinational marker with firm profit, so is interpretable as a relative effect (compared to other firm types) rather than an absolute effect. Foreign multinational status cannot be investigated directly in a fixed-effects model.

Table 5: The Determinants of R&D Investment

	Dependent variable: Log of R&D
Age categories:	
6-10 years	0.758
	(0.480)
11-15 years	0.483
	(0.745)
16-20 years	1.129
	(1.117)
21-25 years	2.580*
	(1.418)
25+ years	5.381***
	(1.747)
Size categories:	
10-49 employees	0.992
	(0.657)
50-249 employees	1.150
	(0.883)
250+ employees	3.399***
	(1.277)
Log of foreign multinational profit	0.211*
	(0.121)
Year fixed effects	√
Firm fixed effects	√
Constant	8.311***
	(1.045)
Observations	2,211
R^2	0.163
Number of firms	341

Source: Authors' analysis based on Revenue data.
Notes: Clustered standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The dropped age category is 0-5 years. The dropped size category is 0-9 employees.

6.2 Baseline Result for Additionality

Equation (3) is our model of choice for determining how the change in tax credit policy impacted on R&D investment. As shown in Equation (3), we employ group and period fixed effects and use a proxy for firm size (employee headcount) as a further time-varying control. As mentioned above, the firm-level fixed effects specification is important to our approach as it controls for permanent differences between firms in the treatment and control group which could affect R&D outcomes, such as multinational status or industry.

The econometric results are presented in Table 6. The average treatment effect (ATE) is positive and significant, at 0.912 log points. This suggests treated firms did respond to the policy change: we interpret the coefficient as meaning that, due to a change in their financial incentives, they performed more R&D relative to the group who had not experienced a change in incentives. The ATE is also economically significant: given observed R&D for the treatment group of €2.3 billion between 2009 and 2014, it implies that the treated firms conducted €1.4 billion in additional R&D. The bang-for-buck of the reform is therefore €2.4.[16]

Table 6: Examining the Additionality of the R&D Tax Credit

		Robustness Checks			
	Baseline (1)	*R&D Grants* (2)	*Economic cycle* (3)	*Foreign multinationals* (4)	*Stricter sample* (5)
Average treatment effect	0.912**	0.917**	0.917**	0.927**	1.835***
	(0.458)	(0.459)	(0.458)	(0.454)	–0.559
Log of firm size (employees)	2.741***	2.742***	2.744***	2.733***	3.408***
	(0.291)	(0.29)	(0.288)	(0.288)	–0.517
Industry-level R&D grants		–2.094	–2.433	–2.229	
		(4.271)	(4.340)	(4.326)	
Industry growth			–0.463	–0.604	
			(1.893)	(1.899)	
Industry growth * Treatment dummy			–5.004*	–5.044*	
			(2.688)	(2.687)	
Log of foreign multinational profit				0.247**	
				(0.119)	
Constant term	–5.053***	–4.838***	–4.651***	–5.705***	–1.352
	(1.104)	(1.194)	(1.208)	(1.329)	–2.092
Year fixed effects	√	√	√	√	√
Firm fixed effects	√	√	√	√	√
Observations	2,552	2,552	2,552	2,552	770
R^2	0.274	0.274	0.276	0.278	0.291
Number of firms	342	342	342	342	103

Source: Authors' analysis based on Revenue data.
Note: Clustered standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

[16] As the policy equates to a 25 per cent subsidy, whether in the form of the original credit or the refundable credit, the Exchequer cost for the €2.3 billion is approximately €580 million (assuming all firms keep trading indefinitely). The additional R&D per unit of foregone tax revenue is therefore €1.4 billion/€580 million = €2.4.

The model is robust to the inclusion or exclusion of outliers (results are available in the Appendix). The employee variable is also significant and implies that for every 1 per cent increase in its employees, a firm conducts 2.7 per cent more R&D on average. It is important to account for this relationship to reduce the possibility that the size of the refund is influencing the result (as larger firms conduct more R&D than small firms, so will have higher tax credit claims).[17]

6.3 Robustness Checks

Although our dependent variable is R&D net of grants (as per the definition set out in the Revenue's R&D Tax Credit Guidelines), it is possible that the incidence and timing of R&D grants may affect residual R&D that must be funded from other sources. Grants may be a determinant of R&D behaviour that we capture in the regression and misattribute to the treatment. To avoid this, we obtained NACE Rev. 2 section-level data on the distribution of grants for foreign and Irish firms, from the IDA and Enterprise Ireland respectively. When we include this as a control in our first robustness check in Column 2, we observe that grants are an insignificant variable and do not materially change the magnitude or significance of our result for the average treatment effect. The insignificant coefficient for grants provides some very tentative evidence that they do not result in additional R&D.[18] This is in keeping with Mulligan *et al*. (2017), who find that R&D intensity for firms using only the R&D tax credit is very similar to firms who both avail of the credit and receive an R&D grant. In a similar vein, Görg and Strobl (2007) find no evidence of additionality for R&D grants given to foreign firms in Ireland and crowding out of private financing for domestic firms when the grant size increases.

We run further robustness checks in the other columns in Table 6. As mentioned previously, the policy change took place during a period of severe economic distress and it is not possible to definitively state that firms in the treated and control group would react similarly to this in terms of R&D outcomes. Perhaps some firms were in a better position to weather the recession, meaning that their R&D, which is typically a pro-cyclical variable, recovered very quickly after 2009 compared to other firms. This could bias our ATE in Column 1. We control for this possibility in Column 3 by including annual real growth in gross value added for industry and services. As a stand-alone variable it is insignificant, but when it is interacted with the treatment we observe that treated and control group firms do respond differently to the economic cycle: as growth increases, a treated firm increases its R&D by less than a control firm. In other words, the gap between them increases. Similarly, during an economic growth contraction, the gap between them decreases. We interpret this to mean that control firms' investment is more sensitive to the economic cycle. Importantly, we note that this robustness check does not change

[17] If firm size is excluded from the model, the ATE rises as expected.

[18] However, we acknowledge the control is not based on firm-level data, but instead captures whether a firm is in an 'R&D grant-intensive' industry, for Irish and foreign firms respectively.

the ATE, suggesting the potential omitted variable bias from this source was not as important as expected.

While multinational status is one of the more obvious firm characteristics that is accounted for in the fixed effects specification, it is possible that the extent of macroeconomic volatility over 2007-2014 means that it does not have a time invariant effect on R&D. With stronger balance sheets and greater access to other forms of financing, foreign multinationals' investment in R&D may be more protected during a downturn. This possibility is explored in the fourth column, by interacting firm profits with foreign multinational status. We see that their R&D increases significantly as their profit gap with other firms increases, but notably this robustness check does not affect the ATE.

In Column 5 we restrict the sample to firms who had positive R&D in both 2007 and 2008. These firms can be considered as the most R&D-active in our sample. The average treatment effect rises, although there is a very substantial reduction in the number of observations used in the sample. A comparison of the ATE results in Columns 1 and 5 in Table 6 supports the interpretation that zero values for R&D do not drive our preferred result for additionality in Column 1. If a treated firm in Column 1 conducted R&D in either of 2007 or 2008, but not both years, some of the resulting average treatment effect could be driven by this. However, because we eliminate this possibility in Column 5, and yet still see a higher ATE, this implies that zero values do not drive our preferred result in Column 1.[19] In other words, we are not simply observing high R&D growth due to a low initial level of R&D.[20]

This last robustness check also highlights the importance of sample size and firm clustering. We note that by including firms with positive R&D in either or both of 2007 and 2008 in the sample (as opposed to exclusively both years), we attenuate the result of our preferred model as we have not precisely isolated the firms who are likely to be most sensitive to the policy change. On the other hand, making the sample stricter results in very large reduction in the sample and in clustering of standard errors on a smaller number of firms, which we seek to avoid.

Lastly, one issue we must acknowledge is the problem of relabelling, which refers to firms' incentive to reclassify ordinary spending as R&D to benefit from preferential tax treatment. However, we note that Revenue audits of the R&D tax credit have increased over time, which would act as a strong deterrent to firms to relabel their activities (Table 7).

[19] We emphasise that this discussion is separate to the issue of decision-making on the extensive margin. All firms in the model sample do R&D prior to the reform, either in 2007, or in 2008, or in both years.

[20] This paragraph's discussion can also be applied to concerns around reversion to the mean or the 'Ashenfelter dip' (where the outcome variable for the treated observations experiences a drop prior to the treatment). However, neither is deemed likely in the particular context of R&D investment (whereas Column 3 addresses the more pressing concern around differential R&D growth in a volatile macroeconomic environment).

Table 7: R&D Tax Credit Audits

Year	*Number of interventions*	*Yield €'000*	*Average yield per intervention €*
2011	26	2,591	99,654
2012	49	5,413	110,469
2013	105	14,483	137,933
2014	162	10,106	62,383
2015	178	13,542	76,079

Source: Office of the Revenue Commissioners.
Note: Information is not available for all Revenue regions prior to 2011.

6.4 Young Firms

Following on from the results in Section 6.3, we next focus on what firm characteristics may drive the additionality result. As discussed in the literature review, it is typically the case that young firms do not have the same access to finance for R&D as older firms and we might expect that a change in financial incentives would induce relatively more R&D from them than from older firms. This relative lack of finance stems from the fact that they have yet to develop a reputation, typically have limited or no access to collateral, and they do not have past profits to rely on (Hall and Lerner, 2010; Brown *et al*., 2012).

We approach the question in a number of different ways. Initially, we split the sample from the baseline result (Column 1 in Table 6) into a young firm sample and an older firm sample. Young firms are defined as aged five years or less and older firms are defined as aged six years or more. The additionality results in Columns 1-2 of Table 8 refer to a treated young firm compared to a control young firm, while the results in Columns 3-4 of Table 8 refer to a treated older firm compared to a control older firm. Looking firstly at the baseline results in Columns 1 and 3, we find no evidence of additionality when the sample is restricted to young firms and the opposite is the case when the sample is restricted to older firms. The effect for older firms is not dissimilar to the baseline result itself in Table 6.

As mentioned previously, care must be taken with a 'young' multinational, as this refers to the age of the subsidiary and not the global parent. However, excluding such cases from the sample does not result in a change in the ATE (results provided in the Appendix); this is not entirely unexpected as 'young' multinationals are a very small proportion of the sample (see Table 4). Regarding the older sample, where foreign multinationals are more numerous, we include an additional robustness check to explore whether multinational status plays a role in the results. However, we find in Column 4 that the additionality result – older treated firms reacting to the reform more than older control firms – continues to hold.

Table 8: Examining Additionality in Different Samples

	Young treated vs young control (1)	*Young treated vs young control – foreign multinationals* (2)	*Old treated vs old control* (3)	*Old treated vs old control – foreign multinationals* (4)
Average treatment effect	0.394	0.172	1.120**	1.093**
	(0.908)	(0.919)	(0.531)	(0.525)
Log of firm size (employees)	2.542***	2.612***	2.934***	2.932***
	(0.521)	(0.518)	(0.360)	(0.357)
Log of foreign multinational profit		–0.450		0.305**
		(0.285)		(0.129)
Constant	–1.795	–1.070	–6.531***	–8.057***
	(1.364)	(1.440)	(1.484)	(1.623)
Year fixed effects	√	√	√	√
Firm fixed effects	√	√	√	√
Observations	514	514	2,038	2,038
R^2	0.349	0.352	0.259	0.262
Number of firms	74	74	268	268
Firms' age in 2009	≤5	≤5	>5	>5

Source: Authors' analysis based on Revenue data.
Note: Clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

However, to fully determine the impact of age on additionality, we next compare treated young firms against treated older firms in Table 9. Here, it is important to not only account for firm size, which can influence R&D, but also firm age (as we are specifically comparing young firms against older firms). Particularly for the young treated firms, we do not want to attribute post-reform R&D to the reform when it may in fact be a result of their subsequent maturing. In Column 1 of Table 9, we observe a significant and negative ATE. In other words, young firms do significantly less R&D than older firms in the presence of a reform which would increase their cashflow. This unexpected result suggests that young firms face more than simply financial barriers when investing in R&D.

In this particular comparison, there are far more foreign multinationals among the old treated firms than the young treated firms, and while multinational status is accounted for as a firm-level fixed effect in the model, it is possible that the extent of macroeconomic volatility over 2007-2014 means that it does not have a time invariant effect on R&D. This possibility is explored as a robustness check in Column 2, by including the interaction of profits and foreign multinational status. However, it appears to have no influence on the ATE, suggesting that the control group's post-reform R&D is not being driven by this non-reform channel.

Finally, as mentioned in Section IV, it is difficult to determine whether treatment and control groups in a quasi-experiment would have the same trends in R&D investment in the absence of the policy reform. Following Nilsen *et al*. (2018), we test this assumption in Column 3 by specifying group-specific linear time trends (here the groups are treated young firms and treated old firms). We find that the ATE is not unduly sensitive to the more restricted model, which suggests that the difference-in-difference model is appropriate for this setting.

Table 9: Examining Age as a Channel for Additionality

	Baseline (1)	*Controlling for multinationals* (2)	*Testing parallel trend assumption* (3)
Average treatment effect	–1.818**	–1.815**	–1.473**
	(0.740)	(0.744)	(0.727)
Log of firm size (employees)	2.050***	2.049***	2.071***
	(0.516)	(0.519)	(0.519)
6-10 years	0.161	0.162	0.472
	(0.638)	(0.638)	(1.004)
11-15 years	0.0610	0.0630	0.277
	(1.104)	(1.115)	(1.263)
16-20 years	0.495	0.497	0.635
	(1.909)	(1.916)	(1.948)
21-25 years	0.898	0.897	0.958
	(2.454)	(2.453)	(2.458)
25+ years	2.914	2.913	2.894
	(2.724)	(2.720)	(2.719)
Log of foreign multinational profit		0.00814	0.0102
		(0.118)	(0.117)
Constant	4.342**	4.306**	87.33
	(2.024)	(2.075)	(187.8)
Group-specific linear time trends			√
Year fixed effects	√	√	√
Firm fixed effects	√	√	√
Observations	917	917	917
R^2	0.177	0.177	0.177
Number of firms	145	145	145

Source: Authors' analysis based on Revenue data.
Notes: Clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Young firms defined as aged 0-5 years.

The results from this section are particularly noteworthy, as the refundable credit would *a priori* be expected to assist young innovative firms, who are often assumed to be inhibited in their R&D investment choices due to liquidity constraints. Our results imply, on the contrary, that they are unaffected by the liquidity boost provided by the refundable credit. This suggests to us that other barriers to these firms may exist besides financial constraints, such as market barriers (D'Este *et al*., 2012; Teece, 1986), inexperience (García-Quevedo *et al*., 2014), or skills shortages (Baldwin and Lin, 2002). In addition to the implications for the YICs literature, our results may have a bearing on the recent productivity literature that suggests that spill-overs between leading and laggard firms have slowed down in recent years (OECD, 2015; Papa *et al*., 2018). Although our findings will need to be firmed up by further research, it may be that one explanation for this spill-over slowdown relates to the 'creative accumulation' of larger, older incumbents, as posited by Schumpeter (1942), which leaves newer and smaller firms behind. Our results suggest that this effect may be occurring at one of the earliest stages of the innovation cycle i.e. the firm's decision to increase its R&D investment.

Overall, the results in this section are valuable for policymakers as they highlight that a tax incentive cannot be relied on in isolation as a policy tool to pursue the outcome of increased R&D by young firms. Such firms likely face other, non-financial barriers to R&D expansion and this could usefully be the subject of further empirical work.[21] With further research, it may be the case that public policy should de-emphasise financial support and focus more on regulation and competition policy, or apply a more holistic mix of the three tools, in order to stimulate persistent R&D in young firms and ultimately reduce the innovation and productivity gaps between firms.

On the other hand, the tax credit scheme appears to be effective for older firms, so another possible policy response is simply to adopt a 'wait and see' approach specifically on fiscal policy. If market forces allow a firm to grow to a sufficient stage of development, then the tax credit (as it is currently designed) can assist that firm to perform additional R&D. It may give rise to further inefficiencies, for example, to try to target inexperienced firms via a tax credit policy that specifically differentiates firms with respect to age or other characteristics.

VII CONCLUSIONS

R&D and innovation policies increasingly rely on tax incentives to support R&D investment by firms. In this paper, we use a novel and rich administrative dataset for the period 2007-2014 on all R&D-active firms in Ireland, and exploit a unique policy reform to quantify the impact of the R&D tax credit for the first time.

First, our results suggest that the credit is reasonably successful on average in its aim of increasing R&D investment. Second, we did not find evidence that the

[21] As well as being the drivers of additional R&D, older firms are also the primary financial beneficiaries, so one interesting avenue for future research would be to explore the magnitude of treatment by firm type.

scheme is effective in encouraging R&D in younger firms, which suggests other, non-financial barriers to conducting R&D for this type of firm may dominate. This unexpected result should be examined in greater detail, and public policy tailored appropriately as a result.

It is often assumed that a refundable R&D tax credit will be more effective for new firms or start-ups, due to their liquidity constraints. Here, we provide evidence against that type of policy advice. This does not make a refundable credit a bad thing in and of itself (for example it protects R&D investment during a recession) but suggests careful design is needed to avoid a large cost to the public purse with little additional R&D from young firms, in particular, to show for it.

A tax credit can only rectify the market failure of under-investment in R&D if the root of the problem is financing. If, for example, the greatest barrier for a young firm relates to market structure or insufficient human capital, the tax credit will not solve the failure and in addition runs the risk of considerable deadweight. The Irish R&D tax credit in its current form can be considered a reasonably successful policy tool, in that it does stimulate additional R&D on average, but the deadweight inherent in the scheme and the firm characteristics associated with that should be carefully considered.

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APPENDIX

Table A.1: Other Regression Results

	Baseline model including outliers	*Young firm sample excluding 'young' multinationals*
Average treatment effect	0.916**	0.0787
	(0.456)	(0.907)
Log of firm size (employees)	2.740***	2.537***
	(0.291)	(0.518)
Year fixed effects	√	√
Firm fixed effects	√	√
Constant term	–5.052***	–1.600
	(1.108)	(1.326)
R^2	0.273	0.368

Source: Authors' calculations.
Notes: Clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.