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# Will the real R&D employees please stand up? Effects of tax breaks on firm level outcomes

Irem Guceri*

**Abstract**

This paper evaluates the effect of R&D tax incentives in a quasi-experimental setting. I identify the impact by exploiting a reform in UK policy which increased the SME threshold from 250 to 500 employees. First, I provide evidence that tax incentives help to increase R&D spending at the company level, and the effect translates to a user cost elasticity of -1.18. Second, R&D generated through the reform may be attributable to an increase in the number of R&D employees. I use R&D survey data for which the companies do not have an incentive to relabel their ordinary spending as R&D.

JEL Classification: H25, O30

Keywords: R&D, tax credits, difference-in-differences

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# 1 Introduction

Governments subsidize R&D in order to reach the socially optimal level of private investment in innovation (Jones and Williams (1998)). From the government's perspective, one way of subsidizing private R&D is to directly fund projects that it chooses from a pool of applicants. From the companies' perspective, R&D is a risky activity and the companies themselves are better informed than the government to decide on the potential success and economic viability of their R&D opportunities. Criticisms over the government's ability in choosing the best R&D projects have led to an increased emphasis on tax incentives to support private R&D. The United States, France and Japan have offered R&D tax incentives for decades now, but in the 2000s, the implementation of this policy became ever more prevalent, with France and Japan substantially increasing the generosity of their R&D tax incentive schemes while some other leading players in R&D and innovation such as South Korea, China and the United Kingdom introducing schemes that later constituted a large portion of government financing for business R&D in these countries.

In this paper, I explore the impact of tax incentives for R&D on various firm-level outcomes. I evaluate the impact of an R&D tax relief on the real R&D spending and R&D employment in a firm. I achieve this by applying a difference-in-differences regression and a propensity score matching approach, using the micro level Business Enterprise Research and Development (BERD) data for the UK collected by the Office for National Statistics. I exploit a discontinuity in the design of the schemes in order to identify the policy impact.

Wider availability of micro level data has enabled quasi-experimental work on R&D policies in the recent years. Bronzini and Iachini (2014) use data on the population of applicants to an R&D subsidy in northern Italy to evaluate a direct subsidy programme with a regression discontinuity design (RDD), and find that the policy was effective in increasing R&D spending by small firms, but not by large firms. Identification through RDD is possible in Bronzini and Iachini (2014)'s work thanks to the discontinuity in scores that are given to each project in the selection of beneficiaries.

There is an emerging literature that explores the impact of tax incentives on R&D by exploiting policy discontinuities. In Guceri and Liu (2015), we use administrative tax returns data to exploit the breaks in the UK policy and estimate the effect of the R&D tax relief on R&D spending that qualifies for the tax breaks. This is among the recent wave of studies that use administrative data in a quasi-experimental setup (other examples are Agrawal et al. (2014), Rao (2015), Lokshin and Mohnen (2012)). These studies generally find a positive and significant effect of tax incentives on R&D spending by businesses. One main advantage of administrative data is the access to information on the population of firms that benefit from the policy. A disadvantage, on the other hand, is that companies may have an incentive to relabel ordinary spending as R&D to obtain the tax credit. Moreover, information in tax returns data is usually more limited, for example, to expenditures that qualify for tax incentives.

The finding that tax incentives for R&D may have a positive impact on R&D spending attracted criticism from two main angles. First, Goolsbee (1998) and Rogers (2010) warned that with the introduction of R&D support policies, the majority of increased R&D expenditures may go to higher salaries for scientists and engineers, rather than fund the employment of a larger number of researchers to scale up R&D activities. Goolsbee (1998) supported this finding by demonstrating that there is a relatively stable supply of scientists, with expenditure on pay rising significantly following increases in government subsidies to support R&D expenditure by firms. Second, many studies flagged the issue of relabelling ordinary expenses as R&D, even though the extent of the problem has rarely been quantified. Some evidence of relabelling was provided in an early report by the US General Accounting Office (1989), which found that around 20 percent of revenue agents were not convinced by the clarity of the definition of qualifying expenses. A more recent US GAO study (2009) identified the main expenditure items which are more difficult to monitor for the tax authority. On the top of their list was the proportion of salaries paid to management level staff who supervise research activities.

The micro level BERD survey that I use in this study is anonymous and the data cannot be matched with the tax records due to ONS's legal promise to the respondents. This legal requirement presents an opportunity for the purpose of this study, as companies do not have an incentive to misreport their ordinary spending as R&D when responding to the BERD survey. The other advantage is that the BERD survey has a measure for R&D headcount within the company, allowing for the study of changes in the firm's R&D employment.

Hall and Van Reenen (2000) underline the difficulty and the importance of finding exogenous variation in the user cost of capital to identify the effect of tax incentive-type R&D support policies. The UK policy setting provides a suitable basis for exploiting such exogenous variation, using difference-in-difference and matching methods with individual fixed effects, as often applied in public policy contexts (for examples, see Yagan (2015), Zwick and Mahon (2014)). In the UK, R&D tax incentives were first introduced for SMEs (in 2000) and then for large companies (in 2002). In 2008, two reforms took place. First the rates for enhanced deduction increased for SMEs from £150 to £175 for each £100 spent on R&D (150 to 175 percent), and for large firms the rate increase was from 125 percent to 130 percent. For the large firms, the increase did not lead to a substantive reduction in the cost of R&D capital because there was also a reduction in the tax rate. For SMEs, the reform had a more substantial effect. In August 2008, more importantly, the definition to qualify as an SME changed from 250 employees to 500 employees (along with other criteria, which I discuss in Section 2). This second reform that took place in 2008 meant a large decline in the user cost of R&D capital for the medium-sized companies whose definition changed from 'large' to 'SME' for the purpose of the R&D tax relief. The drop in the user cost of R&D capital was between 15-21 percent for this 'treated' group of firms depending on their taxable profit.

This paper makes the following contributions. First, the doubling of the thresholds for eligibility to the R&D tax relief for SME provides a valuable opportunity to identify the effects of R&D tax incentives. The policy reform generates a natural control group whose user cost of R&D capital remains unaffected by the reform, and a natural treatment group which experiences a drastic reduction in user cost of R&D capital as a result of the change in the eligibility criteria. Second, the Office for National Statistics reassures firms that the data on individual companies cannot be identified or used for other purposes than statistical analysis.[1] This mitigates firms' incentives to lie about their R&D spending or to relabel ordinary spending as R&D. Third, the BERD survey includes information on R&D employment which helps in exploring whether the R&D spending that appears to have been generated by the reform is a result of firms increasing the scale of their R&D activities.

I find that the treated firms increased their R&D spending by around 20 percent on average in response to the reform. Measuring against the 17 percent average reduction in the user cost of R&D capital, the increase translates to an implied user cost elasticity estimate of around -1.18, which is in the same ballpark as the cross-country finding of Bloom et al. (2002) that used an instrumental variables approach. Without considering the social returns to R&D through spillover effects, I calculate that the return to each £1 foregone in corporation tax is between £0.9 − £1.2 in R&D, suggesting that the Government recovers its cost from implementing the policy.

In the next section, I present some aggregate trends in the R&D performance of UK businesses, describe the R&D tax policy framework in the UK, and then outline the conceptual framework. In Section 3, I describe the data, and in Section 4, present the empirical approach. Section 5 presents the results, Section 6 presents robustness checks and Section 7 discusses the mechanisms that may be driving the results. The final section concludes.

[1] The ONS Code of Confidentiality can be found at https://www.statisticsauthority.gov.uk/monitoring-and-assessment/code-of-practice/

# 2 Background

## 2.1 Trends in the UK private sector R&D intensity

Tax incentives for R&D aim to boost the private sector's R&D performance. An aggregate measure for a country's private R&D performance is the intensity of its Business Enterprise Expenditure on Research and Development (BERD), that is, the share of BERD in total value added of the private sector. In the past several decades, the UK private sector's R&D performance has been sluggish both in absolute terms and in terms of BERD intensity with respect to comparators such as the United States, Germany, France and Japan.

[Figure 1 here]

The OECD Structural Analysis (STAN) and Analytical Business Enterprise Research and Development (ANBERD) Databases report cross country time series data on R&D expenditure volumes and provide a sectoral breakdown. Using these figures, I obtain cross country comparisons of R&D intensities, as in Figure 1. Figure 1 shows that total BERD as a share of value added has been lower, and has been declining in the UK relative to Japan, Germany, France and the USA over the period 1990-2008. Earlier studies (see, for instance, Van Reenen (1997), Griffith and Harrison (2003)) have shown that this relative decline of UK BERD intensity has been continuing for several decades. At the aggregate level without controlling for any other factors, the introduction of tax credits for R&D spending in the UK in 2000 and 2002 appears to have had little impact.

Despite the poor relative performance in overall BERD intensity, the UK manufacturing sector BERD as a share of manufacturing sector value added, has shown a steady increase and a tendency toward catching up with its peers. This is illustrated in Figure 2, which shows that the UK manufacturing sector BERD intensity has been rising over the most recent decade for which this data is available and since the UK R&D tax credits were introduced. In 2000s, as the UK manufacturing sector BERD intensity experienced a rise, so did its competitors'; France, Japan and the US all experienced steep rises, with only Germany demonstrating a rather horizontal trend. In an earlier paper, we noted that these peer trends in neighboring countries may have been a significant factor in driving the rise in the UK manufacturing sector R&D intensity, but even controlling for these effects, the UK experienced a steeper rise starting around the time of introduction of the R&D tax incentives (Bond and Guceri (2012)).

[Figure 2 here]

In general, BERD performed by the services sector as a share of this sector's value added is much lower than that of manufacturing. The share of manufacturing sectors in total UK value added dropped from 26 percent in 1980 to 13 percent in 2007, while the share of service sectors has risen from 56 percent to 76 percent. The trends depicted in this section highlight drastic changes in UK R&D intensity, but purely descriptive evidence is not sufficient to derive causal relationships. The quasi-experimental approach of this paper establishes a causal framework to evaluate the role and the effectiveness of R&D tax incentives in the changing structure of the UK private sector's R&D activity.

## 2.2 The UK R&D tax incentive scheme

Fiscal incentives for R&D allow a special treatment of R&D expenditure for tax purposes, and encompass a range of tax incentives for both current and capital expenditures: tax credits, cash credits, enhanced deductions, special depreciation allowance terms, enhanced loss carrybacks and carryforwards, to list a few. The treatment of R&D expenditure is different for economic, accounting and tax purposes. From an economic perspective, R&D is a type of investment; its main objective is to generate higher revenues in the future. From an accounting perspective, on the other hand, the majority of R&D is treated as current expenditure and such expenditure is 100 percent deducted against current revenue in the calculation of profits each period. If there are no special tax incentives, the tax treatment is broadly in line with the accounting treatment and most of the spending on R&D is expensed in the computation of taxable income. For the small part of R&D that is capitalized, firms can only deduct from their accounting profits some estimate of the depreciation charge on the stock of R&D capital in each period. Currently in the UK, as in many other countries, both the current and the capital expenditures on R&D are subject to a special tax treatment, and the details of this are explained in the rest of this section.

Tax incentive schemes for R&D can be of two types: (i) incremental, where firms benefit only to the extent that they exceed some base level of R&D that they have previously been performing[2] and (ii) volume-based, where firms enjoy benefits on all their R&D expenditure, regardless of their past level. It is becoming more and more common to introduce or increase the emphasis on volume-based schemes among industrialized countries, as the design is simpler and these benefits can be used by a larger group of beneficiaries.

The UK R&D Tax Relief for Corporation Tax is relatively generous in the sense that both the SME and the large company schemes are volume-based. The schemes are in the form of enhanced deductions of qualifying current expenditures from taxable income, and lossmaking companies can carryforward the benefit indefinitely. France had an incremental tax credit until 2008, and then switched to a volume-based credit, greatly simplifying the design of the preceding policy. The US provides an incremental tax credit with a 20-year carryforward option, which is a longer time period than that allowed in most countries. Canada provides a volume-based credit, and both Canada and the US also provide sub-national tax credits (see, for instance, Wilson (2009) for a discussion of sub-national tax credits).

Discussions on a more favorable tax treatment of R&D in the UK began in the late 1990s. This was at least partly in response to the declining trend in the R&D intensity of the UK economy overall, which was already at levels below those of comparators such as France, Japan and Germany as demonstrated in Figure 1. Before 2000, when the first significant tax breaks were introduced,

[2] Countries apply different rules regarding the base R&D expenditure that the firm needs to exceed.

all of current expenditure on R&D was 100 percent deductible against taxable income and a subset of capital expenditures could be expensed under the Research and Development Allowance[3].

The UK R&D Tax Relief for Corporation Tax was introduced in two stages. First, the SME scheme was implemented in April 2000 and then later in 2002, the large company scheme was introduced. The SME scheme was a combination of an enhanced deduction and cash credits, with the former applying to companies with positive taxable profits and the latter to those companies which incurred a tax loss in the reference period. The SME scheme applied to companies which satisfied the SME definition of the EC Regulation 1996/280/EC and allowed these firms to deduct, for every £100 of qualifying R&D expenditure, £150 from their taxable income[4]. These companies could claim up to 24 percent of their R&D expenditure in cash if they did not have taxable profit. The large company scheme was less generous: it allowed the companies that were above the SME threshold to deduct, for every £100 expenditure, £125 against taxable income and did not grant any cash credits. When an SME conducts subcontracted R&D as a result of a contractual relationship with a large company, then the R&D undertaken by the SME is also subjected to the deduction rates for large companies. In this study, I focus on the 'intramural R&D expenditure' of companies, which is the component of R&D spending that is subject to different rates for SMEs and large companies.

Based on a number of company interviews and case studies, a qualitative HMRC review of the R&D tax credit states that the take up has been low in the beginning of the scheme due to lack of awareness by the firms (Michaelis et al. (2010)). Even for the companies that were aware of the tax credit, they may have been inclined to delay their undertaking of R&D to the following year given the apportionment of the tax credit in the first year of implementation. Based on these information, I selected calendar year 2003 as the first implementation period for analysis, after the introduction of both the SME

[3]Formerly known as the 'Scientific Research Allowance'. These capital allowances are still available.

[4]SME definitions are explained in detail later.

and large company tax relief schemes.

The enhanced deduction rates increased from 1 April 2008 onwards, and this was followed by a change in the thresholds for defining an 'SME' for tax credit purposes[5]. According to the EU regulations, the SME definition consists of size thresholds and also requirements related to owner-subsidiary relationships[6]. This implies that small firms which are subsidiaries of large companies, which own stakes more than 25 percent in the firm, cannot benefit from the SME incentive scheme. To qualify for the SME credit, companies need to satisfy the employment criterion and then either the balance sheet size or the turnover criteria.

During the period of interest for this study, eligibility for the SME tax incentive first required that the company has fewer than 250 employees, and either a balance sheet size of less than €43 million or turnover less than €50 million from 2005. In addition to having satisfied these criteria, the company should not have been owned by a group that exceeds these limits, or the individual subsidiaries, when aggregated, should not have exceeded these thresholds. Ownership in this context refers to more than 25 percent of the capital or voting rights. After 1 August 2008, the employment, turnover and asset size thresholds were doubled, allowing companies with fewer than 500 employees and either a balance sheet size of less than €86 million or turnover less than €100 million to be able to benefit from the generous SME scheme.

The doubling of the SME tax relief eligibility thresholds allow for a natural treatment group of medium sized companies that were, prior to 2008, benefiting from the large company scheme and after 2008, from the more generous SME scheme. The reduction in the user cost of R&D capital for the treated medium sized companies was between 15-21 percent thanks to the reform.

[5] The size definition change took place on 1 August 2008, in line with the Corporation Tax Act (CTA09/Ss1119 - 1121).

[6] The criteria for eligibility to the SME tax incentive scheme was determined based on the relevant EC Regulation. Depending on the year, these were: 1996/280/EC and 2003/361/EC, with the latter taking effect for accounting periods ending later than 1 January 2005.

## 2.3 Theoretical framework

The theoretical background on evaluating R&D tax credit schemes is influenced by the literature on tax incentives for physical investment, which is based on the user cost of capital as a determinant of investment decisions, first formalized by Jorgenson (1963) and then developed by Hall and Jorgenson (1967). Both their theoretical finding and the empirical analysis point to a significant positive impact of tax credits and depreciation allowance schemes on the firm's capital intensity. Following Griliches (1979), 'R&D capital stock' or 'knowledge stock' can be considered analogously to the stock of physical capital, and it is possible to establish the same relationship between tax incentives and R&D capital (as in Bloom et al. (2002) and Mairesse and Mulkay (2011)). In this section, I focus on the static R&D spending decision of the firm and abstract away from adjustment costs and the long term accumulation of knowledge capital, so the model is solved as a static optimization problem, which depends on the firm's 'knowledge production ($R_t$)' in each period, using labour input (R&D headcount, $L_t$) and other expenses on R&D ($M_t$). The firm's optimization problem is therefore:

$$\max_{L_t \geq 0, M_t \geq 0} \Pi_t(L_t, M_t) \text{ subject to } F(L_t, M_t) = AL_t^{\alpha_L} M_t^{\alpha_M} \quad (1)$$

where the firm's net revenue function takes into account the taxes paid on corporate profits at rate $\tau$ and tax credits available for inputs into R&D at credit rate $c$. The net revenue function in period $t$ is:

$$\Pi_t(L_t, M_t) = (1-\tau)[p_t F(L_t, M_t) - w_t L_t - r_t M_t] + c(w_t L_t + r_t M_t) \quad (2)$$

Prices of R&D ($p_t$), labour ($w_t$) and other inputs ($r_t^M$) are set exogenously in competitive markets. Denoting the optimal labour, other inputs and R&D output by $L_t^*$, $M_t^*$ and $R_t^*$ respectively, the effects of an increase in the credit rate on total R&D spending and R&D headcount can be pinned down by:

$$\frac{\partial L_t^*}{\partial c} = \frac{1}{(1-\alpha_L-\alpha_M)}(1-\tau)^{(1-\alpha_L-\alpha_M)}(1-\tau+c)^{\frac{\alpha_L+\alpha_M}{(1-\alpha_L-\alpha_M)}}\kappa_L \tag{3}$$

$$\frac{\partial M_t^*}{\partial c} = \frac{1}{(1-\alpha_L-\alpha_M)}(1-\tau)^{(1-\alpha_L-\alpha_M)}(1-\tau+c)^{\frac{\alpha_L+\alpha_M}{(1-\alpha_L-\alpha_M)}}\kappa_M \tag{4}$$

$$\frac{\partial R_t^*}{\partial c} = \frac{\alpha_L+\alpha_M}{(1-\alpha_L-\alpha_M)}(1-\tau)^{(1-\alpha_L-\alpha_M)}(1-\tau+c)^{\frac{-1}{(1-\alpha_L-\alpha_M)}}\kappa_R \tag{5}$$

where $\kappa_i$ are constants for $i \in \{K, L, R\}$, given input and output prices are set in competitive markets. Assuming decreasing returns to scale in the 'production of knowledge', the partial derivatives in Equations 3-5 are always positive. Therefore, an increase in the tax credit rate would be expected to increase the R&D spending by increasing the R&D headcount in a competitive labour market for R&D employees and the amount of other inputs. The empirical specifications in Section 4 can be thought of as estimating the log-linearized version of the factor demand equations derived in this model, with the term that captures taxes and tax credits represented by a dummy variable in a difference-in-differences specification.

In this simple standard model, in response to an increase in the rate of tax credits for R&D, we expect to observe an immediate increase in R&D headcount, materials spending and knowledge production. The assumptions of this framework, such as decreasing returns to scale in knowledge production, and exogenous price setting in competitive input and output markets, are also useful for illustrating the potential reasons why we may expect different responses to increased generosity of tax incentives. For example, if R&D employees have some bargaining power over their compensation, we may then observe a setting where $w_t$ increases in response to an increase in $c$, and this may affect $R_t$ without increasing the R&D headcount. In Sections 5 and 7, I explore the effects of an increase in the rate of R&D tax credits on total R&D spending of a firm, as well as its R&D headcount. The empirical specifications in this paper are influenced by a simple model as the one depicted in this section; however, the quasi-experimental research design is not reliant on any particular theoretical model.

# 3 Data

## 3.1 Available data sources

The Business Enterprise Research and Development (BERD) survey is conducted by the ONS, with the purpose of collecting the aggregate and sectoral UK BERD statistics. The micro level BERD data has recently become available under secure conditions for approved research projects.

ONS follows the Frascati Manual (OECD (2002)) methodology to collect the statistics on Business Enterprise Research and Development. The sampling frame for this data uses the Annual Business Survey (ABS) as its major source to identify R&D performing firms that employ more than 50 employees. Other main data sources to identify firms which perform R&D include the UK Innovation Survey, new R&D sector firms from the business register (Business Structure Database; BSD), information from the Department for Business, Innovation and Skills (BIS), International Trade in Services R&D Exporters data and HMRC data on firms which claim R&D tax credits. ONS uses stratified sampling to select the enterprises which will receive a BERD questionnaire form each year. All questionnaire forms include at least questions on total R&D spending (in-house and contract R&D) and R&D employment. The micro BERD data set contains all the reporting unit-year observations that were identified by the ONS as performing R&D in a given year. The observations that are left outside of the stratified sampling have imputed values for the questions that are not answered, using the mean values of the variable as a share of employment in the size band-sector cell. To avoid introducing measurement error, I do not use these imputed values. Further information is presented in Appendix A and in Guceri (2015).[7] I merge the micro level BERD data set with the other relevant ONS data sets; the ABS and the BSD to obtain firm-level characteristics used as controls in this study.

The large company scheme was introduced in the 2002 fiscal year, with 2003 as the first full calendar year of implementation. In 2013, a new tax

[7]From Centre for Business Taxation Working Paper 15/11, which provides the basis of this paper.

credit was introduced for large companies, along with the Patent Box regime, rendering an estimation sample that is unaffected by other changes than the 2008 policy reform to cover the period 2003-2012.[8].

Real expenditures on R&D is obtained by deflating the nominal intramural R&D expenditure from the BERD dataset using a weighted deflator with 50 percent weight on researcher salaries and 50 percent weight on the GDP deflator. Intramural R&D here means the in-house R&D carried out by the company by its own employees. The researcher salaries component of the weighted deflator is taken from the Annual Survey of Hours and Earnings (ASHE) tables on gross annual pay for science and technology professionals (Table code 2.7a, job code 21). The GDP deflator is obtained from the OECD Economic Outlook 'pgdp' series (base year 2008). In the R&D literature, this kind of weighted deflator is commonly used to reflect the fact that around 50 percent of R&D investment goes to the salaries and wages of research staff (see, for instance, Bloom et al. (2002)). Data on employment is obtained from the BSD.

## 3.2 Characteristics of treated and control groups

I select treatment and control groups based on the threshold for eligibility to the SME Tax Relief. The BSD contains information on ownership, employment and turnover at the company group level for all UK companies, and no information on asset size.[9] The binding threshold to determine eligibility to the SME scheme is the employment threshold, subject to limitations on ownership by larger groups.[10] I use the group-level employment to identify eligibility and 'intent to treat' with the help of the information in the business register (BSD). Before merging the employment information to the reporting unit-level

[8] The datasets used in this study were made available by the Office for National Statistics (ONS) and the Secure Data Service (SDS).

[9] Turnover information is sourced by the VAT records and this is only available for firms that are above the VAT registration thresholds.

[10] For example, an enterprise may itself have 200 employees, and satisfy one of the turnover or the asset size thresholds. Then the group level check involves aggregating the employment numbers of each member in the whole group and then assessing whether the group as a whole remains below the thresholds.

R&D data, I aggregate employment over enterprise groups in the BSD to check whether each reporting unit satisfies the group-level employment thresholds.

The treatment group is composed of companies that: (i) belong to enterprise groups with more than 250 employees in the pre-2008 period and hence are considered 'large' for the purpose of the R&D tax relief, and (ii) belong to enterprise groups with fewer than 500 employees in the post-2008 period and hence are considered 'SME' for the purpose of the R&D tax relief. The control group is composed of companies that: (i) belong to enterprise groups with more than 250 employees in the pre-2008 period, and (ii) belong to enterprise groups with more than 500 employees in the post-2008 period, and hence are considered as 'large' both before and after the reform. I require that the companies appear in the BERD dataset with non-imputed R&D at least once before and once after the reform, and therefore this study explores the effects at the intensive margin. It is possible to restrict the size of the reporting units in the control group to make the size distribution more comparable to the treated group. I present descriptive statistics and results based on a control group sample which removes all observations on a reporting unit if, in the pre-reform period, it belonged to the top percentile in the size (employment) distribution, along with a sample based on a propensity score matching procedure.

The reporting period for BERD is the calendar year.[11] The definition change for determining an SME was introduced in August 2008, which is eight months into calendar year 2008. I therefore ignore each firm's status in 2008 for the purposes of both the allocation into treated and control groups and also in the estimation stage when evaluating the response to the policy.

The full sample then contains a panel of non-imputed observations of BERD variables on medium-sized and large companies. The sample contains 117 unique treated firms and 799 control firms.

More than 80 percent of total R&D activity in the UK is carried out by

[11] If the reporting unit does not have the record covering the calendar year, for instance year $t$, then the record for a business year that ends between April 6th of period $t$ and April 5th of period $t+1$ is reported for the expenditure in year $t$.

firms that have more than 250 employees. The empirical strategy of this paper relies on the performance of medium sized enterprises relative to larger enterprises that are otherwise similar according to their observable characteristics. Within the universe of non-imputed observations, in a representative year[12], around 42 percent of observations had more than 250 employees, representing more than 80 percent of total R&D.

[Figure 3 here]

[Figure 4 here]

The sectoral compositions of medium-sized and large firms between pre- and post-treatment periods are roughly similar, as can be observed in Figure 3 and Figure 4. In the figures, the blue line represents reporting units that belong to medium sized firms and the red line represents reporting units that belong to larger firms with 500-1000 employees. In Figure 3, I present the pre-treatment period shares of observations in each of the sectors for medium-sized and then large firms.[13] Figure 4 traces the changes in the sectoral compositions between pre- and post-treatment periods across the two groups, and apart from the 'Food' sector, the changes between pre- and post-treatment periods in the number of observations seem to have the same sign between the medium sized and large groups.

In Figure 5, I present the trends in real R&D spending by the average reporting unit in the treated and control groups. By nature, large companies are bigger and spend more on R&D than medium sized firms. I present the mean R&D spending series for large companies in ten thousands, and the mean R&D spending for treated firms in thousands (both in real GBP with 2008 as the base year). The two groups follow roughly similar trends, with both groups experiencing higher levels of spending in the 2009-2012 period.

[12] Year 2007

[13] The medium-sized and large firm groups that are presented in these figures are broader than the treated and control group samples used in the regressions. In the final regression samples, the number of observations in a few sectors fall below the ONS disclosure thresholds and therefore I present these statistics in the larger samples, which provide a similar picture as the treated and control groups in the final regressions.

[Figure 5 here]

The number of R&D employees is another variable of interest, and the R&D headcount data is available for all observations in BERD data for which there is non-imputed information. Since BSD data provides total employment information for all enterprises, it is possible to trace the evolution of the share of R&D employees in total workforce of enterprises (Figure 6). This metric is scaled by total firm size, and therefore we do not observe a substantial difference between the levels of the share of R&D workers in total employment across treated and control groups. Possibly because of the smaller number of treated observations relative to control observations, the mean of the share of R&D employees in total fluctuates more for the treated group than for the control group.

[Figure 6 here]

# 4 Empirical approach

As the difference-in-difference specification, I estimate the following base model:

$$r_{it} = \gamma + \delta_I D_i T_t + \delta_T T_t + \mathbf{x'}_{it} \beta_x + \eta_i + \nu_{it} \tag{6}$$

where $r_{it}$ is the natural logarithm of R&D spending of reporting unit $i$ in year $t$ in 2008 prices, $D_i$ is a dummy that takes on a value of 1 for treated observations, 0 for the control group, $T_t$ is a dummy that takes on a value of 1 for post-2008 and 0 otherwise. The coefficient $\delta_I$ on the interaction term $D_i T_t$ thus captures any differential change in $r_{it}$ between the pre- and post-2008 periods for the treatment group compared to the control group, and the null hypothesis of no impact of the introduction of more generous tax incentives for larger firms corresponds to $\delta_I = 0$. $\eta_i$ are reporting unit fixed effects. I later drop $T_t$ and include a full set of year dummies. $\mathbf{x}_{it}$ is a $K \times 1$ vector of controls, which, in different sets of results, include sector dummies, year dummies, lagged employment, employment growth rates and a quadratic term for lagged level of employment.

Identification with the difference-in-differences estimator requires that the common trends assumption be satisfied, that is, in the absence of treatment, we should expect the change in the outcome variable between pre- and post-intervention periods for the control group to be similar to the change in the outcome variable for the treatment group. In Section 5, I present results from regressions with placebo reforms in earlier years than the policy change to verify that there are no significant differential trends between treated and control groups in other years than the treatment year.

The control group has a larger number of observations than the treated group. We may wish to improve on the similarities between the treated and control groups, while exploiting the panel structure of the data. In Section 6, following Heckman et al. (1997), Heckman et al. (1998) and Heckman et al. (1998), I consider a difference-in-difference matching estimator. Difference-in-difference (diff-in-diff) matching pairs treated observations with control observations based on observable characteristics $\mathbf{x}$. Differently from the cross-section propensity score matching, the diff-in-diff matching estimator evaluates the average treatment effect on the treated based on the changes in the outcome variable between the pre- and the post-treatment periods.

The observed characteristics $X$ on which to match treated and control firms should not be influenced by treatment, therefore, I estimate the propensity scores based on pre-reform average characteristics. Each of the treated firms is matched with a control firm (which are drawn with replacement), using propensity scores estimated based on the firms' pre-reform average values for employment growth rate (natural logarithm), age (natural logarithm), the foreign ownership indicator and an indicator variable for high tech firms based on the OECD sector classifications. Firm size measures such as employment and real turnover have a strong effect on determining assignment to treatment, however, these variables cannot be used in the matching process as they result in matched pairs that are far from satisfying the overlap assumption. Propensity scores are estimated using a logit. Table 1 presents the results of this 'first stage' logistic regression of the binary dummy variable 'treatment' on firms' pre-reform average characteristics.

[Table 1 here]

Based on these variables, the matched treatment group retains the original 117 firms, and because the control observations are selected with replacement based on their distance in their estimated propensity score from treated observations, a small subset of control observations get matched with more than one treated observation. 98 unique control firms are matched with a treated observation in the final sample.

In order to check the specification of the propensity score model, Table 2 presents comparisons between the means of treated and control groups. The first column lists the variables used for matching in the preferred specification. The third and the fourth columns present the means of the variables, followed by the t-statistics for the test of equal means between treated and control, and then the fourth column presents the p-value for the test. For the matched sample, on average, there does not seem to be significant differences between the treated and control observations. Figure 7 presents the distribution of estimated propensity scores for the treated and control groups. Violations of the overlap assumption can be detected if the treated and control groups have large masses in the distributions at opposite ends of the scale, which is not the case in Figure 7.

[Table 2 here]

[Figure 7 here]

# 5 Results

Using two methods, diff-in-diff regression and matching diff-in-diff, I find broadly similar results that point at an increase in R&D spending at the firm level by treated companies. Table 3 presents the diff-in-diff regression results from the largest possible sample in Columns (1)-(5), then in Column (6)-(10), I refine the control group by removing all observations on reporting units which fall in the largest category in terms of their pre-treatment period average employment levels. Columns (1) and (6) present estimates from the model in Equation 6 without any controls. The positive effect of the policy is captured by the coefficient labeled 'Interaction' (diff-in-diff), but it is statistically insignificant at conventional levels without controlling for the firm size. In Columns (2) and (7), the 'Post 2008' dummy is replaced by year fixed effects and two digit sector dummies are also included in the model. In Columns (3) and (8), I include controls for the size of the firm, and the diff-in-diff coefficient becomes significant at the 10 percent level. Firm size and growth rate variables are all lagged by one period to avoid potential issues due to the simultaneous determination of total employment and R&D spending. In Columns (4) and (9), I include a control for the lagged growth rate of the firm, which turns out to be a significant control variable, and drives the magnitude of the diff-in-diff coefficient upward by 2 percentage points. Finally, in Columns (5) and (10), I add the full set of control variables including a quadratic term for the firm size measure. In the preferred specification (estimated in Columns (5) and (10)), the diff-in-diff estimates indicate a positive and significant effect of the policy on treated firms, with a magnitude of around 20 percent.

[Table 3 here]

# 6 Robustness

## 6.1 Placebo tests

Identification using the diff-in-diff method requires that in the absence of the policy intervention, the treated and control group outcomes follow similar trends. I test this assumption using placebo interventions in the pre-treatment periods. These are presented in Table 4. In each of these years, using the preferred specification, no significant differential change in any of the pre-reform periods has been found, supporting that the common trends assumption has not been violated in the pre-treatment years.

[Table 4 here]

### 6.2 Matching

Understandably, the inclusion of size controls is important for detecting the differential effect of the policy on the treated group of firms. As the next step, I implement matching diff-in-diff to obtain more comparable treatment and control groups. The matching process is as described in detail in Section 4. In Table 5, Column (1) presents results from propensity score matching on pre-treatment average values of age (natural log), enterprise level employment growth rate (natural log) and the foreign ownership indicator. In Column (2), the set of variables used in the matching process additionally includes an indicator for a 'high technology firm' following the OECD technology classification of sectors. The standard errors that I present in Table 5 are calculated following Abadie and Imbens (2006). The two matching procedures find an effect of the policy of 27 percent and 41 percent, respectively. Despite the 14 percentage point difference between the two point estimates, it is difficult to argue that these two coefficients are statistically different from each other, as they are estimated with large standard errors.

[Table 5 here]

### 6.3 Did the reform come as a surprise?

One question in a policy setting where the announcement of the policy predates implementation is whether beneficiaries adjust their investment behaviour after the announcement but prior to implementation of the policy. In the case of the R&D Tax Relief schemes in the UK, the Chancellor announced the Government's intention to introduce the policy reform in the prior year's Budget before the reform took place, but enactment required EU State Aid clearance and implementation was at best uncertain from the perspective of potential beneficiaries. In this section, I present results from regressions which remove the years after the Chancellor's announcement prior to the reform, and the first period after reform.

The simplest way of assessing whether there has been any strategic delaying is to omit all the periods between announcement and the first period of implementation. Omission of the years 2007 and 2008 achieves this objective (Table 6). In Table 7, I further remove 2009. In both Tables 6 and 7, regressions in Columns (1)-(5) use all the observations and Columns (6)-(10) exclude the firms that fall in the top percentile of the size distribution according to their pre-treatment average employment. The estimated impact of the introduction of the more generous tax relief for larger firms remains very similar to that obtained using the full sample, suggesting an increase in R&D by around 18-19 percent. The smaller sample size results in a marginal reduction in the statistical significance of the estimated coefficient on the diff-in-diff interaction term, but there is no indication that our full sample results are seriously biased by firms postponing R&D expenditure until after the introduction of the change in the eligibility criteria in August 2008. In these robustness checks, the point estimate remains very close to the original estimates presented in Table 3.

[Table 6 here]

[Table 7 here]

# 7 Mechanisms and discussion

Next, I explore the mechanisms that drive the increase in R&D spending. First, I examine the effect of the policy on the R&D employment of the treated companies. Goolsbee (1998) argues that, due to the inelastic supply of scientists and researchers, R&D subsidies only boost the salaries of researchers instead of driving firms to take on new R&D projects and therefore increase their R&D efforts. If companies responded to the tax relief by increasing their R&D headcount, this would provide evidence to counter Goolsbee's critique. Because R&D employment is a count variable, I use a Poisson regression approach with reporting unit fixed effects to evaluate the impact of the reform on the R&D headcount. Table 8 presents the results from the Poisson regressions with R&D employment as the dependent variable. As before, Columns (1)-(5) present the diff-in-diff regression results from the largest possible sample, then in Columns (6)-(10), the control group is refined by removing all observations on reporting units which fall in the largest category in terms of their pre-treatment period average employment levels. The results presented in this table does not offer sufficiently strong evidence for or against Goolsbee (1998)'s critique. There is some indication of a positive effect of the policy on the R&D headcount, but none of the diff-in-diff results in Table 8 is statistically significant.[14] Regarding the effect on salaries, the short form BERD questionnaire does not ask any question on salaries, and restricting the sample to long form recipients reduces the sample size substantially.[15]

[Table 8 here]

Finally, I test the impact of the policy change on firms' spending on 'extramural R&D', which includes R&D that is subcontracted to external parties by the firm. There is a small number of firms that report positive extramural R&D in the survey, and perhaps unsurprisingly, I do not find any significant effect of the reform on this variable.

The UK R&D tax incentive scheme has gradually become more generous, now with more than £1 billion cost to the Exchequer in foregone corporation tax revenue annually. The findings of this paper suggest that the reform in the R&D tax relief that changed the status of the enterprises in the treatment group from 'large' to 'SME' caused these firms to increase their R&D spending by more than 20 percent. Based on matching diff-in-diff, the point estimates may go up to about 41 percent, although it is important to acknowledge that there is a large overlap between the confidence intervals of these estimates. In

[14] The results in the estimation of models without reporting unit fixed effects with standard errors clustered at the reporting unit level result in highly significant positive estimates of the effect of the policy on R&D headcount.

[15] I separately estimate the effect of the policy change on R&D employment using matching diff-in-diff. The point estimates are positive but have large standard errors and therefore it is not possible to detect any effect of the policy on the R&D headcount of treated firms using this methodology.

Guceri and Liu (2015), we estimated that the drop in the user cost of R&D capital for the treated group of firms thanks to the 2008 reform of the SME tax relief eligibility criteria was around 17 percent.[16]

From the diff-in-diff point estimate of 20 percent, one can back out the elasticity of R&D with respect to its user cost, based on the finding that the introduction of the change in the SME scheme eligibility criteria resulted in a reduction in the user cost of R&D by about 17 percent in the UK. The 20 percent increase in spending therefore corresponds to a user cost elasticity estimate of about -1.18. Using the BERD dataset, it is not clear whether the increase in R&D spending is attributable to an increase in R&D headcount, or higher salaries for R&D personnel.

Based on the estimated additionality effect of the policy of 20 percent and the corresponding cost of the R&D tax relief to HMRC, it is possible to calculate an estimate for the return for every pound of HMRC's foregone corporation tax revenue. The reform increased the burden of each unit of a medium sized firm's R&D on the Exchequer from $0.30 \times \tau$ to $0.75 \times \tau$, where $\tau$ is the statutory tax rate that applied to each firm.[17] In addition to this extra cost per unit of R&D, treated firms increase their R&D spending by about 20 percent in response to the policy reform, and hence the cost to the Exchequer increases indirectly as well. For a firm that pays taxes at the main rate of 28 percent in the 2008-2010 period, every £1 R&D generated by the policy reform of 20 percent results in HMRC to forego £0.23 of tax revenue. Similarly, for a firm that pays taxes at the small profits rate of 21 percent, after the reform, HMRC loses £0.17 of tax revenue due to the reclassification of treated firms as SME and not large for the purpose of the R&D tax relief. These two estimates result in an estimated bang-for-the-buck ranging between £0.9 and £1.2. Based on the simple calculation without considering any spillovers that

[16]In Guceri and Liu (2015), we are able to observe the precise tax positions of each company and therefore can estimate the reduction in the user cost of R&D capital.

[17]The calculation assumes away the firm specific discounting of losses carried forward and the value of cash claims. The calculation can be thought of as one where all the firms pay taxes, at least at the small profits rate. I also assume that R&D that qualifies for the R&D tax relief increased by the same amount as estimated in this paper.

may be generated by the policy, the results suggest that the Exchequer recovers its cost.

Do the firms relabel their non-R&D employees as researchers in this context? In the BERD survey, firms should not have an incentive to lie about their R&D spending, as they are informed that their responses in the BERD survey cannot be matched with their tax returns. To the extent that firms keep their R&D records for the purpose of responding to ONS's BERD Survey separate from their records of qualifying R&D for the purpose of reporting to the HMRC to claim R&D tax relief, we should not expect to observe relabeling of ordinary spending as R&D in the BERD data.

# 8 Conclusion

The number of countries which offer R&D tax incentives to stimulate business R&D spending has been increasing rapidly in the past few decades. After a long period of relative decline in aggregate R&D intensity, the UK joined the group of countries which offer generous fiscal incentives for R&D in 2000. The first reform in 2000 was the introduction of the SME Tax Relief Scheme, followed by the introduction of the large company scheme in 2002, which was less generous than the SME scheme. In 2008, the definition of an 'SME' for the purpose of the R&D Tax Relief expanded to include a group of medium sized companies with up to 500 employees. In this study, I exploited the reduction in the user cost of R&D for medium sized companies in comparison to their slightly larger counterparts to obtain difference-in-differences and matching (with diff-in-diff) estimates of the impact of R&D tax incentives.

Tax credits have a direct effect on the firms' cost of investing in R&D. Motivated by a simple neoclassical theoretical framework, the empirical specifications in this paper examined the effects of the change in the eligibility thresholds to the SME tax relief scheme on R&D spending and on R&D per worker at the enterprise level.

Controlling for firm size and growth using firm-level employment information from the business register, I have found that treatment group companies which started to benefit from the SME scheme after the 2008-09 fiscal year increased their R&D spending by around 20 percent in comparison to the control group after the introduction of the policy. The robust estimate of the 20 percent increase over the counterfactual scenario of less generous tax credits for treated firms translates to an elasticity of R&D with respect to its user cost of around -1.18. The corresponding bang-for-the-buck estimates of £0.9-£1.2 suggest that the tax authority roughly recovers its additional cost of implementing the new policy.

The BERD survey does not give any incentives to its respondents to relabel ordinary spending as R&D. I therefore argue that, differently from the studies that use administrative data, there is no reason for the magnitude of the effect found in this study be affected by concerns related to relabeling.

I find some evidence of an increase in R&D headcount in response to the policy, but the effect is weaker than for overall spending in R&D. Therefore, if the policymakers are interested in scaling up a certain type of spending within business R&D, in the policy design, they may consider differentiating between R&D spending items such as headcount, salaries or materials.

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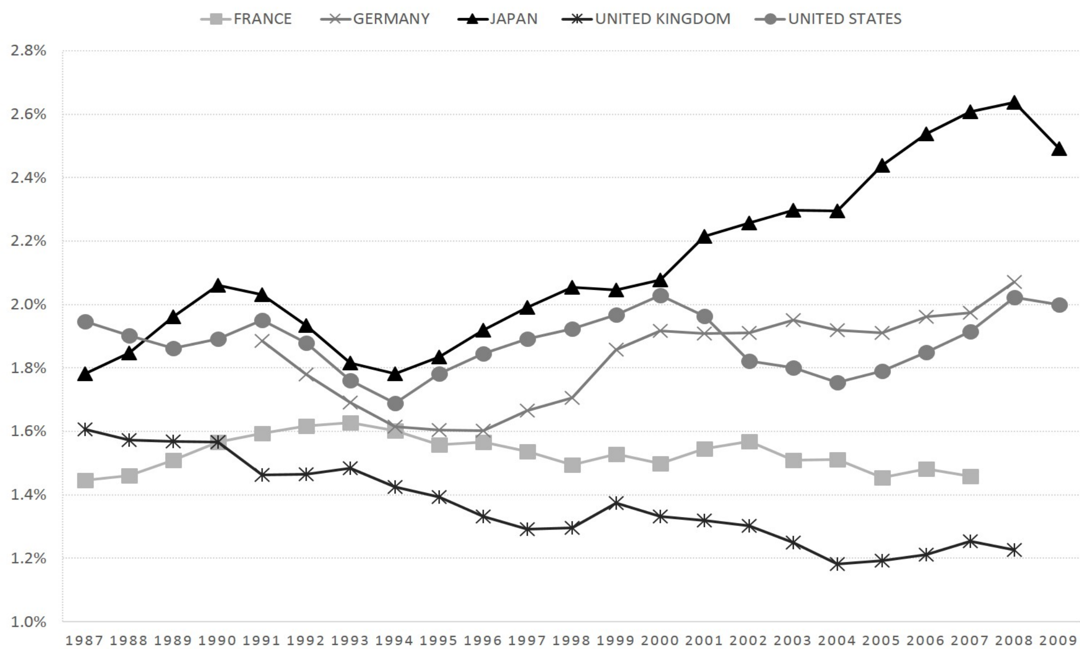
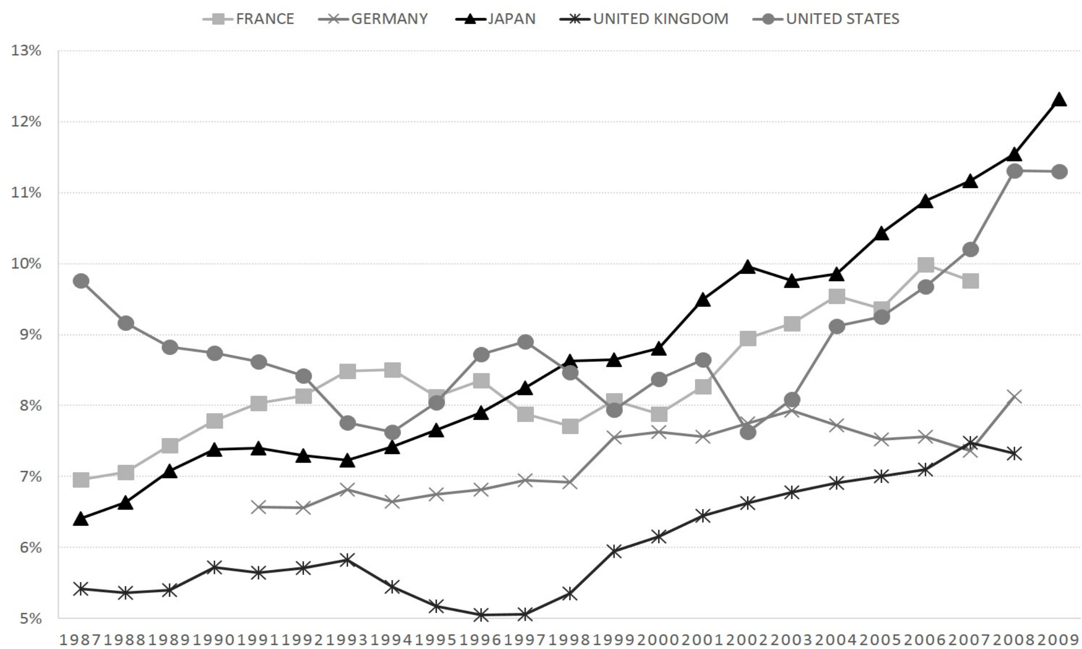
Figure 1: Total BERD intensity, UK and comparators




Source: OECD

Figure 2: Manufacturing sector BERD intensity, UK and comparators




Source: OECD

Figure 3: Sectoral distribution of medium-sized and large companies in the pre-treatment period, non-imputed observations

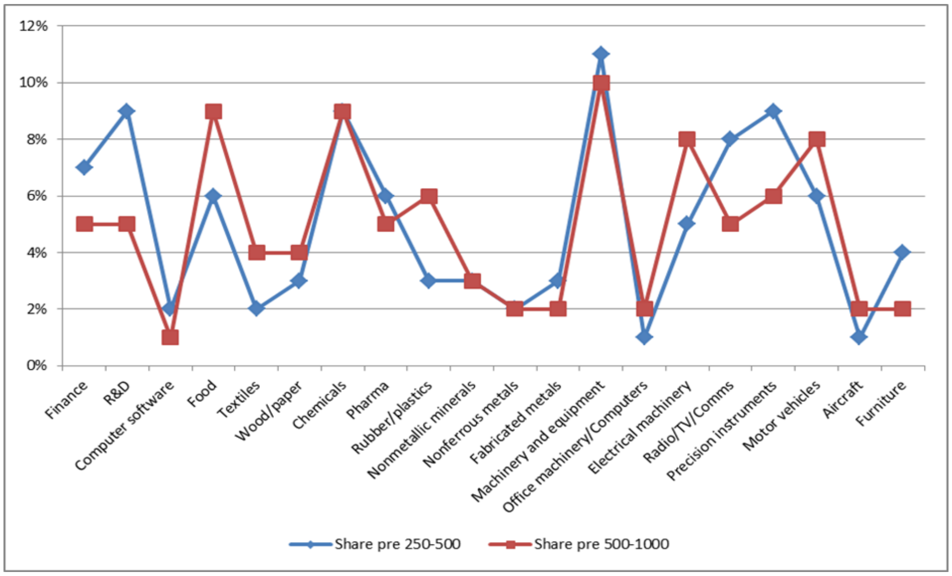



Figure 4: Change in the sectoral distribution of medium-sized and large companies in the post-treatment period, non-imputed observations

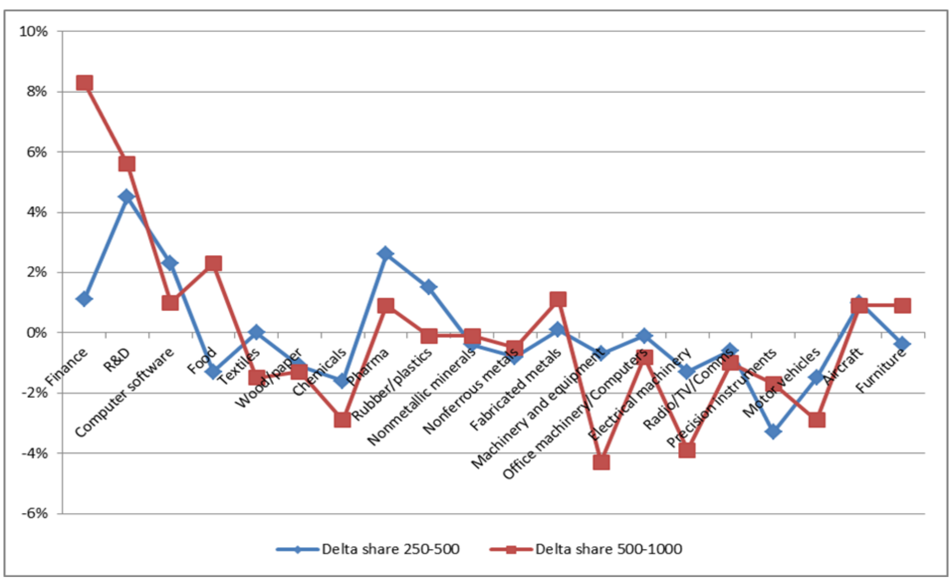


Figure 5: Average real R&D spending, treated and control groups

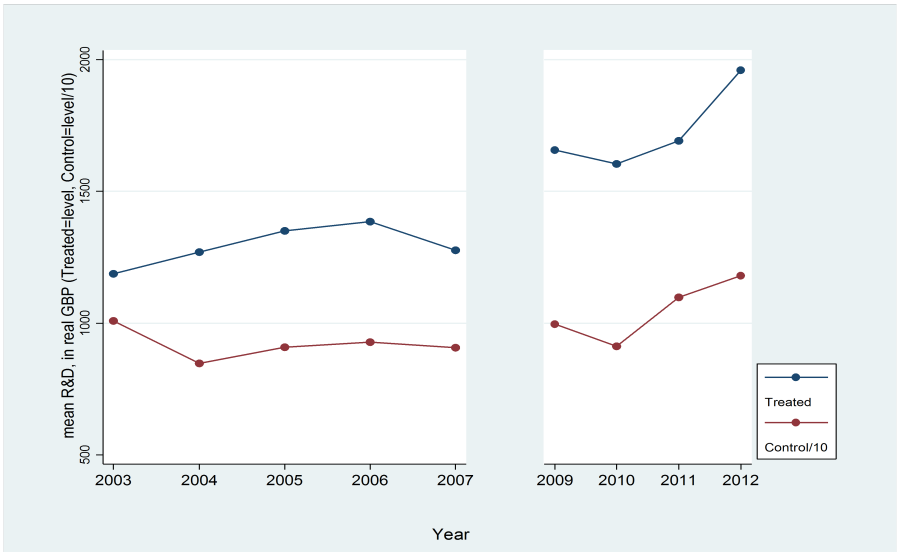



Figure 6: Share of R&D employees in group level employment, treated and control groups

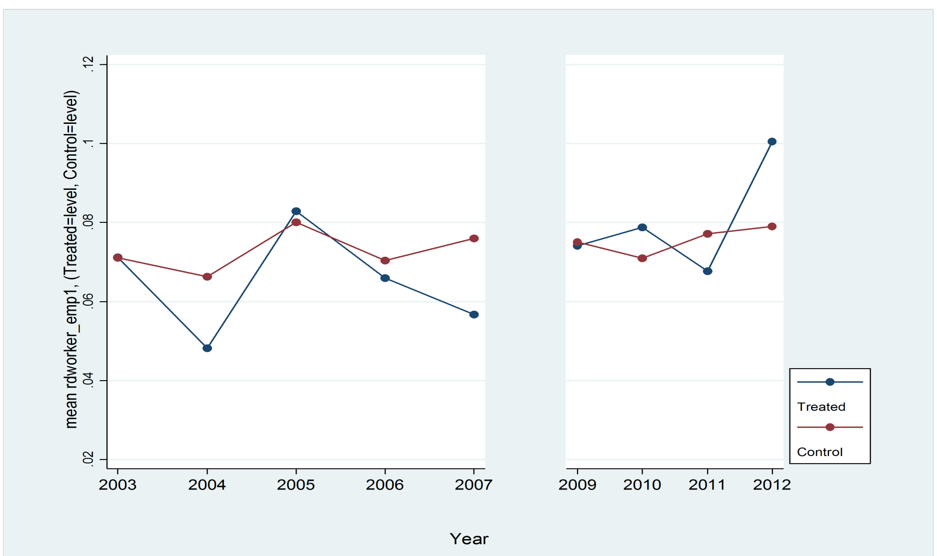


Figure 7: Density of estimated propensity scores, treated and control groups

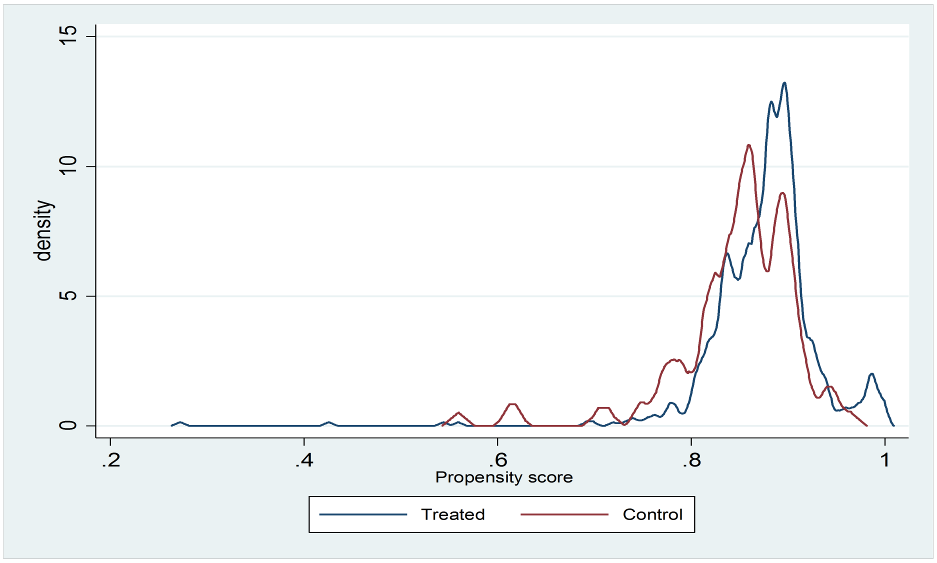


Table 1: Determinants of assignment to treatment

| Outcome: Treatment | (1) | (2) |
|---|---|---|
| ln(employment growth rate) | -2.469*** | -2.514*** |
| (pre-reform) | (0.631) | (0.634) |
| ln(age) | -0.724** | -0.760** |
| (pre-reform) | (0.330) | (0.328) |
| OECD high tech dummy | 0.222 | |
| | (0.215) | |
| Foreign ownership† | suppressed | suppressed |
| (pre-reform) | (insig.) | (insig.) |
| No of obs | 914 | 914 |
| Treated no of firms | 117 | 117 |
| Control no of firms | 799 | 799 |

†According to Secure Lab requirements, at least one coefficient in each table needs to be suppressed

Table 2: Balancing tests

| Variable (pre-reform avg.) | Sample | Treated | Control | t-stat | p-val. | Cell count |
|---|---|---|---|---|---|---|
| ln(emp.growth) | Matched | -0.03964 | -0.04834 | 0.38 | 0.707 | 98 |
| ln(age) | Matched | 3.3754 | 3.3936 | -0.49 | 0.625 | 98 |
| OECD high tech ind. | Matched | 0.65812 | 0.64103 | 0.27 | 0.785 | 98 |
| Foreign ownership | Matched | 0.52137 | 0.45299 | 1.04 | 0.297 | 98 |

Table 3: Difference-in-difference regression results

| Outcome: ln(Real R&D) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Post2008 | 0.006 | | | | | 0.013 | | | | |
| | (0.030) | | | | | (0.031) | | | | |
| Interaction | 0.105 | 0.104 | 0.165* | 0.180* | 0.209** | 0.099 | 0.099 | 0.162 | 0.177* | 0.203* |
| | (0.097) | (0.098) | (0.098) | (0.099) | (0.105) | (0.097) | (0.098) | (0.099) | (0.100) | (0.105) |
| Group level employment | | | 0.121*** | 0.148*** | 0.411 | | | 0.122*** | 0.148*** | 0.405 |
| (in logs, lagged) | | | (0.025) | (0.027) | (0.264) | | | (0.025) | (0.027) | (0.281) |
| Growth of group empl. | | | | -0.069*** | -0.069*** | | | | -0.066*** | -0.066*** |
| (in logs, lagged) | | | | (0.019) | (0.019) | | | | (0.019) | (0.019) |
| Group level employment | | | | | -0.018 | | | | | -0.017 |
| (in logs, lagged, squared) | | | | | (0.017) | | | | | (0.018) |
| Rep.unit fixed effects | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Sector effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Year effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| R-squared | 0.001 | 0.019 | 0.03 | 0.033 | 0.034 | 0.001 | 0.017 | 0.029 | 0.032 | 0.033 |
| No of observations | 5434 | 5434 | 5434 | 5434 | 5434 | 5005 | 5005 | 5005 | 5005 | 5005 |
| Treated no of unique firms | 117 | 117 | 117 | 117 | 117 | 117 | 117 | 117 | 117 | 117 |
| Control no of unique firms | 799 | 799 | 799 | 799 | 799 | 738 | 738 | 738 | 738 | 738 |

Standard errors are clustered at the reporting unit level.

Table 4: Results from placebo interventions in the pre-treatment period

| Outcome: ln(Real R&D) | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Interaction2004 | 0.079 | | | |
| | (0.109) | | | |
| Interaction2005 | | 0.106 | | |
| | | (0.109) | | |
| Interaction2006 | | | 0.129 | |
| | | | (0.104) | |
| Interaction2007 | | | | 0.137 |
| | | | | (0.100) |
| Group level employment | 0.351 | 0.361 | 0.369 | 0.376 |
| (in logs, lagged) | (0.259) | (0.263) | (0.266) | (0.269) |
| Growth of group empl. | -0.062*** | -0.064*** | -0.064*** | -0.065*** |
| (in logs, lagged) | (0.019) | (0.019) | (0.019) | (0.019) |
| Group level employment | -0.014 | -0.015 | -0.015 | -0.016 |
| (in logs, lagged, squared) | (0.017) | (0.017) | (0.017) | (0.017) |
| Reporting unit fixed effects | Y | Y | Y | Y |
| Sector effects | Y | Y | Y | Y |
| Year effects | Y | Y | Y | Y |
| R-squared | 0.031 | 0.031 | 0.032 | 0.032 |
| No of observations | 5005 | 5005 | 5005 | 5005 |
| Treated no of unique firms | 117 | 117 | 117 | 117 |
| Control no of unique firms | 738 | 738 | 738 | 738 |

Standard errors are clustered at the reporting unit level.

Table 5: Matching difference-in-difference results

| | (1) | (2) |
|---|---|---|
| Outcome | ln(Real R&D) | ln(Real R&D) |
| Match var.s | foreign own.ind., ln(age), ln(emp. growth) | foreign own.ind., OECD high tech ind., ln(age), ln(emp. growth) |
| ATET | 0.269* | 0.406*** |
| Std. errors | (0.148) | (0.146) |
| Treated no of unique RU | 117 | 117 |
| Matched no of control RU | 98 | 98 |
| Total no of control RU | 799 | 799 |

Table 6: Robustness: Response to Early Announcement of the Policy – dropping 2007 and 2008

| Outcome: ln(Real R&D) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Post2008 | 0.024 | | | | | 0.037 | | | | |
| | (0.033) | | | | | (0.034) | | | | |
| Interaction | 0.073 | 0.083 | 0.145 | 0.157 | 0.188* | 0.061 | 0.072 | 0.137 | 0.149 | 0.178 |
| | (0.106) | (0.107) | (0.108) | (0.109) | (0.113) | (0.106) | (0.108) | (0.108) | (0.109) | (0.113) |
| Group level employment | | | 0.128*** | 0.149*** | 0.454* | | | 0.128*** | 0.148*** | 0.457* |
| (in logs, lagged) | | | (0.025) | (0.029) | (0.247) | | | (0.025) | (0.029) | (0.265) |
| Growth of group empl. | | | | -0.057*** | -0.056*** | | | | -0.054** | -0.052** |
| (in logs, lagged) | | | | (0.021) | (0.022) | | | | (0.022) | (0.022) |
| Group level employment | | | | | -0.021 | | | | | -0.021 |
| (in logs, lagged, squared) | | | | | (0.016) | | | | | (0.017) |
| Rep.unit fixed effects | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Sector effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Year effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| R-squared | 0.001 | 0.02 | 0.033 | 0.035 | 0.037 | 0.001 | 0.019 | 0.033 | 0.035 | 0.037 |
| No of observations | 4493 | 4493 | 4493 | 4493 | 4493 | 4136 | 4136 | 4136 | 4136 | 4136 |
| Treated no of unique firms | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 |
| Control no of unique firms | 718 | 718 | 718 | 718 | 718 | 662 | 662 | 662 | 662 | 662 |

Standard errors are clustered at the reporting unit level.

Table 7: Robustness: Response to Early Announcement of the Policy – dropping 2007, 2008 and 2009

| Outcome: ln(Real R&D) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Post2008 | 0.055 | | | | | 0.069* | | | | |
| | (0.037) | | | | | (0.038) | | | | |
| Interaction | 0.029 | 0.036 | 0.105 | 0.120 | 0.180 | 0.016 | 0.024 | 0.097 | 0.111 | 0.170 |
| | (0.124) | (0.125) | (0.126) | (0.127) | (0.128) | (0.124) | (0.125) | (0.126) | (0.128) | (0.128) |
| Group level employment | | | 0.147*** | 0.174*** | 0.715*** | | | 0.148*** | 0.174*** | 0.747*** |
| (in logs, lagged) | | | (0.027) | (0.031) | (0.142) | | | (0.027) | (0.031) | (0.148) |
| Growth of group empl. | | | | -0.075*** | -0.075*** | | | | -0.071*** | -0.070*** |
| (in logs, lagged) | | | | (0.024) | (0.024) | | | | (0.025) | (0.025) |
| Group level employment | | | | | -0.036*** | | | | | -0.039*** |
| (in logs, lagged, squared) | | | | | (0.009) | | | | | (0.010) |
| Rep.unit fixed effects | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Sector effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Year effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| R-squared | 0.002 | 0.024 | 0.04 | 0.043 | 0.048 | 0.003 | 0.024 | 0.042 | 0.045 | 0.051 |
| No of observations | 3695 | 3695 | 3695 | 3695 | 3695 | 3409 | 3409 | 3409 | 3409 | 3409 |
| Treated no of unique firms | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 |
| Control no of unique firms | 650 | 650 | 650 | 650 | 650 | 601 | 601 | 601 | 601 | 601 |

Standard errors are clustered at the reporting unit level.

Table 8: Difference-in-difference Poisson regression results – effect on R&D employment

| Outcome: R&D employment | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Post2008 | -0.080 | | | | | 0.015 | | | | |
| | (0.057) | | | | | (0.037) | | | | |
| Interaction | 0.130 | 0.136 | 0.141 | 0.141 | 0.141 | 0.036 | 0.053 | 0.050 | 0.050 | 0.049 |
| | (0.094) | (0.096) | (0.097) | (0.097) | (0.096) | (0.084) | (0.089) | (0.088) | (0.088) | (0.088) |
| Group level employment | | | -0.001 | -0.001 | 0.005 | | | 0.007** | 0.007** | 0.013** |
| (lagged) | | | (0.002) | (0.002) | (0.004) | | | (0.003) | (0.003) | (0.005) |
| Growth of group empl. | | | | 0.000 | 0.000 | | | | 0.000 | 0.000 |
| (lagged) | | | | 0.000 | 0.000 | | | | 0.000 | 0.000 |
| Group level employment | | | | | -0.000*** | | | | | -0.000* |
| (lagged, squared) | | | | | 0.000 | | | | | 0.000 |
| Firm fixed effects | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Sector effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| Year effects | N | Y | Y | Y | Y | N | Y | Y | Y | Y |
| No of observations | 5447 | 5447 | 5447 | 5447 | 5447 | 4987 | 4987 | 4987 | 4987 | 4987 |
| Treated no of unique firms | 119 | 119 | 119 | 119 | 119 | 117 | 117 | 117 | 117 | 117 |
| Control no of unique firms | 810 | 810 | 810 | 810 | 810 | 738 | 738 | 738 | 738 | 738 |

Heteroskedasticity robust standard errors.

# A Data appendix

BERD data is available at the 'reporting unit' level, which corresponds to the geographical unit that has the postal address of the firm. The reporting unit may or may not be larger than a 'local unit', therefore it may be larger than a single plant or a single R&D lab. It may be attached to the headquarters or can be a separate unit. A slightly larger statistical unit than the reporting unit is the 'enterprise', which is defined in the EU Regulation on Statistical Units (EEC 696/93) as "...an organizational unit producing goods or services, which benefits from a certain degree of autonomy in decision-making, especially for the allocation of its current resources...". BERD observations have the reporting unit as their identifier and most of them also contain the enterprise reference number.

An 'enterprise group' is defined as "an association of enterprises bound together by legal and/or financial links. A group of enterprises can have more than one decision-making centre [...]. It constitutes an economic entity which is empowered to make choices, particularly concerning the units which it comprises (EEC 696/93)". The definition of an enterprise group is important for our purposes, as assignment to the treatment group depends on whether the group as a whole satisfies the criteria for eligibility to the SME scheme. Reporting unit level R&D data in BERD is matched to the BSD at the enterprise level. BERD provides information on both the reporting unit and enterprise references for each observation.

The ONS constructs the BERD dataset using the responses to two types of questionnaire forms sent out to firms: a long form and a short form. About 400 largest spenders (those who spent more than £3 million in a reference year) on R&D receive a long form questionnaire, and the rest receive a short form questionnaire. This latter form contains a small set of questions tracing basic information, namely, the unit's: (i) in-house R&D expenditure, (ii) extramural R&D expenditure, (iii) full time equivalent number of R&D personnel, and (iv) total headcount on R&D. The long form collects a much wider set of variables, including a breakdown of R&D expenditure to product groups; capital and current expenditure, broken down into salaries and other current expenditure; sources of funding for R&D; a breakdown of the skills set for R&D employment; and a breakdown of R&D expenditure into geographic locations (UK postcodes). As smaller firms tend to spend less on R&D than larger firms, the information available on SMEs is mostly limited to the questions asked in the short form.

The group of smaller firms (as they are less likely to be among the top 400 spenders) are subject to sampling at different sampling fractions depending on their size measured by employment. Since the stratified sampling procedure is repeated every year, this causes gaps in the time series data. Based on the publicly available BERD First Release data[18], the breakdown of participants to BERD Inquiry into long and short form recipients is around 4000 sampled firms, out of which around 400 are sent a long form and the rest are sent a short form. Out of the firms which receive short forms, all those with more than 400 employees are sampled. Within the size band of interest, there are firms with 250-400 employees, for which the sampling ratio is 1:3.[19] The smallest firms, that is, those with fewer than 100 employees are sampled with a 1:4 ratio.

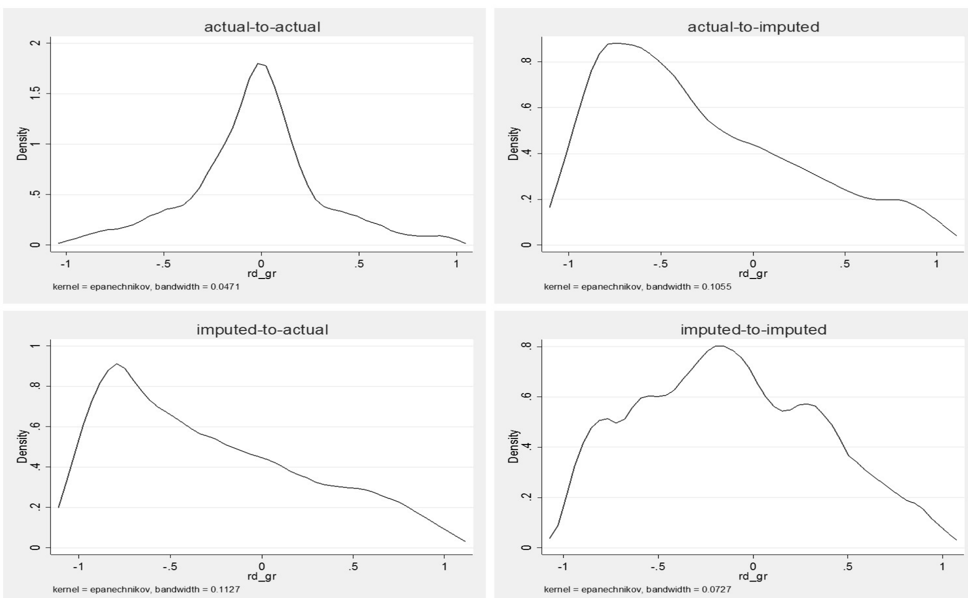
When aggregating the data for the BERD publication, the ONS imputes the values for the unsampled firms based on their employment number and product group. In each of the 99 product group-size band 'cells' available (33 product groups over 3 size bands), the values for the unsampled observations are imputed using the average R&D per worker value of those observations which are not imputed, with employment as the scaling variable. For instance, if an unsampled firm in sector H (Pharmaceuticals) and size band 2 (100-400 employees) has "$x$" employees (this information is available through the IDBR for all firms), their unknown in-house R&D spending is imputed as the mean R&D per worker in that cell multiplied by the employment number "$x$" of the observation. This imputation procedure introduces a high level of variation across years for a given reporting unit when the micro panel version of the data set is used. The variance of the growth rate in R&D spending from

[18]Until 2007, this publication was part of the MA14 Business Monitor.

[19]Firms with 100-400 employees are sampled with this ratio.

one year to the next increases significantly between two years of data when these are imputed, and also when one of the two values is imputed. Figure 8 is taken from an earlier working paper on this topic (Guceri (2015)), and demonstrates the uneven distribution of changes in R&D over time when the observation moves from an actual value to an imputed value and vice versa. The distribution of R&D growth rates is a smooth bell shaped curve only for those observations which move from an actual value to another year's actual value.

Figure 8: Kernel density estimates for y-o-y real growth in R&D, size band 100-399



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