Oxford University Centre for Business Taxation

Tax incentives and R&D: an evaluation of the 2002 UK reform using micro data

August 2015

WP15/11

Irem Guceri
Oxford University Centre for Business Taxation

Working paper series | 2015

SAID BUSINESS SCHOOL
UNIVERSITY OF OXFORD

Tax incentives and R&D: an evaluation of the 2002 UK reform using micro data

Irem Guceri*

Abstract

The United Kingdom introduced an R&D tax incentive scheme first for SMEs in 2000 and then for large firms in 2002, gradually increasing the generosity of both schemes after 2008. This study exploits the differences between companies with similar characteristics that were just above the size threshold for eligibility to the SME scheme and those that were just below, before and after the 2002 reform. This allows for a difference-in-differences approach to measure the (additional) impact of the tax incentives on firms around this size threshold. Treatment group firms are found to have increased their R&D spending by around 18 percent on average in response to the large company tax incentive, implying a user cost elasticity of -1.35. We do not find significant differences in this effect between sectors.

JEL Classification: H25, O31

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

*Department of Economics, St.Peter's College and Centre for Business Taxation, University of Oxford. The author thanks Stephen R. Bond, Michael Devereux, Simon Quinn and Li Liu for valuable comments, the Office for National Statistics and Secure Data Service (UK Data Archive) for providing the data. The author is grateful for the financial support from Argela through the doctoral studentship agreement between Oxford University and Argela. All errors are the responsibility of the author. Contact: irem.guceri@economics.ox.ac.uk.

Contents

1 Introduction

Private returns to knowledge production have been shown to fall short of its social returns in the pioneering work of Arrow (1962). Inappropriability of innovation outputs and technology spillovers reduce the private sector's incentives to engage in the socially optimal level of innovative activity. Due to the public good nature of research and development (R&D) investments, governments have been actively supporting R&D performed by businesses.

This paper uses a difference-in-differences approach to investigate the effects of tax incentives for R&D, using the micro level Business Enterprise Research and Development (BERD) data for the UK. Differently from other papers in this literature, this study exploits a clear cut discontinuity in the design of the schemes in order to identify the policy impact. A difference-in-differences approach has been possible thanks to the step by step implementation of the tax incentive scheme in the UK. A pound foregone in corporate tax revenues is found to generate 3.85 pounds in additional R&D by medium sized companies. The tax incentives are found to have prevented a downward trend in R&D spending. Despite this paper's focus on the UK case, the implications are general for tax incentives and R&D policy.

The Government of the United Kingdom (UK) is expanding its support to R&D activity by businesses. The 2011 Budget Document introduced the much debated 'Patent Box' policy, which grants a 'reduced 10 percent rate of corporate tax for profits arising from patents, effective from April 2013'[1]. In the same document, the Government proposed an enhancement to the small and medium enterprise (SME) tax incentives. The SME scheme started in 2000 with a rate of relief amounting to 150 percent of eligible expenses. In 2008, this rate was raised to 175 percent, and increased further to 200 percent in 2011 and 225 percent in 2012. A prominent question now is whether the impact is high enough for these enhanced tax incentives to generate the desired level of R&D expenditures by the private sector.

Medium sized firms are an important engine for innovative activity. Measuring SMEs' contribution to R&D is difficult, as reporting of formal R&D in published accounts is only compulsory for larger corporations. However, the entrepreneurship and innovation literature documents the role played by SMEs in aggregate innovative activity, emphasizing the importance of small businesses in the forward leap of the United States (US) in innovation towards the end of the twentieth century (Acs and Audretsch (1993)). The data used in this study enables that the effect of an R&D tax incentive on medium sized firms be identified.

The UK scheme is particularly suitable for the difference-in-differences design to analyze medium sized firms, thanks to the timing differences in the introduction of tax incentives first for SMEs and then for large companies. This allows the examination of the effect on firms that were marginally above the

[1] Treasury (2011); p.56, Article 2.71

size threshold for eligibility to the SME scheme, as they start benefiting from R&D tax incentives only in 2002, exactly two years after the introduction of the SME tax incentive scheme. Firms that were marginally below the size threshold for eligibility to the SME scheme then constitute the control group for this study. The treatment and control groups are limited to medium sized companies to maintain comparability between the two groups.

In most policy implementations, the announcement of the scheme before implementation may cause changes in the behavior of affected agents. With investment tax breaks, it can be expected that firms may delay their investment spending for a few periods until the introduction of the policy to attain the maximum possible benefit from the pre-announced incentive schemes. In the estimation stage, this paper explores the possibility of firms delaying their R&D spending strategically to increase the benefit from the policy.

The next section presents some aggregate trends in the R&D performance of UK businesses, followed by a summary of relevant events that took place in the run up to the introduction of R&D tax breaks and a description of the tax incentive schemes in the UK. It then outlines the theoretical background, while reviewing the existing literature on evaluating R&D tax incentive schemes. The third section describes the data, the fourth section presents the estimation procedure and robustness checks and the final section concludes.

2 Background

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

The OECD Frascati Manual (OECD (2002)) sets out clear guidelines for defining research, development, R&D personnel, R&D capital goods, facilities, and other related terminology. The main expenditure items for R&D activities are:

- Current expenditures: labor, materials, supplies and 'other';

- Capital expenditures: land, buildings, instruments, equipment and software.

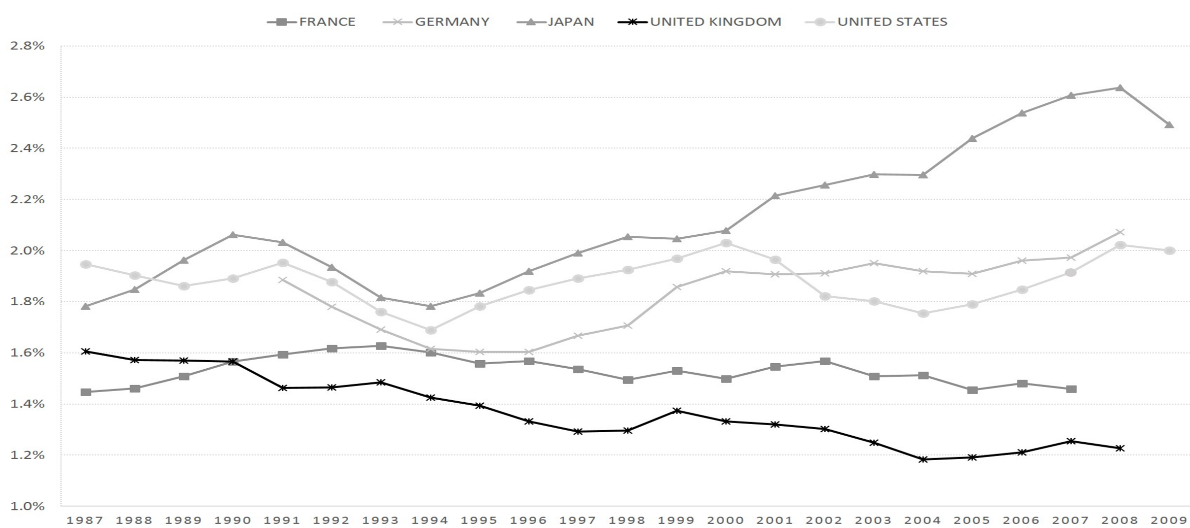
The main sectors which fund R&D activities are: (i) business enterprise[2], (ii) government, (iii) private non-profit, (iv) higher education, (v) abroad. Having obtained the funding from these sources, public or

[2] In the Frascati Manual, 'Business enterprise' is defined as 'all firms, organizations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price' and 'the private non-profit institutions mainly serving them (p.54)'. For the private non-profit institutions, their allocation to the business enterprise sector as opposed to the private non-profit sector depends on how they are administered and financed. The decision mechanism for such institutions can be found in the Manual (p.55).

private sector institutions then 'perform' R&D. Therefore, 'funding' and 'performance' of R&D need not take place under one roof. Our main focus here is the business enterprise sector expenditures on research and development (BERD), which corresponds to the R&D performed by the private sector.

R&D intensity measures the ratio of R&D expenditures to an output measure, which can be the gross domestic product in the macro context. In the past several decades, the UK private sector's R&D investment 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: Total BERD intensity, UK and comparators

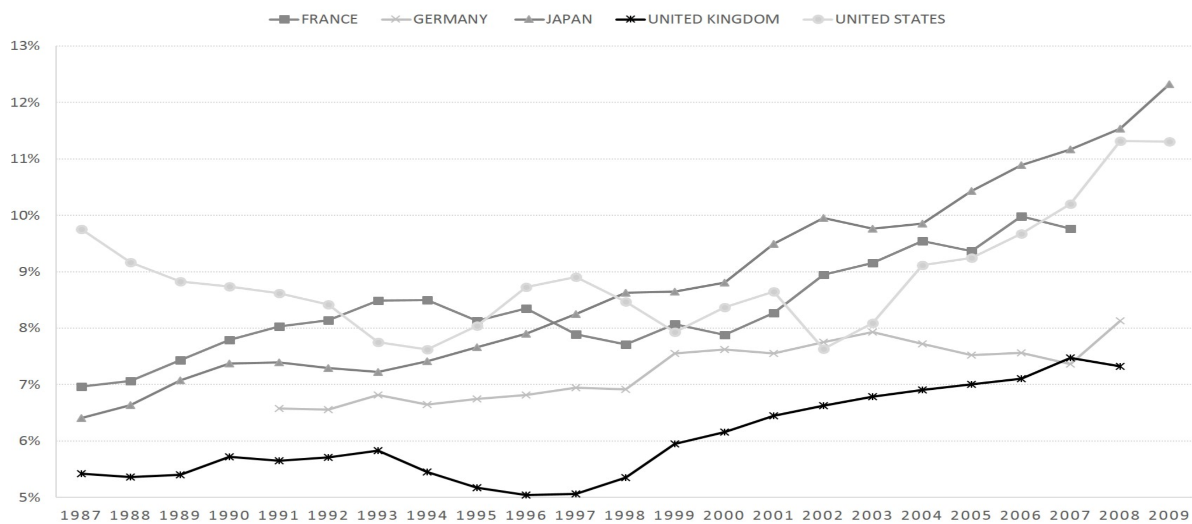


Source: OECD

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, cross country comparisons of R&D intensities can be obtained, as in Figure 1. Figure 1 shows that total BERD as a share of value added has been lower in the UK than in 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 this aggregate level, 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, in contrast, 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: Manufacturing sector BERD intensity, UK and comparators



Source: OECD

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. It is therefore reasonable to argue that the compositional shift in the UK economy towards service sectors is among the primary reasons for the declining overall BERD intensity in the UK.

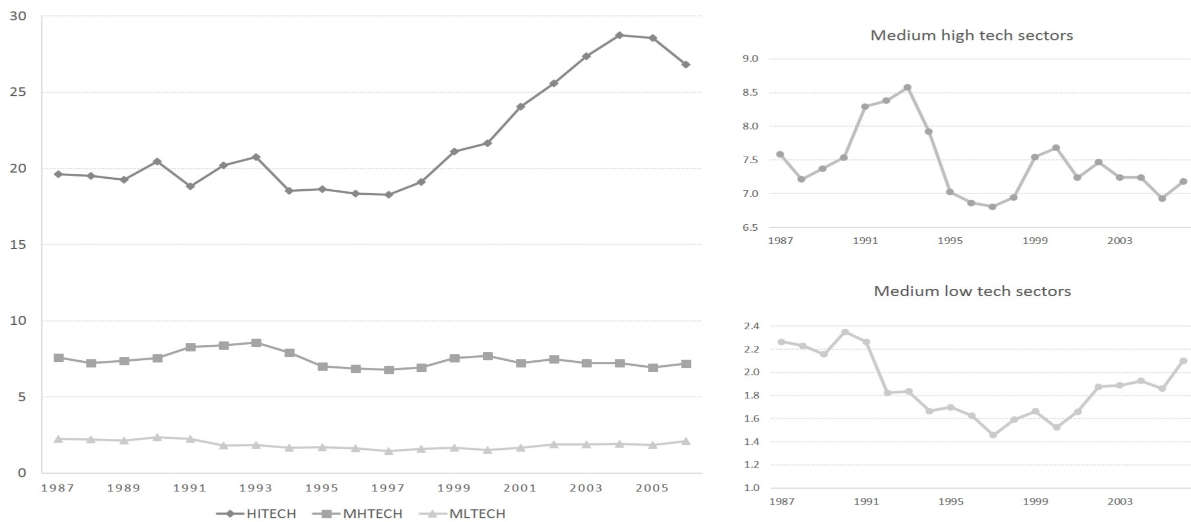
Within manufacturing sub-sectors, there are large heterogeneities in trends of R&D intensity, which can be observed in Figure 3 for broad technology groups[3]. The UK high technology sectors have experienced a steep rise in R&D intensity starting in 1997, while R&D intensity in medium technology sectors did not demonstrate similar trends over the same period. If we magnify the neighborhood of medium high and medium low technology sectors, as in the right hand side panel of Figure 3, it can be observed

[3]A technology classification is available by the OECD, where the groups are identified as high technology, medium high technology, medium low technology and low technology sectors. The latest version of the classification is explained in the OECD Science, Technology and Innovation Scoreboard for 2003 and it is based on three indicators for technology and R&D intensity, averaged over ten large OECD countries.

that the increasing trend starting in late 1990s is much more mild for these sectors, with small drops in R&D intensity in some of the years. It is therefore fair to argue that the increasing trend in the UK manufacturing sector R&D intensity was driven mostly by the high technology sectors.

From the point of view of the neoclassical theory of investment, there does not seem to be an obvious reason for different sectors to be affected differently by the implementation of a tax incentive scheme for R&D. In Section 2.3, we discuss these theoretical underpinnings and in the empirical analysis, conduct checks to examine whether there is significant sectoral heterogeneity in firms' response to the R&D tax incentives at the micro level.

Figure 3: BERD intensity of technology groups

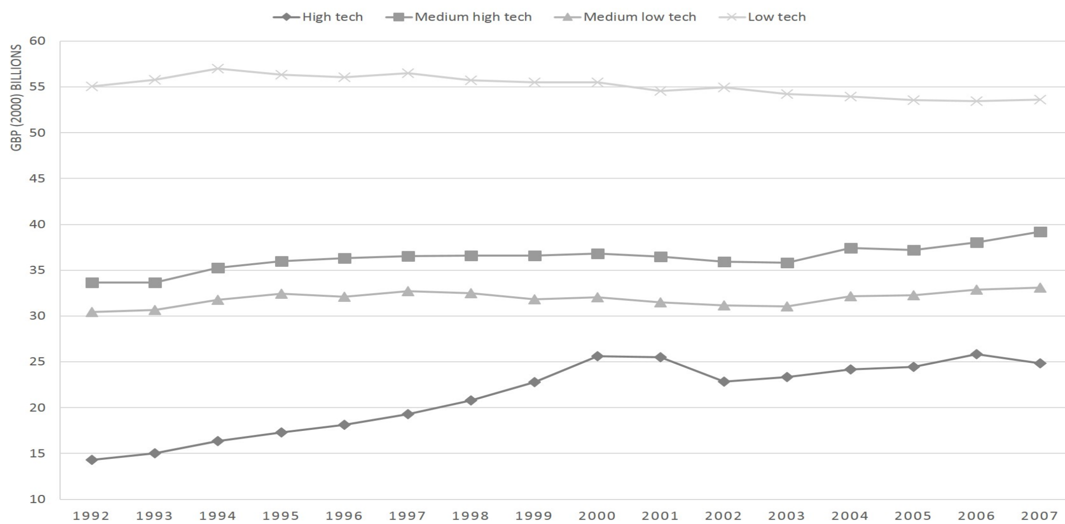


Source: OECD

Higher technology sub-sectors of manufacturing have been growing both in their total R&D spending and also in terms of value added (Figure 4). While the total value added and R&D intensity of higher technology industries have been increasing, the number of such enterprises and their total employment have been falling[4]. Such reallocation within manufacturing towards higher technology sub-sectors is commonly observed in developed economies. One explanation to this shift is discussed in the empirical trade literature, which finds that import competition drives productivity higher in lower technology import-competing sectors while moving the focus of local manufacturing towards more high technology sectors. Such movements may explain the steeper rise in R&D intensity of UK manufacturing after 1997 (See, among others, Pavcnik (2002) and Bloom et al. (2011)).

[4]Source: OECD and Business Structure Database over 1998-2007 made available through the Secure Data Service.

Figure 4: Total value added in constant (2000) prices by manufacturing sub-sectors



Source: OECD

2.2 The UK R&D tax incentive scheme

The term 'R&D tax credit' is often used to refer to the general class of fiscal incentives which allow a special treatment of R&D expenditure for tax purposes, encompassing 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 expenditure 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 is 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[5] and (ii) volume-based, where firms enjoy benefits on all their R&D expenditure, regardless of their past level. It is

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

becoming more and more common to introduce or increase the emphasis on volume-based schemes among industrialized countries, as these are simpler and can reach 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 in the form of an enhanced deduction of qualifying current expenditures from taxable income, and the enhanced deductions do not apply to capital expenditures. 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 and more detailed consultations followed in the subsequent years. 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, 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[6].

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[7]. 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, in a sense, 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.

The enhanced deduction rates were subsequently increased from 1 April 2008 onwards, and this was followed by a change in thresholds for defining an 'SME' for tax credit purposes[8]. The firm size thresholds before and after the policy change are shown in Figure 5. These changes were announced in the 2006

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

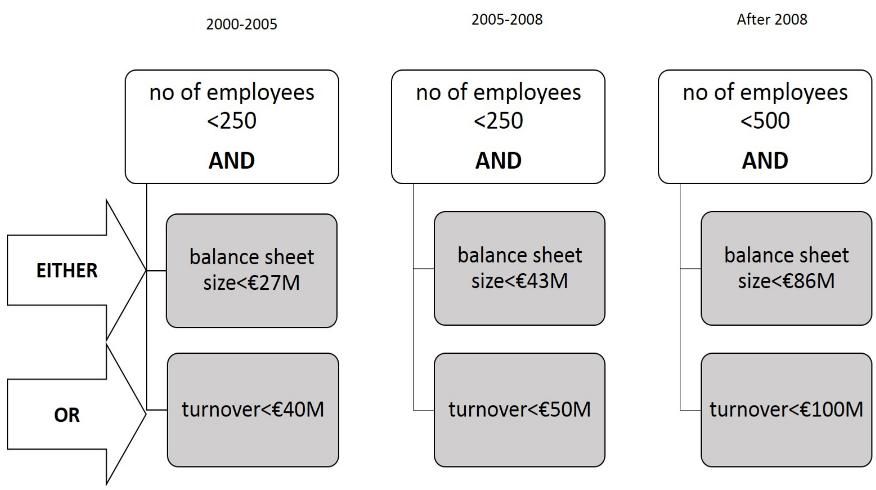
[7]SME definitions are explained in detail later.

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

Budget. To reduce the risk of capturing changes to R&D following from this announcement, the empirical analysis in this study uses data up to and including calendar year 2006 but not later.

According to the EU regulations, the SME definition consists of size thresholds and also provisions of owner-subsidiary relationships[9]. This implies that small firms which are subsidiaries of large companies, which own stakes over and above 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. Figure 5 depicts the relevant size thresholds which define an SME in terms of both pre- and post-2008 criteria.

Figure 5: Size thresholds for SME tax credit



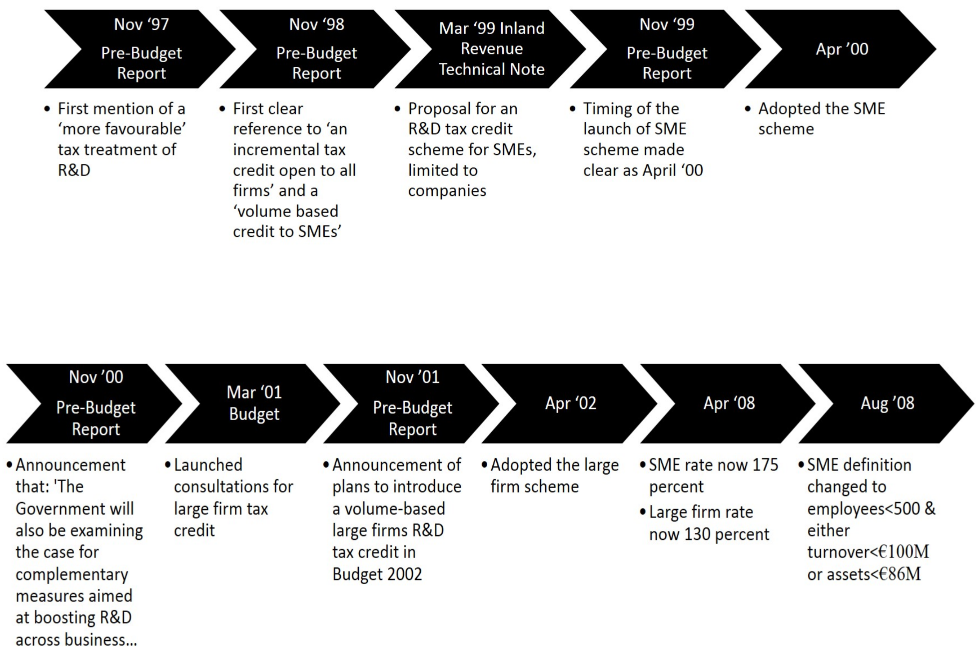
During the period of interest for this study, eligibility for the SME tax incentive required that the company has fewer than 250 employees, and either a balance sheet size of less than €27 million (€43 million from 2005) or turnover less than €40 million (€50 million from 2005). In addition to having 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.

Earlier in the paper, we alluded to the possibility that companies may anticipate the introduction of the tax credit and hence behave strategically by delaying their expenditures on R&D until after the implementation of the policy. Such strategic behavior might have been likely in the case of the R&D Tax Relief, as the policy was announced well before its introduction, both for the SME scheme and the large company scheme. Figure 6 presents the major events in relation to the implementation of the R&D

[9] 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, 2003/361/EC.

Tax Relief, where it can be seen that the government announced its plans to introduce R&D tax breaks in 1998, without giving much detail about the rates, conditions or their time line. March 2001 marked the beginning of consultations for a large firm tax credit, and the announcement of the large company scheme followed in November 2001. We will later show that despite the early announcement, there is little evidence that larger firms delayed their R&D spending until after the policy implementation.

Figure 6: Events in the early years of the R&D Tax Relief



2.3 An overview of the theoretical underpinnings

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). In their seminal paper, Hall and Jorgenson devise a model of investment to analyze the effect of the investment tax credits and various forms of depreciation allowances in the United States. Their model is based on Jorgenson's 'Theory of Investment Behavior (1963),' building on the neoclassical optimal capital accumulation framework in which firms maximize their profits subject to a form of neoclassical production function by choosing input levels. For simplicity, the model assumes that replacement investment is made at a rate proportional to the capital stock and the investment is not irreversible. Under these assumptions, firms then set their demand for capital input at the level where the marginal product of capital is equal to the 'user cost of capital'. The user cost is described as: "the shadow price or implicit rental of one unit of capital service per period of time (Jorgenson (1963; p.249))". Hall and Jorgenson embed taxation, depreciation allowances and tax credit rates into the present discounted value from 'capital services', equate this to the price of capital goods and find an optimal level of capital for the firm as a function of output price, output quantity, user cost of capital and the elasticity of output with respect to capital. 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. The main difference lies in the empirical result, as dynamic models often find longer adjustment periods in the context of R&D investment, which may be due to for instance training requirements for staff upon acquisition of new computer software, setting up advancements in equipment and adaptation of newly hired R&D personnel.

Summarizing this theoretical framework in simplified terms helps in demonstrating the relationship between tax incentives and R&D. Firms acquire knowledge stock (R&D capital) to maximize profits subject to the law of motion of R&D capital. The first order condition equates the marginal product of (R&D) capital to its user cost and the marginal product of the variable input to its real price. Assuming a Cobb Douglas production function, the cost of knowledge capital is then inversely related to the optimal level of (R&D) capital[10]:

$$C^* = \alpha \frac{Q}{U} \tag{1}$$

where Q is the output level, α is the elasticity of output with respect to knowledge stock and U is the

[10]See Jorgenson et al. (1965), Jorgenson (1963) and Hall and Jorgenson (1967) for a formal discussion. The results generalize to other constant elasticity of substitution (CES) production functions.

user cost of capital[11]. Taking logs and rearranging:

$$lnC - lnQ = constant - lnU \tag{2}$$

The user cost of knowledge capital must equal the before tax present value of a unit of investment in R&D so that the marginal project breaks even. A standard expression for the user cost of R&D capital can be derived as in Bloom et al. (1997):

$$U = \frac{1-A}{1-\tau}[r+\delta] \tag{3}$$

where τ is the statutory tax rate and r is the discount rate. A represents the net present value of all current and future depreciation allowances and tax credits applicable to the marginal R&D investment, so they are reductions in the cost of making a unit investment in R&D. The form of A depends on the design of the tax incentive system. When there is 100 percent expensing of R&D expenditure and no special tax credits, $A = \tau$, offsetting the effect of corporate income tax on the required rate of return. With an additional tax credit or an enhanced deduction for more than 100 percent of the R&D expenditure, $A > \tau$, leading to a lower required rate of return.

Tax incentives therefore enter the R&D equation through the user cost term. The user cost, scaled by the firm size, is directly related to the R&D investment undertaken by the firm.

This paper is influenced by the simple neoclassical model of optimal R&D presented here as a motivation for tax incentives to affect the accumulation of knowledge capital in the firm; however, there may be other channels through which tax incentives may affect R&D spending. The quasi-experimental research design used in this study is not reliant on any particular theoretical model, but the discussion in Section 4.3 on our implied user cost elasticity estimates relate to the framework summarized in this section.

2.4 Estimates of the impact of R&D tax credits

To date, a clear policy discontinuity as in the UK R&D Tax Relief schemes has not been exploited in other papers in this literature. Our study identifies the policy impact by focusing on the variation at the size threshold for eligibility to the SME scheme. Through this policy experiment, we can back out an estimate for the user cost elasticity, given that the drop in the user cost of R&D capital in the

[11] In order to increase R&D capital as a share of total output, firms increase R&D investment as a share of output. For our empirical specification, the relationship between R&D investment and R&D capital need not be proportional, but for the purposes of the model summarized in this section, under a steady state assumption, C can be shown to equal $\frac{\kappa+1}{\kappa+\delta}R_{it}$ with κ denoting the growth rate of the capital stock, δ denoting the rate of depreciation of R&D capital and R_{it} denoting R&D investment.

UK induced by the introduction of the large company R&D Tax Relief was about 13 percent (Bond and Guceri (2012)).

Bloom et al. (2002) employ the Hall-Jorgenson (1967) approach to calculate the tax-adjusted cost of investing in R&D across a panel of nine OECD countries over nineteen years. Specifying a dynamic model with manufacturing sector business enterprise R&D intensity as the dependent variable, they find a negative long run elasticity with respect to the user cost of R&D, with a value close to minus one.

In their paper, Bond and Guceri (2012) use publicly available macro level data to first calculate the reduction in the user cost of R&D induced by the scheme, then compare the evolution of manufacturing sector BERD intensity with predictions based on the model estimated by Bloom et al. (2002). They find that the increase in R&D in response to the introduction of the tax credit has been around 13 percent, in line with the Bloom et al. prediction, but with quicker adjustment to the long run equilibrium.

An evaluation of the Dutch R&D tax incentive scheme is carried out by Lokshin and Mohnen (2012), who work with an unbalanced panel data set covering the period 1996-2004. They assume a CES production function (as conventional in the literature) and a constant price elasticity of demand. They present three different empirical models to estimate the user cost elasticity of R&D stock: (i) a static model with no adjustment dynamics, (ii) a partial adjustment model (following Nadiri and Rosen (1969)), (iii) an error correction model. Their findings, which are consistent across the models, point to a significant negative long run elasticity of R&D stock with respect to its user cost in the range 0.54-0.79 in absolute value, with a relatively fast convergence of about 2-3 years. Mairesse and Mulkay (2011) study the R&D tax incentive scheme in France, which has gradually moved from an incremental scheme over the period 2004-2008, to a fully volume based scheme in 2008, increasing the budgetary cost of the program threefold. Their study has two components: the first component analyzes the effect of the user cost reduction over the period 2000-2007, and the second component simulates the projected evolution of R&D starting in 2008. In the first part, they find an elasticity of R&D with respect to its user cost around -0.4. The simulations indicate a large increase in R&D, but a slow adjustment to the new long run equilibrium. Harris et al. (2009) estimate the impact for Northern Ireland and find a long run user cost elasticity of -1.36.

Czarnitzki et al. (2011) use the nonparametric matching approach, exploring the effect of the Canadian Federal and Provincial R&D tax credits on a set of outcome variables, such as the share of innovative products in sales, 'new-to-the-world' innovations and some proxies for the impact of the innovation on the firm. They find significant positive effects of the tax credits on the number of new products and their sales, while they do not find any effect on the firm's profitability or market share. Corchuelo and Martinez-Ros (2009) evaluate the effects of the tax incentive scheme for R&D in Spain, also using a nonparametric matching estimator and propensity score matching, finding that the tax incentives have a positive and significant effect on R&D for large firms.

Our study focuses on the medium sized firms around the size threshold for eligibility to the SME scheme, and finds that the treated firms increased their R&D spending by about 18 percent in response to the policy intervention. After the introduction of the large company tax incentive scheme, the gap between treatment and control group R&D spending has widened (Figure 10). This is indicative of the tax incentive having helped to counter a decreasing trend in R&D investment by firms that remained above the size threshold for eligibility to the SME tax incentive scheme. For medium sized firms, the policy is found to have generated an additional £3.85 in R&D for every pound foregone in corporate tax revenues.

Where the data is available, measuring innovation outputs is beneficial to overcome concerns about relabeling and inflated salaries for scientists and researchers. Goolsbee (1998) and Rogers (2010) warn that with the introduction of tax incentives, the majority of increased R&D expenditures may go to higher salaries for scientists and engineers, rather than to a larger number of researchers. Goolsbee (1998) documents 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. For subnational credits, another concern is the geographical shift of R&D activity away from high tax jurisdictions to those states with a more generous tax treatment of R&D (Wilson (2009)), essentially resulting in a zero sum game. Wilson finds a long run elasticity of R&D with respect to its user cost around -2.5, but this is offset by an out-of-state user cost elasticity of around +2.5.

Many studies underline the issue of relabeling ordinary expenses as R&D but the extent of the problem has rarely been quantified. Evidence on relabeling is provided in an early report by the US General Accounting Office (GAO (1989)). In their study based on the financial reports of 800 large US corporations, US GAO finds that around 20 percent of revenue agents are not convinced by the clarity of the definition of qualifying expenses. A more recent US GAO study dated November 2009 (GAO (2009)) lays out the main expenditure items which are more difficult to monitor for the tax authority. On the top of their list is the proportion of salaries paid to management level staff who supervise research activities. The report is based on interviews with the parties involved in the accounting of R&D for tax purposes, namely, officials from the Internal Revenue Service (IRS), taxpayers and tax consultants, and identifies large differences between the opinions of all involved parties regarding the identification of qualifying expenses. While relabeling is an important obstacle in identifying the true effect of R&D tax incentives, there are now high penalties for misreporting in the United States and other developed countries, and tax authorities have advanced their practice of monitoring eligible expenses over the years of implementation.

In the 2009 GAO report, it is argued that IRS is very stringent in determining the share of qualifying research expenditure especially for the salaries of management level staff.

3 Data

3.1 Available data sources

In the UK, only a limited group of companies and the firms above a certain size threshold are required to disclose R&D expenditure in company accounts[12]. As a result, data on R&D expenditures by smaller enterprises is rather scarce. A list of data sources for UK R&D is presented in Table 1 below, which is reproduced from Office for National Statistics (ONS) Guidance Notes dated 13 November 2012 (Steer (2012)).

Table 1: Data sources for R&D in the UK

Dataset	Source	Definition of R&D
Business Enterprise R&D (BERD)	Survey	Frascati Manual
Gross Expenditure on R&D (GERD)	Survey	Frascati Manual
Northern Ireland GERD	Survey	Frascati Manual
Defence Statistics	Survey	Frascati Manual
R&D Tax Relief and Credit	Administrative	Other
R&D Scoreboard	Administrative	Other

Source: Office for National Statistics (Steer (2012)), own contribution

As can be seen in the table, there are only a handful of data sources on R&D available at the firm level. Out of these resources, only the R&D Scoreboard data published by the Department for Business, Innovation and Skills is in public domain, and this provides information only on the largest spenders on R&D[13]. To conduct an analysis of the firms around the size threshold of interest for us, the only data sets available are the BERD data by the ONS and the administrative data on R&D Tax Relief by the HMRC. Only the ONS data set goes back long enough in time for us to exploit the discontinuity in 2002 which is

[12]SSAP 13 provides guidance on the accounting rules for research and development. Paragraphs 19 and 20 of this document explain the rules for disclosure of R&D expenditure in the profit and loss accounts of the firm. Disclosure is limited to: "...public limited companies, or special category companies, or subsidiaries of such companies, or which exceed by a multiple of 10 the criteria for defining a medium sized company under the Companies Act 1985. (Statement of Standard Accounting Practice No.13, Revised January 1989)"

[13]Department for Business, Innovation and Skills announced in 2012 that the collection of R&D Scoreboard data was discontinued.

the introduction of the large company scheme[14].

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. Recently, the micro level BERD data has been 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 include the UK Innovation Survey, new R&D sector firms from the Business Register, 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.

The micro level BERD data set can be merged with other ONS data sets such as the Annual Respondents' Database (ARD 1973-2009; previously, the Census of Production) and the Business Structure Database (BSD 1997-2011; snapshot of the Business Register) to obtain a match with the firm-level characteristics used as controls in this study. Because employment and turnover growth rate control variables are sourced by the Business Structure Database, the first year in the merged data set needed to be 1998. These data sets are available in different statistical units. BSD is provided at the 'enterprise level' which is the smallest autonomous unit in a firm with own decision-making capability. BERD and ARD data are collected at the 'reporting unit' level, which is where the postal address of the firm is registered. The reporting unit is smaller than an enterprise, but the majority of the enterprises are made up of only a single reporting unit. An enterprise group encompasses one or more enterprises, all legally connected to each other. The analyses in this paper are carried out at the enterprise level. These units are explained in more detail in Appendix A.1, which also explains the data cleaning procedures. The clean merged data set is available for the period 1998-2008[15].

ONS uses stratified sampling to select the enterprises which will receive a BERD questionnaire form each year. There are two types of BERD questionnaires, namely, the long form and the short form questionnaires. A long form questionnaire is sent each year to around 400 largest spenders in R&D, and this form asks for detailed information about the breakdown of the respondent's R&D spending into different categories. For the remaining reporting units, a stratified sampling procedure is used to select the ones that will receive a short questionnaire form, which includes a summary set of questions, such as total R&D spending (in-house and contract R&D) and R&D employment (See Appendix A.2 for further

[14]In a separate project we examine results from a later reform using the administrative data and make comparisons, but this is not possible for the 2002 reform.

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

detail).

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, we refrain from using these imputed values. Details on the severity of the measurement error caused by the imputed values are presented in Appendix A.2. For enterprises with multiple reporting units, only those that have all associated reporting units with non-imputed values have been kept.

BSD contains the most complete information on employment, turnover, enterprise groups (ownership data), sector and other firm characteristics that are sourced by the Inter-Departmental Business Register (IDBR) and it is available at the enterprise level only. In the IDBR and hence the BSD, observations on enterprises are constructed using the data from HMRC on VAT traders and PAYE employers.

3.2 Selection of treatment and control groups

We selected treatment and control groups based on the threshold for eligibility to the SME Tax Relief. In the period of introduction of the large company scheme (2002), eligible SMEs which were already benefiting from the SME Tax Relief are assigned to the control group, which consists of enterprises just below the SME size threshold. This means enterprises that have between 100 and 249 employees, and are not owned by a group that has more than 249 employees or, when aggregated, the total number of employees in group member enterprises do not add up to more than 249. The treatment group is composed of enterprises just above the SME employment size threshold; with employment between 250 and 400, which may or may not be owned by a larger group. The interval of 100-400 employees is chosen specifically because it constitutes a size band used by ONS in their stratified sampling procedure, which determines the enterprises that will receive a questionnaire form in a given year (See Appendix A.2). In the 100-400 size band, enterprises are sampled at a ratio of 1:3, and this helps us in maintaining a roughly similar number of enterprises in each of the treatment and control groups.

For firms' eligibility to the SME tax credit, which places them to the control group, there are two more criteria that are not used here. If the firm has fewer than 250 employees (in aggregate), then it is subject to the asset/turnover test. According to the EC recommendation applicable to this incentive scheme, the size threshold to define an SME is for the enterprise to have fewer than 250 employees AND either less than 40 million Euros of turnover OR less than 27 million Euros of balance sheet size. The enterprise should also not be linked to a larger enterprise which does not possess these properties which define an SME. The reason for not undertaking the asset and turnover tests is because there is no data available on assets or group level turnover. Regarding the turnover criterion, simply summing the enterprise turnover values to obtain the enterprise group level turnover is not a valid method of calculating consolidated group level turnover. Nevertheless, the results are verified with a robustness check that defines the treatment group using both the employment and this approximation to the turnover criteria[16].

Defining the treatment group based solely on the employment measure only affects the composition of the control group, and allows all observations in the treatment group to be those classified as large enterprises by the EC recommendation. The control group however may contain some treated firms, since having a total of fewer than 250 employees does not guarantee SME status, if the enterprise fails both the asset and the turnover tests. This limitation does not jeopardize identification, but it reduces power while testing the null hypothesis of no effect of the tax incentive in the specifications presented later.

The reporting period for BERD is the calendar year. 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. The Large Company Tax Relief was introduced in April 2002, which is three months into calendar year 2002 but earlier than 2003. If a firm's accounting year begins on any date later than the UK fiscal year, which runs between April 6, 2002 and April 5, 2003, then the R&D spending which is made in 2002 after the introduction of the R&D tax credit for large companies will be included in the company's BERD returns for 2003. For example, if Company A's accounting year runs between July 1, 2002-June 30, 2003, then all the R&D expenditure of Company A carried out between these dates would be recorded in the BERD returns for 2003. If, on the other hand, Company B's accounting year runs between April 1, 2002-March 31, 2003, then the R&D expenditure of Company B that was carried out between these dates would be recorded in the BERD returns for 2002.

In the corporation tax returns, all the qualifying R&D can be used to claim tax credits in the 2002-2003 fiscal year (depending on eligibility). If the firm's accounting year coincides with the calendar year, then the R&D reported for 2002 in BERD reflects exactly the expenditure incurred in 2002, and the company may claim tax credit on three quarters of the qualifying expenditure made in 2002, as the eligible expenditure will be apportioned for the period April 1, 2002-Dec 31, 2002.

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, demonstrated in the example above. Based on these

[16] The results from these regressions are not included in the paper.

information, we selected calendar year 2003 as the first implementation period for analysis. It may be argued that the inclusion of R&D spending during 2002 as part of the pre-reform period is problematic because companies may be apportioning some of the R&D done in the 2002-2003 fiscal year to R&D recorded in calendar year 2002. We later show in Section 4.2 that the results are not sensitive to the removal of 2002 from the sample.

While running the regressions, the sample is further limited to observations which are identified as 'active' in the BSD, in the manufacturing sector, with reported R&D expenditures above £10,000. For eligibility to any tax relief, companies needed to spend at least £10,000 until 2013. Table 2 presents the number of observations that remain in the sample after all filtering.

There are two sources of information on sectors in the BERD data set: (i) sector of R&D information returned only by long form respondents, and (ii) sector of activity sourced by the business register, which is available for both short and long form recipients. In the size band of interest for this study, that is the 100-400 employee size band, observations are mainly based on short form responses and therefore the sector of R&D information is not available. To maintain consistency across short form and long form recipients, the two digit sector of activity information in BERD is used instead of the two digit sector of R&D activity, which is only available for the long form recipients.

There is a small subset of long form recipients which fall in the size bands of interest for this study (fewer than 1000 enterprise-year observations) and comparisons between sector of activity and sector of R&D for this small group is informative for verifying the association between the two different sector variables. Regarding the broad split into manufacturing and services using the two digit sector of activity in comparison to using the two digit sector of R&D, for more than 65 percent of the observations, the two variables are in agreement. For the remaining observations, it is most common to observe a services sector flag according to the sector of activity matched with a flag for manufacturing by the sector of R&D. These firms are usually R&D labs which operate in the SIC sectors 'scientific research and development' and 'computer programming, consultancy and related activities'. Robustness checks which include additional observations on these firms confirmed the main results, which used only firms classified as manufacturing by their sectors of activity and hence excluded these service sector firms.

Table 2: Number of observations, treatment and control groups across years

period	1998	1999	2000	2001	2002	2003	2004	2005	2006
control	111	180	178	162	125	160	277	148	152
treatment	154	274	218	214	161	164	274	145	121

A key aspect is that, due to the stratified sampling procedure, the micro BERD data covers different enterprises in the treatment and control categories in each of these years. It is not necessarily the case that the same enterprise is observed both before and after the reform, as a genuine panel cannot be constructed in this stratum. Most of the observations are only observed in either the pre-treatment or the post-treatment periods.

3.3 Variables and deflators

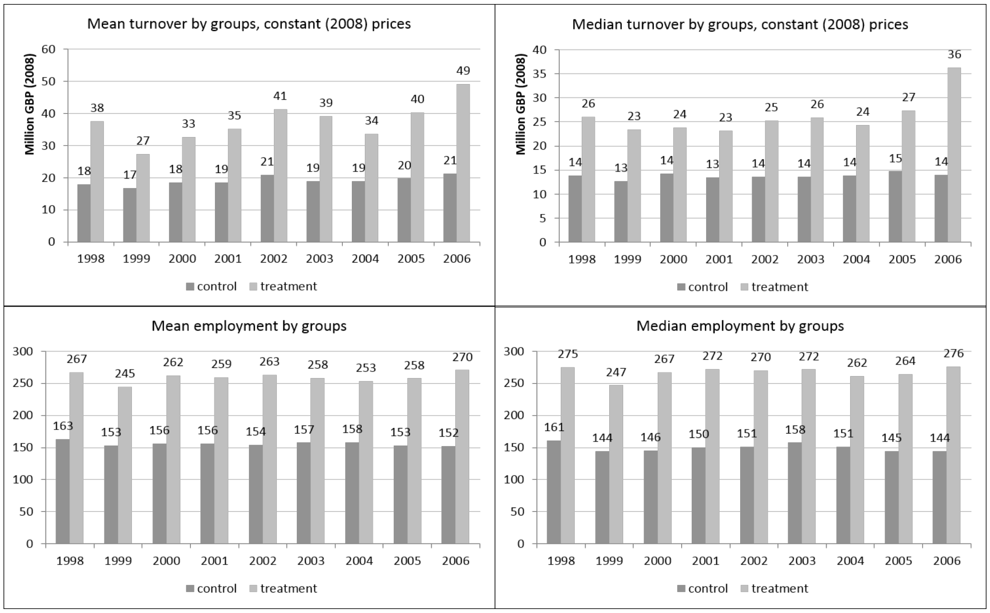
The main regressions reported in Tables 4 and 5 in the Results Section use real expenditures on R&D which is obtained by deflating the nominal intramural R&D expenditure from the BERD data set using a weighted deflator with 50 percent weight on researcher salaries and 50 percent weight on the GDP deflator. 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 turnover and employment is obtained from the BSD. Turnover controls (both levels and growth rates) are deflated using the manufacturing output component of the UK producer price index series (JVZ7).

3.4 Descriptive statistics

Identification with the difference-in-differences estimator requires that 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 equal to the change in the outcome variable for the treatment group. The counterfactual for the treatment group is not observed, but the trends in other variables may indicate if there is a large differential change between pre- and post-intervention periods for the treatment and control groups. Reliable information on employment, turnover and sector is available thanks to the BSD. Trends in turnover and employment can be observed in Figure 7[17]. The levels of enterprise employment and turnover are naturally very different for the treatment and control groups, but here the point is to

[17]The bottom graphs in the Figure show mean and median employment for treatment and control groups at the enterprise level; therefore, the values may remain below the threshold level of 250 even for the treatment group, as the determining criteria for eligibility to the SME credit considers enterprise group employment.

Figure 7: Comparison of treatment and control groups



see whether there is a large differential change or not, which does not seem to be the case around the periods 2002 and 2003.

The sectoral compositions across treatment and control groups are presented in Table 3. For our purposes, it is important to have a similar distribution of high tech, medium tech and low tech firms in the pre- and post-intervention periods across treatment and control groups. One way of identifying this is to use the OECD technology classifications that are laid out in OECD (2003) based on the average R&D intensity of relevant two, three or four digit sub-sectors of activity in manufacturing. In order to establish a classification of this kind for our sample, we use the R&D intensities of the two digit sectors available in our own data. The correspondence between the OECD high, medium high, medium low and low technology sectors with our classification can be observed in Table 9 in Appendix A.2. There are no large discrepancies between the two classifications.

First, we identify each observation in the sample as 'above' or 'below' the overall median R&D intensity. We then categorize each two-digit sector as 'high', 'medium' or 'low' R&D intensity, where the 'high R&D intensity' group has more than 65 percent of observations above the median, 'medium R&D intensity' group has between 40 to 65 percent of observations above the median and 'low R&D intenstiy' group has fewer than 40 percent of observations above the median. Table 3 demonstrates that there is some significant change in sectoral compositions between pre- and post-treatment periods. In Table 3, the percentages represent the share of observations in a given cell in high, medium and low technology sectors, where a cell can be one of the following: (i) control group pre-treatment, (ii) control group post-treatment,

(iii) treatment group pre-treatment, and (iv) treatment group post-treatment. It can be observed in the Table that the share of observations belonging to high technology sectors has increased in the control group over time from 24 to 31 percent, whereas in the treatment group, there is no such increase, and conversely the share of medium technology sectors decreased in the control group from 44 to 36 percent. These compositional changes relate to the fact that the samples of treatment and control group enterprises available are not genuine panels. This demonstrates the potential importance of controlling for sectors in the estimation stage. Table 9 in Appendix A.3 provides further evidence for such changes over time at the more detailed two-digit sector level.

Table 3: Share of observations in high, medium and low intensity of R&D sectors

R&D intensity:	high		medium		low	
	control	treat.	control	treat.	control	treat.
1998-2002	24%	24%	44%	42%	32%	34%
2003-2006	31%	24%	36%	39%	33%	37%

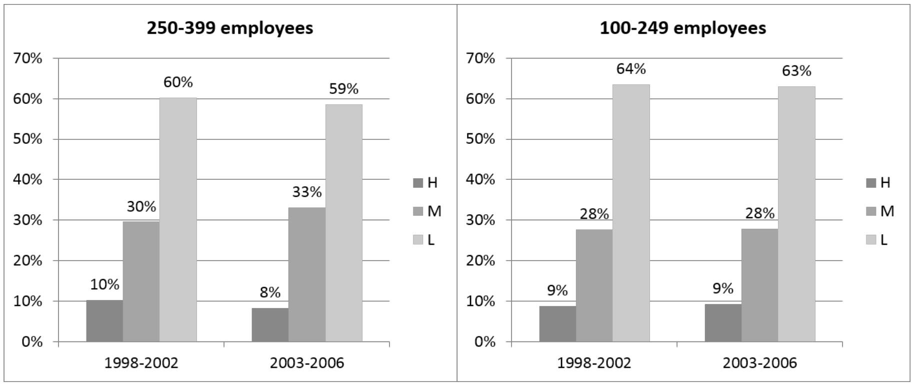
There may be several reasons underlying the increase in the share of high technology firms in the control group. First of all, this may be a reflection of a compositional shift in the whole economy, outlined in Section 2.1. The reallocation towards higher technology sectors of manufacturing may be taking place more intensively at the lower end of the firm size distribution, with the smaller low productivity firms dropping out faster than the larger ones. Alternatively, the observed sectoral shift in the control group may merely be an artifact of the sampling procedure for the BERD data set.

The Business Structure Database (BSD) allows for a further investigation of the shift in the sectoral composition of the UK manufacturing sector by size bands. Comparing the distribution of enterprises across high, medium and low technology sectors for the 100-249 employee size band with that for the 250-399 employee size band is informative in finding out whether the patterns observed in the BERD sample are a reflection of broader trends in the economy. Figure 8 demonstrates that such reallocation effects across our size bands of interest are not very pronounced, at least for the period that can be studied using the BSD data available.

The difference-in-differences estimator aims to capture the average or expected impact of the intervention on the treatment group, that is, it aims to estimate:

$$\{E[Y|t > 2002, D = 1] - E[Y|t \leq 2002, D = 1]\} - \{E[Y|t > 2002, D = 0] - E[Y|t \leq 2002, D = 0]\} \quad (4)$$

Figure 8: Share of UK enterprises in high, medium and low technology sectors for medium size bands



where

$$D = \begin{cases} 1, & \text{if treated} \\ 0, & \text{if control} \end{cases} \tag{5}$$

t represents the year and Y stands for the outcome of interest, in our case, it is the R&D investments made by the sample enterprises.

The sample analogue of the expression in Equation 4 compares differences in means between pre- and post-intervention periods across treatment and control group observations. Figure 9 presents the mean R&D spending in each of these cells. In the subsequent analysis, we use the natural logarithm to have a percentage change interpretation, and the shape of the graphs look similar if we use the natural logarithm of R&D spending instead of the levels. These cell means simply correspond to the coefficients in a diff-in-diff regression without any controls. In a regression sense, the diff-in-diff coefficient captures the additional R&D generated thanks to the policy intervention, after having accounted for any treatment-specific or control-specific effects as well as common trends. In the Figure, it can be observed that there is a differential change between the two groups, mainly owing to a fall in the control group R&D between the two periods, rather than a rise in the treatment group R&D. If the specification with no controls were correct, then it suggests that the policy intervention may have prevented a greater decline in R&D around the size threshold of interest for this study. The trend in the average R&D spending by control and treatment firms are presented in Figure 10, showing the widening gap between treatment and control group firms after the introduction of the R&D tax credit.

Figure 9: R&D spending across treatment and control groups, pre- and post-2003

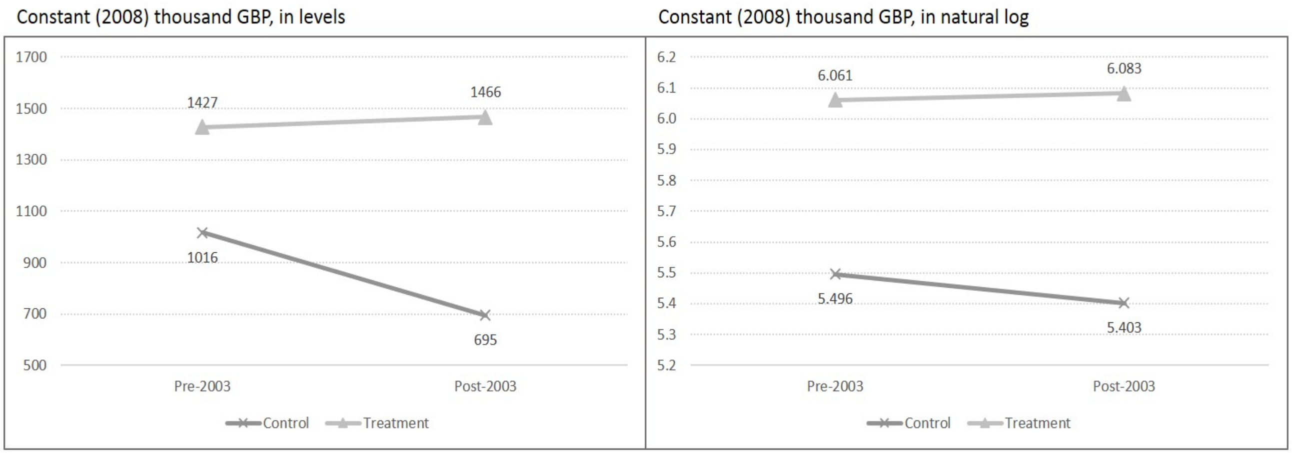
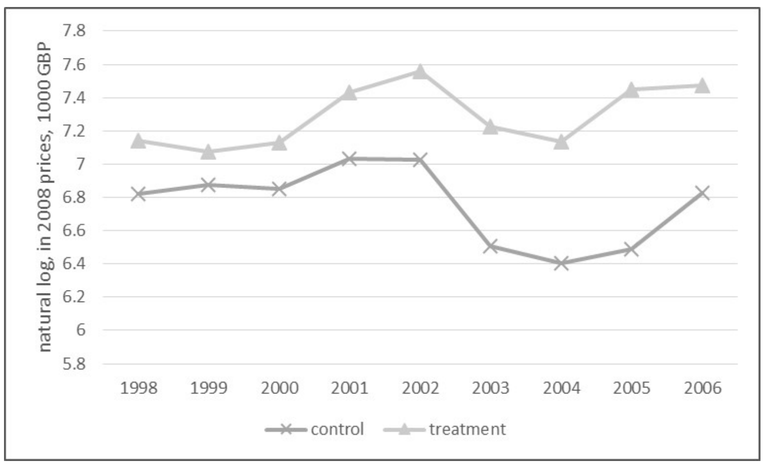


Figure 10: Comparison of treatment and control groups, mean R&D



4 Results

4.1 Model

We estimate the following base model:

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

where r_{it} is the natural logarithm of R&D spending of enterprise 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 years 2003 onwards and 0 otherwise. The coefficient δ_I on the interaction term D_iT_t thus captures any differential change in r_{it} between these two periods for the treatment group compared to the control group, and the null hypothesis of no impact of the introduction of the tax credit for larger firms corresponds to $\delta_I = 0$. We later drop T_t and include a full set of year dummies. x_{it} is a $K \times 1$ vector of controls, including sector dummies, sector-year interaction terms, employment, real turnover and their growth rates.

Table 4 presents the results from using this specification with different choices of controls. Column 1 presents the most simple specification with no controls, which replicates (in a regression sense) the right hand side picture in Figure 9. After the addition of each control variable, the sample size changes as some of these variables are only available for a more limited sample. In order to trace if the results change due to the reduced sample size or the addition of the control variable, regressions are run on the same sample with and without the controls and the results are presented in the column beside the one with the particular control variable(s).

The most important set of controls turns out to be the sector dummy variables. In Columns (1) and (3), the diff-in-diff coefficient is not significantly difference from zero, but in all regressions with sector controls, this coefficient is close to 0.2 and at least borderline significant at the 10 percent level. We saw in Table 3 above that the composition of the control group shifts towards more high tech sectors in the later period, and this illustrates the importance of controlling for this change.

The addition of turnover and employment variables at the same time, is our best proxy for controlling for productivity given the available data. In Column (6) of Table 4, the addition of the turnover and employment controls in levels induces a slight drop of the diff-in-diff coefficient from 0.23 (Column (7)) to 0.18 (Column (6)) and the t-statistic goes down from 2.0 to 1.7 as the estimate becomes more imprecise. In Columns (8) and (9), we control for turnover and employment growth rates. Column (9) results include both the levels and the growth rates of (the natural logarithm of) turnover and employment. The results in Columns (8), (9) and (10) require the availability of turnover and employment information from two periods back, and the effect of having a smaller sample size is reflected in the results in Column (10). Without introducing any employment and turnover controls, the reduction in sample size because of the increased data requirement in Column (10) reduces the t-statistic of the diff-in-diff coefficient to 1.85. The magnitude of the coefficient remains at 0.21. The addition of turnover and employment growth rate controls then induces a drop in the magnitude of the coefficient from 0.21 (Column (10)) to 0.18 (Column (9)), and the t-statistic drops to 1.6 as the estimate becomes more imprecise. The turnover variable is very jumpy and contains outliers, which were not removed from the sample to retain comparability across the results, but the addition of this variable increases the variance of estimated coefficients. The 95 percent confidence intervals for the estimates in Columns (8), (9) and (10) largely overlap.

In Table 5, this base model is then complemented by a specification which has R&D scaled by firm employment as the outcome of interest, with $r_{it} - l_{it}$ as the dependent variable (l_{it} denotes the natural logarithm of employment). This specification is more in line with the theoretical background, which is explained in Section 2.3 where it has been shown that:

$$lnR - lnQ = constant - lnU \tag{7}$$

Since we do not have information on Q, which is the firm's output, we can use the next best available firm size measure, that is the total employment of the firm. Turnover is also an alternative here, but as mentioned earlier, the turnover values exhibit high variation and do not seem to be a very reliable benchmark. Regression results with the turnover variable as an additional control have been included in Tables 4 and 5[18]. The results presented in Table 5 from estimating the model with R&D scaled by the firm size as the dependent variable are very similar to those in Table 4 in terms of both the magnitude and the significance of the diff-in-diff coefficients.

Having established that the sector level controls are important in the results, several variations of the model allowing for sector-specific difference-in-differences coefficients have been run. These specifications were of interest for comparing the micro level findings for the size band studied here with the aggregate trends discussed in Section 2.1. The null hypothesis of equal diff-in-diff coefficients for high, medium high, medium low and low technology sectors cannot be rejected. In aggregate data, on the other hand, the increase in R&D intensity appears to be driven by the high technology manufacturing sectors. In line with the basic neoclassical theory of R&D investment, our results suggest that the impact of the R&D tax credit was similar between high technology and lower technology sectors. If this is correct, it follows that other factors caused the composition of UK BERD to shift towards high technology sectors over this period. One explanation may be the increased competition from BRIC countries in lower technology sub-sectors of manufacturing, as discussed in Bloom et al. (2011), which induced a rise in the intensity of innovation in more high technology sectors in the UK. Such trends would be captured by the interactions between year and sector dummy variables in the micro analysis. Another explanation may be that the size band of interest for the purposes of this study (100-400 employees) is smaller than that where the bulk of R&D is performed (larger companies) and the trends may be different than at the upper end of the size threshold. Given that the share of UK manufacturing BERD which is conducted by the firms in the 100-400 employee size band is about 14 percent around the time period studied, this possibility cannot be ruled out.

[18] In other specifications, the coefficient on the log of employment is allowed to differ from unity. In all cases where sector dummies are included, a significant differential effect of the tax incentive of around 17-23 percent is found in comparison to the counterfactual scenario. Since these results do not provide new insights, the tables have not been included in the paper.

Table 4: Results (I)

$$r_{it} = \gamma + \delta_D D_i + \delta_T T_t + \delta_I D_i T_t + x'_{it}\beta_x + \nu_{it}$$

	1	2	3	4	5	6	7	8	9	10
control, pre	5.496	4.998	5.399	4.972	6.234	-2.967	2.741	7.657	0.834	7.862
	(70.73)	*(20.62)*	*(49.65)*	*(19.80)*	*(6.65)*	*(-3.36)*	*(3.61)*	*(3.77)*	*(0.37)*	*(3.82)*
treated group	0.565	0.548	0.566	0.552	0.557	0.194	0.543	0.560	0.190	0.556
	(5.86)	*(6.38)*	*(5.85)*	*(6.39)*	*(6.30)*	*(2.06)*	*(6.10)*	*(5.93)*	*(1.88)*	*(5.87)*
post-reform period	-0.093	-0.164								
	(-1.10)	*(-2.05)*								
diff-in-diff	**0.115**	**0.224****	**0.123**	**0.227****	**0.212***	**0.184***	**0.228****	**0.214***	**0.179**	**0.213***
	(0.94)	***(2.05)***	***(1.01)***	***(2.06)***	***(1.89)***	***(1.70)***	***(2.03)***	***(1.86)***	***(1.61)***	***(1.85)***
ln(employment lag)						0.143			0.0585	
						(1.37)			*(0.52)*	
ln(real turnover lag)						0.506			0.594	
						(6.46)			*(7.77)*	
empl. growth (lag)								0.212	0.396	
								(1.97)	*(3.33)*	
turn. growth (lag)								-0.028	-0.204	
								(-0.52)	*(-3.03)*	
sector dummies	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
sector*year	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
No of obs	3218	3218	3218	3218	3218	3199	3199	2902	2902	2902

t-values in brackets below the coefficient
standard errors clustered at the enterprise level

Table 5: Results (II)

$$r_{it} - l_{it} = \gamma + \delta_D D_i + \delta_T T_t + \delta_I D_i T_t + x'_{it}\beta_x + \nu_{it}$$

	1	2	3	4	5	6	7	8	9	10
control, pre	0.479	-0.031	0.337	-0.0985	1.738	-4.672	-2.124	1.884	-0.928	2.082
	(6.34)	*(-0.15)*	*(3.23)*	*(-0.45)*	*(1.83)*	*(-5.78)*	*(-3.01)*	*(0.92)*	*(-0.42)*	*(1.01)*
treated group	0.097	0.086	0.097	0.088	0.094	0.007	0.078	0.095	0.025	0.091
	(1.05)	*(1.04)*	*(1.04)*	*(1.06)*	*(1.11)*	*(0.08)*	*(0.91)*	*(1.04)*	*(0.26)*	*(0.99)*
post-reform period	-0.091	-0.156								
	(-1.08)	*(-1.99)*								
diff-in-diff	**0.107**	**0.216****	**0.117**	**0.219****	**0.210***	**0.187***	**0.228****	**0.214***	**0.170**	**0.213***
	(0.90)	***(2.05)***	***(0.98)***	***(2.07)***	***(1.95)***	***(1.76)***	***(2.11)***	***(1.92)***	***(1.56)***	***(1.91)***
ln(employment lag)						-0.402			-0.515	
						(-4.31)			*(-5.37)*	
ln(real turnover lag)						*0.470*			*0.561*	
						(6.30)			*(7.62)*	
empl. growth (lag)								0.206	0.383	
								(2.07)	*(3.56)*	
turn. growth (lag)								-0.032	-0.205	
								(-0.66)	*(-3.13)*	
sector dummies	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
sector*year	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
No of obs	3218	3218	3218	3218	3218	3199	3199	2902	2902	2902

t-values in brackets below the coefficient
standard errors clustered at the enterprise level

4.2 Robustness checks

The results presented in the preceding section are robust to estimating the model at the reporting unit level, using sectors of R&D rather than sectors of activity to define the manufacturing subsample and the sector dummy variables, and using the turnover criterion in addition to employment to define the treatment group.

Placebo tests have been run with a difference-in-differences variable for all other years available in the data, and no effect has been found in any other year than 2003. Had the effect been driven by the more productive firms that may be surviving in the treatment group differentially more than the control group, we would have observed a significant difference-in-difference in other years of the analysis as well.

The main concern in a policy setting where the announcement of the policy predates implementation is that beneficiaries may adjust their investment behavior after the announcement but prior to implementation to obtain the maximum gain from it. In the case of the R&D Tax Relief schemes in the UK, neither the SME nor the large company scheme came as a surprise for the firms that were going to benefit.

The expected behavior of a forward-looking profit maximizing firm would be to delay some R&D investment spending after the announcement until after the implementation of the policy, or maybe even until the firm's first complete tax year after the introduction of the tax credit, to avoid the apportionment of the benefit. For example, any R&D undertaken in the period January-December 2002 would attract only 75 percent of the credit, while R&D undertaken in January-December 2003 would attract 100 percent of the credit. Consultations for the large company scheme were launched with the 2001 Budget, a year prior to implementation (Figure 6). In this case one may observe a drop after the announcement but before the introduction of the policy, and then an overshoot of R&D investment shortly after the policy has been introduced as all the postponed investment would tend to be made in these early periods. If this were the case, then what we observe as the difference-in-difference effect could solely have been the reflection of postponement of R&D spending to a later date, rather than a genuine increase in R&D spending as a result of the policy.

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. In the context of the large company scheme, omission of the years 2002 and 2003 achieves this objective. Table 6 reports results for the same specifications presented in Table 4, but with observations for these two years excluded from the sample. The estimated impact of the introduction of the tax credit for larger firms remains very similar to that obtained using the full sample, suggesting an increase in R&D by approximately 19-22 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 tax credit in April 2002. Results with R&D per worker as the dependent variable reported in Table 7 are very similar to the finding in Table 6.

4.3 Discussion

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 a robust 18-23 percent increase in R&D spending after the enterprises in the treatment group became eligible for this tax incentive.

The ONS data allows us to estimate that the total R&D spending in the size band of interest for this study (100-399 employees) in 2003 by the manufacturing sector was about £747 million. Using micro level data on BERD, we can estimate that 68 percent of this, or £506 million, was done by the enterprises in the treatment group (250-399 employees). If our most modest estimate of an 18 percent increase applied to all R&D undertaken by manufacturing firms with 250-399 employees, then the additional R&D generated for this size group would have been about £77 million in 2003 prices.

From the estimate of 18-23 percent, one can back out the elasticity of R&D with respect to its user cost, utilizing the finding that the introduction of the large company scheme resulted in a reduction in the user cost of R&D by about 13 percent in the UK (Bond and Guceri (2012)). The lower bound of 18 percent increase in spending therefore corresponds to a user cost elasticity estimate of about -1.35.

Table 6: Robustness Checks (I) - 2002-2003 omitted, dep. var. real R&D (natural log)

	1	2	3	4	5	6	7	8	9	10
control, pre	5.484	2.236	5.596	4.86	6.234	-3.142	2.575	-0.428	-7.524	-0.542
	(66.76)	*(9.10)*	*(55.24)*	*(15.61)*	*(4.79)*	*(-4.23)*	.	*(-0.36)*	*(-4.46)*	*(-0.44)*
treated group	0.552	0.555	0.552	0.557	0.564	0.203	0.549	0.563	0.199	0.562
	(5.40)	*(6.05)*	*(5.39)*	*(6.05)*	*(5.95)*	*(1.99)*	*(5.76)*	*(5.52)*	*(1.85)*	*(5.49)*
post-reform period	-0.0847	-0.13								
	(-0.88)	*(-1.44)*								
diff-in-diff	0.16	0.221	0.171	0.225	0.211	0.191	0.226	0.221	0.19	0.217
	(1.17)	*(1.81)*	*(1.25)*	*(1.84)*	*(1.69)*	*(1.58)*	*(1.80)*	*(1.71)*	*(1.53)*	*(1.67)*
ln(employment lag)						0.128			0.0196	
						(1.09)			*(0.15)*	
ln(real turnover lag)						0.511			0.618	
						(5.86)			*(7.50)*	
empl. growth (lag)								0.254	0.463	
								(2.05)	*(3.28)*	
turn. growth (lag)								-0.0463	-0.231	
								(-0.74)	*(-3.21)*	
sector dummies	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
sector dummies*year	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
No of obs	2608	2608	2608	2608	2608	2594	2594	2311	2311	2311

t-values in brackets below the coefficient
standard errors clustered at the enterprise level

Table 7: Robustness Checks (II) - 2002-2003 omitted, dep. var. real R&D per worker (natural log)

	1	2	3	4	5	6	7	8	9	10
control, pre	0.465	-2.576	0.576	-0.207	1.857	-4.865	-2.04	-5.584	-9.486	-5.701
	(5.82)	*(-6.72)*	*(5.72)*	*(-0.79)*	*(1.41)*	*(-7.93)*	.	*(-4.74)*	*(-6.08)*	*(-4.75)*
treated group	0.090	0.099	0.089	0.100	0.106	0.024	0.088	0.102	0.033	0.101
	(0.92)	*(1.12)*	*(0.90)*	*(1.12)*	*(1.16)*	*(0.25)*	*(0.97)*	*(1.04)*	*(0.33)*	*(1.03)*
post-treatment period	-0.0763	-0.115								
	(-0.81)	*(-1.29)*								
diff-in-diff	0.142	0.202	0.154	0.206	0.197	0.179	0.214	0.208	0.169	0.204
	(1.06)	*(1.71)*	*(1.16)*	*(1.75)*	*(1.64)*	*(1.52)*	*(1.78)*	*(1.68)*	*(1.39)*	*(1.63)*
ln(employment lag)						-0.422			-0.553	
						(-4.08)			*(-5.27)*	
ln(real turnover lag)						0.475			0.591	
						(5.82)			*(7.61)*	
empl. growth (lag)								0.264	0.457	
								(2.29)	*(3.58)*	
turn. growth (lag)								-0.057	-0.234	
								(-1.02)	*(-3.36)*	
sector dummies	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
sector dummies*year	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
No of obs	2608	2608	2608	2608	2608	2594	2594	2311	2311	2311

t-values in brackets below the coefficient
standard errors clustered at the enterprise level

5 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 with the introduction of the SME Tax Relief Scheme, followed by the large company scheme in 2002. In this study, the gap in the timings of these two policies was utilized to obtain difference-in-difference estimates of the impact of the large firm tax credit on those large firms that are closest in size to the largest SMEs, which were already benefiting from the SME scheme when the large company scheme was introduced.

Tax credits have a direct effect on the user cost of R&D capital, or the required rate of return from the marginal R&D project which is just sufficient for the project to be commercially viable. Based on the neoclassical optimal capital accumulation framework, an inverse relationship between the user cost of R&D and the firm's investment in R&D can be expected. Motivated by this theoretical background, the empirical specifications in this paper examined the effects of the introduction of the large company tax credit scheme on R&D spending and on R&D per worker at the enterprise level.

Controlling for firm size and growth using employment and turnover, more importantly, for changes in the sectoral composition of our samples using dummy variables for two digit sectors of activity (and their interactions with time), we found that treatment group companies which started to benefit from the large company scheme in the 2002-03 fiscal year increased their R&D spending by around 18 percent in comparison to the control group after the introduction of the policy. The announcement of the scheme pre-dated implementation by about a year; therefore, we conducted robustness checks to verify that the effect found in this study was not simply a result of the postponement of R&D spending to the period after the introduction of the scheme.

The robust 18 percent increase over the counterfactual scenario of no tax credits for large firms corresponds to an elasticity of R&D with respect to its user cost of around -1.35. If we assume that the estimate of an 18 percent increase applies to all R&D undertaken by manufacturing firms with 250-399 employees, then the additional R&D generated for this size group would have been about £77 million in 2003 prices. Given that the total cost of the large company scheme to the Exchequer was £340million, and assuming that the treated firms in our sample would be responsible for the same share of the cost as their share in total R&D, we may argue that the firms in our treatment group was responsible for a cost of about £20 million in foregone taxes. This then translates to the generation of an additional £3.85 in R&D per pound foregone in taxes.

According to our findings, the UK R&D tax incentive scheme has been successful in generating a considerable amount of additional R&D spending by the business sector. Further research may seek to shed light on the decomposition of this improved performance into different expenditure items such as researcher salaries and newly hired researchers, using more detailed data.

A Data appendix

A.1 Data cleaning

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. Missing values for the enterprise references in BERD have been filled using the ARD, which contains both the reporting unit and enterprise reference numbers. Other information in ARD has not been used due to the low overlap between the BERD and ARD stratified sample for firms in the size range which is the main focus of this study.

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 control 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 aggregated to the enterprise level to match with BSD. For enterprises with multiple reporting units, only those that have all associated reporting units with non-imputed values have been kept. The procedure of removing reporting units with imputed values reduced the sample size substantially, while the fact that all reporting units needed to be aggregated to the enterprise level did not seriously worsen the reduction in sample size.

Similar to ARD, BERD provides information on both the reporting unit and enterprise references for each observation, but around a total of 40,000 observations appear to be missing the enterprise reference numbers in BERD for the years included in this study[19]. To remedy this problem, the ARD dataset was used, completing a significant portion of the missing enterprise references in BERD. This was possible, because the micro level ARD dataset with some basic information is available for all observations, even if they are not selected for sampling in a given year. Other information in ARD than the reporting unit-enterprise reference mapping was not used, as the sampling ratios in ARD are different from those

[19] By an observation, here we mean a unique reporting unit-year combination.

in BERD for the size range of interest in this study and we did not observe sufficient overlap between sampled observations in BERD and ARD in the relevant size range[20].

In order to match the data with the business register, it was necessary to sum reporting unit values to the enterprise level as BSD is provided at the enterprise level, which is also a more meaningful economic unit in comparison to the reporting unit to run the analyses. Nevertheless, we later ran robustness checks at the reporting unit level and observed that the results were not highly affected by the change in units. Table 8 presents the number of observations left in various data cleaning steps. The number of non-imputed observations are also presented in this Table, where it can be seen that sampled enterprises constitute a small fraction of total enterprises which were identified as conducting R&D. Appendix A.2 provides further information about the imputed values in the BERD data set. In the Table, the number of enterprises which only have one reporting unit, and the number of enterprise groups that only have one enterprise are provided to give an idea about the group structures, and also the large overlap between the reporting unit and the enterprise.

Table 8: Number of reporting units and enterprise references across years

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006
All BERD, total rows	14,906	14,226	16,272	15,666	19,407	17,141	19,384	20,364	24,251
All BERD, total real responses	2,037	3,168	3,051	3,103	3,132	3,017	3,166	3,036	2,769
Unique rep unit year obs in BERD	9,197	8,544	9,515	9,506	11,896	10,334	12,783	13,874	18,018
Unique rep unit year real responses in BERD	1,369	2,384	2,344	2,472	2,483	2,519	2,641	2,529	2,252
Rep units singly attached to an enterprise	8,552	7,920	8,645	8,850	10,945	10,064	12,361	13,186	17,552
Total BERD represented by the rep units singly attached to an enterprise	76%	80%	81%	77%	85%	80%	69%	69%	74%
Unique entref year obs in collapsed BERD	8,622	7,987	8,729	8,937	11,055	10,167	12,529	13,301	17,672
Number of entref year observations with all non-imputed rep unit observations	1,296	2,303	2,248	2,383	2,342	2,406	2,492	2,389	2,094
Number of entref year observations with all imputed rep unit observations	7,292	5,654	6,437	6,509	8,646	7,702	9,978	10,853	15,516
Number of entref year observations with some imputed rep unit observations therefore needed to be dropped	34	30	44	45	67	59	59	59	62
Number of entref year observations with all non-imputed rep unit observations-all unmatched entrefs to BSD	1,232	2,239	2,186	2,300	2,268	2,317	2,440	2,279	2,060
Unmatched to BSD	64	64	62	83	74	89	52	110	34
Number of enterprise groups in the resulting data set	1,059	1,949	1,975	2,127	2,114	2,178	2,244	2,164	1,944
Enterprises singly attached to an enterprise group	972	1,797	1,846	2,014	2,008	2,080	2,118	2,089	1,861
Number of groups with more than a single enterprise	87	152	129	113	106	98	126	75	83
Total BERD represented by enterprises singly attached to an enterprise group (within this 'non-imputed, BSD-matched' data set	59%	44%	54%	69%	67%	74%	80%	86%	77%
Filter further to, real R&D>£10K and non-missing; number of enterprises	1,188	2,095	2,041	2,152	2,163	2,192	2,316	2,162	1,965
Filter further to real R&D>£10K and non-missing, active, employment size band 100-400; number of enterprises	347	598	523	517	442	472	730	485	448
Filter further to real R&D>£10K and non-missing, active, employment size band 100-400 and manufacturing; number of enterprises	265	454	396	376	286	324	551	293	273

[20]ARD contains important information such as gross value added and other variables from the Annual Business Inquiry.

A.2 Imputed values in BERD

For the analyses in this paper, the BERD data set has some drawbacks, which arise from its sampling procedures. There are 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 the given 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 such as 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. In the micro level data set, unfortunately there is no short-form based information on the number of R&D personnel or 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.

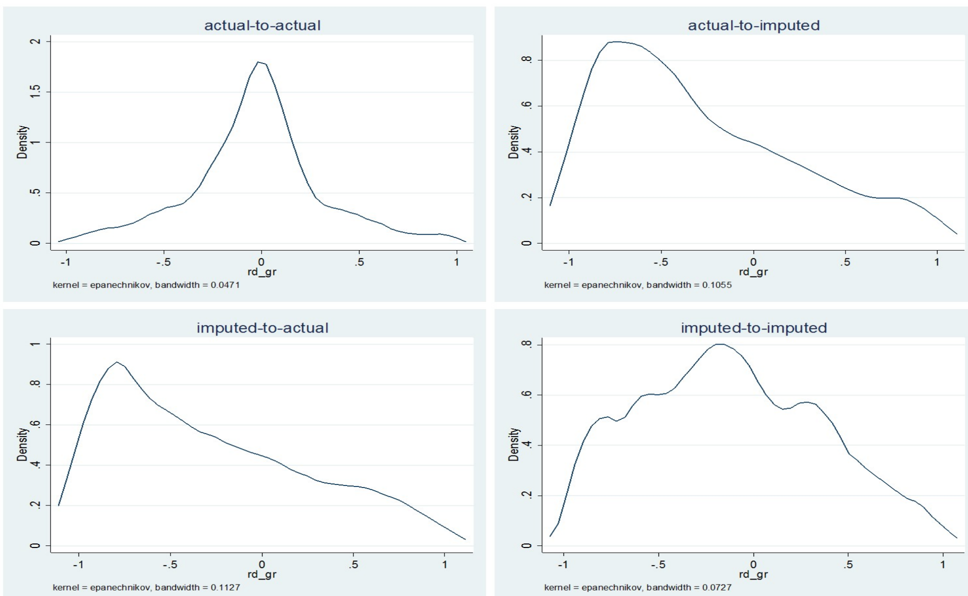
The group of smaller firms (as they are less likely to be among the top 400 spenders) are subject to sampling at different sampling fractions depending on their size measured by employment. Since the stratified sampling procedure is repeated every year, this causes many gaps in the time series data, making it difficult to obtain a clean panel structure with the same firm being followed across time. Based on the publicly available BERD First Release data[21], 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. In our size band of interest, which has firms with 100-400 employees, the sampling ratio is 1:3. The smallest firms, that is, those with less 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

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

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 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 11 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 11: Kernel density estimates for y-o-y real growth in R&D, size band 100-399



While aggregating from the reporting unit level to the enterprise level, it would not be consistent to add up an imputed value with a nonimputed value, hence we only aggregate the nonimputed values for each observation where available. For the enterprise-year observations which include an imputed value by one of the reporting units, the whole enterprise-year observation is considered as 'missing'.

A.3 Sector distribution of enterprises

Heterogeneities across treatment and control groups in terms of their sectoral compositions have been discussed in Section 3.4. Table 3 demonstrated that the change in sectoral compositions over time requires us to control for sectors in the estimation stage. More detailed evidence on this can be observed in Table 9, where the distribution of observations over two digit manufacturing sectors is presented. In the Table, columns represent number of observations in a given sector, period (pre or post) and treatment or control group. The percentages show the share of observations in the sector for a given cell, where a cell can be one of the following: (i) control group pre-treatment, (ii) control group post-treatment, (iii) treatment group pre-treatment, and (iv) treatment group post-treatment.

Table 9: Distribution of enterprise-year observations across two digit sectors

			TREATMENT GROUP				CONTROL GROUP			
	OECD class	Own class	pre	%in tot	post	%in tot	pre	%in tot	post	%in tot
Food, beverages, tobacco	L	L	47	5%	52	7%	31	4%	35	5%
Textiles and clothes	L	L	36	4%	17	2%	24	3%	13	2%
Wood, paper, publishing, printing	L	L	19	2%	15	2%	20	3%	23	3%
Refined petroleum	ML	M	..	..	..	..	..	..	..	..
Chemicals	MH	M	130	13%	75	11%	91	12%	90	12%
Pharmaceuticals	H	H	29	3%	15	2%	11	1%	36	5%
Rubber and plastics	ML	L	56	5%	44	6%	29	4%	38	5%
Nonmetallic minerals	ML	L	29	3%	17	2%	20	3%	24	3%
Basic iron and ferro alloys	ML	L	..	..	..	..	..	..	..	..
Nonferrous metals	ML	L	14	1%	20	3%	..	..	..	..
Fabricated metal products	ML	L	45	4%	23	3%	38	5%	29	4%
Machinery	MH	M	166	16%	114	16%	145	19%	111	15%
Office machinery and computers	H	H	26	3%	18	3%	18	2%	15	2%
Electrical machinery	MH	M	90	9%	60	9%	60	8%	44	6%
Radio, TV, communication	H	H	74	7%	71	10%	64	8%	93	13%
Precision instruments	H	H	121	12%	64	9%	90	12%	82	11%
Motor vehicles	MH	L	56	5%	40	6%	25	3%	32	4%
Railway, rolling stock	MH	M	..	..	..	..	..	..	..	..
Shipbuilding	ML	L	..	..	..	..	..	..	..	..
Aircraft, spacecraft	H	M	16	2%	13	2%	..	..	..	..
Furniture	L	L	29	3%	20	3%	33	4%	26	4%
Recycling	L	M	..	..	..	..	..	..	..	..
Total			1021		704		756		737	

.. represents disclosive figures. Columns add up to 100 percent including these figures.

OECD technology classes: L: low technology, ML: medium low technology, MH: medium high technology, H: high technology

Technology classes according to own sample: L: low technology, M: medium technology, H: high technology

References

Acs, Z. J. and Audretsch, D. B., editors (1993). *Small firms and entrepreneurship: an East-West perspective*. Cambridge University Press. Available at SSRN: http://ssrn.com/abstract=1496202.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, NBER Chapters, pages 609–626. National Bureau of Economic Research, Inc.

Bloom, N., Chennells, L., Griffith, R., and Reenen, J. V. (1997). How has tax affected the changing cost of R&D? evidence from eight countries. IFS Working Papers W97/03, Institute for Fiscal Studies.

Bloom, N., Draca, M., and Reenen, J. V. (2011). Trade induced technical change? the impact of chinese imports on innovation, it and productivity. NBER Working Papers 16717, National Bureau of Economic Research, Inc.

Bloom, N., Griffith, R., and Reenen, J. V. (2002). Do R&D tax credits work? Evidence from a panel of countries 1979-1997. *Journal of Public Economics*, 85(1):1 – 31.

Bond, S. R. and Guceri, I. (2012). Trends in UK BERD after the introduction of R&D tax credits. Working Papers 1201, Oxford University Centre for Business Taxation.

Corchuelo, B. and Martinez-Ros, E. (2009). The effects of fiscal incentives for R&D in spain. Open Access publications from Universidad Carlos III de Madrid info:hdl:10016/3870, Universidad Carlos III de Madrid.

Czarnitzki, D., Hanel, P., and Rosa, J. M. (2011). Evaluating the impact of R&D tax credits on innovation: a microeconometric study on Canadian firms. *Research Policy*, 40:217–229.

GAO (1989). The research tax credit has stimulated some additional research spending. Technical Report GAO/GGD-89-114, US General Accounting Office.

GAO (2009). The research tax credit's design and administration can be improved. Technical Report GAO-10-136, US Government Accountability Office.

Goolsbee, A. (1998). Does government R&D policy mainly benefit scientists and engineers? *American Economic Review*, 88(2):298–302.

Griffith, R. and Harrison, R. (2003). Understanding the UKs poor technological performance. Technical report, Institute for Fiscal Studies.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *Bell Journal of Economics*, 10(1):92–116.

Hall, R. E. and Jorgenson, D. W. (1967). Tax policy and investment behavior. *The American Economic Review*, 57(3):pp. 391–414.

Harris, R., Li, Q. C., and Trainor, M. (2009). Is a higher rate of R&D tax credit a panacea for low levels of R&D in disadvantaged regions? *Research Policy*, 38(1):192 – 205.

Jorgenson, D. W. (1963). Capital theory and investment behavior. *The American Economic Review*, 53(2):pp. 247–259.

Jorgenson, D. W. in Duesenberry, J., Kuh, E., Fromm, G., and Klein, L. (1965). *The Brookings Quarterly Econometric Model of the United States*, chapter Anticipations and Investment Behavior, pages 35–92. Rand McNally.

Lokshin, B. and Mohnen, P. (2012). How effective are level-based R&D tax credits? evidence from the netherlands. *Applied Economics*, 44(12):1527–1538.

Mairesse, J. and Mulkay, B. (2011). Evaluation de l'impact du crdit impot recherche. Working Papers 2011-35, Centre de Recherche en Economie et Statistique.

Michaelis, C., King, K., and Radevsky, A. (2010). Qualitative research into businesses research and development (R&D) decision-making processes. Technical Report 101, HM Revenue and Customs.

Nadiri, M. I. and Rosen, S. (1969). Interrelated factor demand functions. *American Economic Review*, 59(4):457–71.

OECD (2002). *OECD Frascati Manual*, 2002 edition.

OECD (2003). Oecd science, technology and industry scoreboard 2003. Technical report, OECD. url = "/content/book/sti_scoreboard-2003-en".

Pavcnik, N. (2002). Trade liberalization, exit, and productivity improvements: Evidence from chilean plants. *Review of Economic Studies*, 69(1):245–276.

Rogers, M. (2010). R&D and productivity: using uk firm-level data to inform policy. *Empirica*, 37(3):329–359.

Steer, C. (2012). Coherence of UK research & development statistics. Office for National Statistics.

Treasury, H. M., editor (2011). *Budget 2011*. United Kingdom. Retrieved from: http://www.official-documents.gov.uk.

Van Reenen, J. (1997). Why has britain had slower R&D growth? *Research Policy*, 26(4-5):493–507.

Wilson, D. J. (2009). Beggar thy neighbor? the in-state, out-of-state, and aggregate effects of R&D tax credits. *The Review of Economics and Statistics*, 91(2):431–436.

Datasets:

Office for National Statistics, Business Expenditure on Research and Development, 1994-2008: Secure Data Service Access. Colchester, Essex: UK Data Archive, March 2011. SN: 6690, http://dx.doi.org/10.5255/UKDA-SN-6690-1

Office for National Statistics, Business Structure Database, 1997-2011: Secure Data Service Access. 3rd Edition. Colchester, Essex: UK Data Archive, October 2012. SN: 6697, http://dx.doi.org/10.5255/UKDA-SN-6697-3

Office for National Statistics, Annual Respondents Database, 1973-2009: Secure Data Service Access. 3rd Edition. Colchester, Essex: UK Data Archive, June 2012. SN: 6644, http://dx.doi.org/10.5255/UKDA-SN-6644-3

Oxford University Centre for Business Taxation
Working Paper series recent papers

WP 15/10 Rita de la Feria and Parintira Tanawong *Surcharges and penalties in UK tax law*

WP 15/09 Ernesto Crivelli, Michael Keen, Ruud de Mooij *Base erosion and profit-shifting in developing countries*

WP 15/08 Judith Freedman *Managing tax complexity: the institutional framework for tax policy-making and oversight*

WP 15/07 Michael P Devereux, Giorgia Maffini and Jing Xing *Corporate tax incentives and capital structure: empirical evidence from UK tax returns*

WP 15/06 Li Liu and Ben Lockwood *VAT notches*

WP 15/05 Clemens Fuest and Li Liu *Does ownership affect the impact of taxes on firm behaviour? Evidence from China.*

WP 15/04 Michael P Devereux, Clemens Fuest and Ben Lockwood *The taxation of foreign profits: a unified view*

WP 15/03 Jitao Tang and Rosanne Altshuler *The spillover effects of outward foreign direct investment on home countries: evidence from the United States*

WP 15/02 Juan Carlos Suarez Serrato and Owen Zidar *Who benefits from state corporate tax cuts? A local labour markets approach with heterogeneous firms*

WP 15/01 Ronald B Davies, Julien Martin, Mathieu Parentis and Farid Taboul *Knocking on Tax Haven's Door:Multinational firms and transfer pricing*

WP 14/27 Peter Birch Sørensen *Taxation and the optimal constraint on corporate debt finance*

WP 14/26 Johannes Becker, Ronald B Davies and Gitte Jakobs *The economics of advanced pricing agreements*

WP 14/25 Michael P Devereux and John Vella *Are we heading towards a corporate tax system fit for the 21st century?*

WP 14/24 Martin Simmler *Do multinational firms invest more? On the impact of internal debt financing on capital accumulation*

WP 14/23 Ben Lockwood and Erez Yerushalmi *Should transactions services be taxed at the same rate as consumption?*

WP 14/22 Chris Sanchirico *As American as Apple Inc: International tax and ownership authority*

WP 14/19 Jörg Paetzold and Hannes *Taking the High Road? Compliance with commuter tax allowances and the role of evasion spillovers*

WP 14/18 David Gamage *How should governments promote distributive justice?: A framework for analyzing the optimal choice of tax instruments*

WP 14/16 Scott D Dyreng, Jeffrey L Hoopes and Jaron H Wilde *Public pressure and corporate tax behaviour*

WP 14/15 Eric Zwick and James Mahon *Do financial frictions amplify fiscal policy? Evidence from business investment stimulus*

WP 14/14 David Weisbach *The use of neutralities in international tax policy*

WP 14/13 Rita de la Feria *Blueprint for reform of VAT rates in Europe*

WP 14/12 Miguel Almunia and David Lopez Rodriguez *Heterogeneous responses to effective tax enforcement: evidence from Spanish firms*

WP 14/11 Charles E McLure, Jack Mintz and George R Zodrow *US Supreme Court unanimously chooses substance over form in foreign tax credit*

WP 14/10 David Neumark and Helen Simpson *Place-based policies*

WP 14/09 Johannes Becker and Ronald B Davies *A negotiation-based model of tax-induced transfer pricing*

WP 14/08 Marko Koethenbuerger and Michael Stimmelmayr *Taxing multinationals in the presence of internal capital markets*

WP 14/07 Michael Devereux and Rita de la Feria *Designing and implementing a destination-based corporate tax*

WP 14/05 John W Diamond and George R Zodrow *The dynamic economic effects of a US corporate income tax rate reduction*

WP 14/04 Claudia Keser, Gerrit Kimpel and Andreas Oesterricher *The CCCTB option – an experimental study*

WP 14/03 Arjan Lejour *The foreign investment effects of tax treaties*

WP 14/02 Ralph-C. Bayer Harald Oberhofer and Hannes Winner *The occurrence of tax amnesties: theory and evidence*

WP14/01 Nils Herger, Steve McCorriston and Christos Kotsogiannisz *Multiple taxes and alternative forms of FDI: evidence from cross-border acquisitions*

WP13/25 Michael Devereux, Niels Johannesen and John Vella *Can taxes tame the banks? Evidence from European bank levies*

WP13/24 Matt Krzepkowski *Debt and tax losses: the effect of tax asymmetries on the cost of capital and capital structure*

WP13/23 Jennifer Blouin, Harry Huizinga, Luc Laeven, Gaëtan Nicodème *Thin capitalization rules and multinational firm capital structure*

WP13/22 Danny Yagan *Capital tax reform and the real economy: the effects of the 2003 dividend tax cut*

WP13/21 Andreas Haufler and Christoph Lülfesmann *Reforming an asymmetric union: on the virtues of dual tier capital taxation*

WP13/20 Michael Blackwell *Do the haves come out ahead in tax litigation? An empirical study of the dynamics of tax appeals in the UK*

WP13/19 Johannes Becker and Ronald B Davies *Learning and international policy diffusion: the case of corporate tax policy*

WP13/18 Reuven S Avi-Yonah *And yet it moves: taxation and labour mobility in the 21st century*

WP13/17 Anne Brockmeyer *The investment effect of taxation: evidence from a corporate tax kink*

WP13/16 Dominika Langenmayr and Rebecca Lesterz *Taxation and corporate risk-taking*

WP13/15 Martin Ruf and Alfons J Weichenrieder *CFC legislation, passive assets and the impact of the ECJ's Cadbury-Schweppes decision*

WP13/14 Annette Alstadsæter and Martin Jacob *The effect of awareness and incentives on tax evasion*

WP13/13 Jarkko Harju and Tuomos Matikka *The elasticity of taxable income and income-shifting between tax bases: what is "real" and what is not?*

WP13/12 Li Liu and Andrew Harper *Temporary increase in annual investment allowance*

WP13/11 Alan J Auderbach and Michael P Devererux *Consumption and cash-flow taxes in an international setting*

WP13/10 Andreas Haufler and Mohammed Mardan *Cross-border loss offset can fuel tax competition*

WP13/09 Ben Lockwood *How should financial intermediation services be taxed?*

WP13/08 Dominika Langenmayr, Andreas Haufler and Christian J bauer *Should tax policy favour high or low productivity firms?*

WP13/07 Theresa Lohse and Nadine Riedel *Do transfer pricing laws limit international income shifting? Evidence from European multinationals*

WP13/06 Ruud de Mooij and Jost Heckemeyer *Taxation and corporate debt: are banks any different?*

WP13/05 Rita de la Feria *EU VAT rate structure: towards unilateral convergence?*

WP13/04 Johannes Becker and Melaine Steinhoff *Conservative accounting yields excessive risk-taking - a note*

WP13/03 Michael P.Devereux, Clemens Fuest, and Ben Lockwood *The Taxation of Foreign Profits: a Unified View*

WP13/02 Giorgia Maffini *Corporate tax policy under the Labour government 1997-2010*

WP13/01 Christoph Ernst, Katharina Richter and Nadine Riedel *Corporate taxation and the quality of research & development*