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Effectiveness of Fiscal Incentives for R&D: Quasi-Experimental Evidence

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Abstract

With growing academic and policy interest in research and development (R&D) tax incentives, the question about their effectiveness has become ever more relevant. In the absence of an exogenous policy reform, the simultaneous determination of companies' tax positions and their R&D spending causes an identification problem in evaluating tax incentives. To overcome this identification challenge, we exploit a U.K. policy reform and use the population of corporation tax records that provide precise information on the amount of firm-level R&D expenditure. Using difference-in-differences and other panel regression approaches, we find a positive and significant impact of tax incentives on R&D spend- ing, and an implied user cost elasticity estimate of around -1.6. This translates to more than a pound in additional private R&D for each pound foregone in corporation tax revenue.

JEL Classification Numbers: H25, O31

Keywords: Tax incentives; corporation tax returns; quasi-experiment

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I. INTRODUCTION[1]

Many governments use tax incentives to stimulate private expenditure on research and development (R&D), including the majority of OECD countries and other large economies such as China, India, Brazil and Russia.[2] In the aftermath of the fiscal crisis, R&D tax incentives have become more generous in many countries, in the hope of improving competitiveness and stimulating long-run economic growth.

The rising popularity of R&D tax incentives was accompanied by a surge in the number of descriptive studies that pinned down strong correlations between R&D tax incentives as a policy instrument and increased R&D spending by the private sector.[3] In terms of establishing whether and to what extent tax incentives stimulate R&D spending, the literature confronts three main empirical challenges. The first main challenge, as described in Hall and Van Reenen (2000), is "...the intractability of finding exogenous variation in the user cost of capital (p. 450)." This identify problem of simultaneity between the user cost of capital and investment shocks arises both in the context of incentives for physical investment and in R&D investment. There is, therefore, a recent emphasis on evaluation of R&D policy based on evidence from quasi experiments, which could use changes in the tax price of R&D that are exogenous to firm investment decisions (for instance, Bronzini and Iachini 2014 and working papers by Agrawal and others 2014, Dechezlepretre and others 2016, and Guceri 2017).

The second important challenge faced by the literature is the scarcity of large-scale, administrative data that accurately reflects the characteristics and choices of the overall population of corporations. For many years, R&D surveys that are standardised across OECD countries have provided an important resource to develop the research that seeks to identify the causal effect of tax incentives for R&D (Lokshin and Mohnen 2012, Lokshin and Mohnen 2013, Mulkay and Mairesse 2013, Guceri 2017). Now, the availability of administrative data, which enables the precise measurement of the firms' marginal tax rates and the rates at which they

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[2] OECD (2014) reports that in 2013, 27 of the 34 OECD Member States offered tax incentives for R&D.

[3] Earlier studies include, among others, Mansfield (1986), Cordes (1989), Hines (1993), Griffith and others (1996), Bloom and others (1996). Hall and Van Reenen (2000) provides a detailed review.

obtain R&D tax incentives, offers an invaluable opportunity to carry out an accurate analysis of the impact of tax incentives on R&D spending (Rao 2016, forthcoming).

Third, the elasticity of the R&D user cost, similar to the elasticity of taxable income, depends on the tax system (Saez and others 2012, Slemrod and Gillitzer 2013). Each country with an R&D tax incentive scheme implements a different design. Often, these schemes are quite complex and difficult for firms to understand. Studies that estimate the elasticity of R&D with respect to its user cost using data from a complex system may face the additional issues of salience and compliance. In a complex policy design, even when an increase in the generosity of tax incentives is used as a policy experiment, the results may not fully reflect the reaction of firms to the reduction in the R&D user cost, but rather it may reflect the fi improved understanding of the system thanks to the publicity generated by the reform. Volume-based schemes, which base the benefits on the total amount of qualifying R&D performed in the reference period are easier to take up for firms than incremental schemes, which base the benefits on the increase in R&D spending from an earlier reference period. Incremental schemes have been found to trigger stop-and-go strategies among firms creating a potential inefficiency (Ientile and Mairesse, 2009).

Our paper makes three main contributions to the existing literature on R&D tax credits, while addressing the three challenges that we outlined above. First, we exploit a policy change in the SME threshold that made the R&D tax credit more generous for a group of firms that would otherwise be defined as large and entitled with a less generous tax credit. Remarkably, this definition change only applies for the purpose of the R&D tax credit (and no other incentive scheme in the United Kingdom) and there are no concurrent policy changes at the national level that are directly targeted at this group. This policy reform thus allows us to identify the causal effect of R&D tax incentives by addressing the simultaneous determination of R&D spending and its tax price in a quasi-experimental setting. Our difference-in-diff approach allows us to exploit both the cross-section and the time-series variation in the data, and we then verify these results with direct estimates of user cost elasticity in a pooled sample.

Second, we use a large-scale administrative dataset that links corporation tax records and qualifying R&D expenditures, which provides precise information on the amount of R&D spending that qualifies for the tax incentive, an indicator of each firm's eligibility for the particular type of R&D tax incentive, and other non-tax determinants of R&D spending. In particular, we observe among all the companies that claim R&D tax credits their precise status as SME or large company, and hence the precise amount of tax credit on their next pound of R&D investment. We use both the employment size from the firms' accounting data and the exact position of firms as SME or large based only on the information from the tax return. The use of multiple sources to identify treated firm addresses any measurement error issues that may arise from the misclassification of firms when other indicators are used. This provides a useful contrast to the recent working paper by Dechezlepretre and others (2016), which uses balance sheet information on fixed total asset size as a proxy for the SME/large company status.

Third, the R&D tax policy in the United Kingdom has the advantage of being relatively simple—the tax benefits that we study are in the form of enhanced deductions from the tax base and apply to the total amount of R&D every year for all firms that carry out R&D activities. Compared to the R&D tax incentive schemes in the United States, France, and many other OECD countries, the simplicity and transparency of the U.K. scheme alleviates many of the issues that may interact with the evaluation of the effectiveness of the R&D tax credit, such as questions about whether firms understand the scheme, salience or uncertainties regarding policy continuity. Since the introduction of the scheme, the U.K. government regularly held consultations with the beneficiaries to achieve high take up and salience. These characteristics of the U.K. policy allow us to analyze the effectiveness of the tax incentive in a simpler institutional setting.

During our sample period of 2002–11, the United Kingdom's R&D tax incentive scheme was in the form of enhanced deductions of R&D spending from taxable income, with small- and medium-sized enterprises (SMEs) enjoying a substantially more generous deduction rate than large companies. The policy reform that we focus on is an expansion in the SME definition that took effect in 2008, which doubled the thresholds measured in employment size, turnover, and total assets below which a company would be qualified as an SME. As a result, a number of companies that would have been classified as large companies under the old system became qualified as SMEs and were henceforth entitled to more generous deduction rates. The reform resulted in differential changes in the user cost of R&D faced by newly-classified SMEs compared to companies that remained as large, whose user cost of R&D remained roughly stable in the years before and after the reform.

We analyze the effect of this reform by linking the population of corporation tax and R&D spending records in the United Kingdom. We further link the tax record to the financial statement for each company and year for more information on other contemporaneous, non-tax determinants of R&D investment such as firm size, profitability and growth rate, which allows us to disentangle the true effect of the tax incentive from other confounding factors.

As a separate experiment, we analyze additional increases in the R&D tax relief rates that small companies (which remained small) experienced and verify our results. We describe all the relevant policy reforms and the changes to the statutory corporation rate which affect the user cost of R&D capital in detail in Section II. Incorporating all the tax changes that took place in 2008, for a profitable firm, the overall reduction in the tax component of the user cost of R&D capital amounts to 10–31 percent for a newly classified SME, depending on the size and the precise tax position of the company. In our data, companies which claimed R&D tax relief under the large company scheme before the reform and under the SME scheme after the reform experienced an average reduction in their user cost of R&D by about 21 percent between 2007 and 2009. By comparison, the reform brought almost no change in the user cost of R&D capital for companies that remained as large companies.[4]

We estimate the causal effect of the R&D tax relief on qualifying R&D expenditure using a difference-in-difference (diff-in-diff) approach by exploiting the differential change in the R&D tax incentives in 2008 between the treated and the control groups. The key identifying assumption is that the changes in R&D over time follow parallel trends for the treated and the

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[4] Due to the reduction in statutory tax rates and a 5 percentage point increase in the enhanced deduction rate under the R&D tax relief which partly offset each other, firms that were eligible to the large company relief both before and after the reform experienced a reduction in their user cost of capital of 0.3 percent, which we consider to be negligible. We discuss these policy changes in Section II.

control groups in the absence of a policy change. We present results from regressions with placebo policy interventions in each of the pre-reform years and demonstrate that there were no differential trends between the treated and the control groups.

Our main finding suggests that companies in the treatment group on average increased their R&D spending by about 26.4 percent in response to the increased generosity of tax incentives in 2008. The positive and significant effect of the change in R&D tax incentive is robust to controlling for aggregate macroeconomic shocks, other non-tax determinants of R&D investment, and any potential anticipation effects of companies in response to early announcement of the policy change.

Our empirical fisupport that tax incentives for R&D have a statistically significant, positive effect on the level of R&D spending for companies that were actively performing qualifying R&D both before and after the reform. Based on our diff-in-diff estimates, we can back out the implied estimate for the elasticity of R&D spending with respect to its user cost, which is around -1.55.[5] We present additional evidence to show that companies do not systematically relabel their ordinary investment expenditure as R&D spending to benefit from the larger tax deduction.

For each pound of foregone tax revenue, the qualifying R&D spending increases by around £1.30 for a company paying at the main rate of 28 percent and by around £0.8 for a company paying at the "small profits" rate of 21 percent.

The ultimate goal of promoting business R&D spending is to boost productivity. Hall and others (2010) gather examples from the vast empirical literature on the relationship between productivity of R&D, with the main conclusion that companies' spending in R&D have strongly positive private returns (larger than the returns to physical capital). There are additional spillover effects of R&D which benefit the society at large via its impact on other firms and consumers. Our current analysis focuses on the increase in private R&D spending thanks to the reduction in the tax price of this activity. The extent of the productivity effects of the generated additional R&D remains to be an important area for future research.

Our work relates to several strands of literature. First, our conceptual framework relies on the analogy between investment in physical capital and knowledge capital (Griliches 1979) within the neoclassical optimal capital accumulation framework in the spirit of Jorgenson (1963) and Hall and Jorgenson (1967). Recent empirical evaluations of fiscal incentives for physical investment include studies by Cummins and others (1994), Caballero and others (1995), Chirinko and others (1999), Edgerton (2010), Yagan (2015), Bond and Xing (2015), and Zwick and Mahon (2017), which estimate the elasticity of physical capital with respect to its user cost, as well as heterogeneities across firms in their responses to such incentives.[6] Second, our study links to the literature on the relationship between financing constraints, R&D and innovation policy and

[5] An earlier version of this paper estimated the user cost of capital to be around -2.3 (Guceri and Liu 2015). The revision to this estimate leaves the predictions and conclusions of the paper unaffected. This latter estimate is based on an alternative definition of the treatment group which takes into account both pre- and post-treatment size status. This calculation is available in Section 6.4 of the present paper.

[6] See Hassett and Hubbard (2002) for a recent survey on this topic.

productivity (Hall and others 2010, Hall and others 2015, Bloom and others 2002). Third, as highlighted earlier, this paper relates to recent studies on the effects of firm incentives for R&D using administrative data (Rao 2016 and Agrawal and others 2014). Some other studies explore the effects of corporate taxation on related outcomes such as patent location (Karkinsky and Riedel 2012), wages of R&D employees (Lokshin and Mohnen 2013) and new or improved products introduced to the market (Czarnitzki and others 2011).

Our findings have implications for R&D tax policy outside the United Kingdom. The current R&D tax scheme in the United Kingdom is permanent, relatively simple, and involves low administrative costs. These features of the R&D tax credit present a sharp contrast with the U.S. system, under which the R&D tax credit has only been made permanent in December 2015,[7] and has expired periodically since its introduction in 1981. The exact amount of R&D spending on which the tax credit applies involves a complicated computation and depends on the current-year R&D as well as R&D expenditures from previous years (an "incremental" scheme). Due to the incremental nature of the scheme, the amount of R&D tax credits in the current period can affect a firm's ability to take the credit in the future.[8] The French R&D tax credit used to be another example to complex R&D tax incentive schemes implemented in countries of comparable size. In its early years, the French R&D tax credit was designed as an incremental credit, which gradually switched to a simpler system until being transformed completely into a volume-based scheme in 2008 (Mulkay and Mairesse 2013). Finally, most jurisdictions (for example, Canada, France, and Norway) apply maximum spending limits, which may limit the effectiveness of R&D tax incentives for spending above the threshold. Overall, in many jurisdictions, the administrative cost borne by the firms that claim R&D tax credits is relatively high, and the exact level of R&D tax benefits available may be hard to understand for the beneficiaries. These complexities are likely to constitute part of the reason why the previous papers that use U.S. or French data have found smaller effects of the R&D tax credit in stimulating R&D spending. In the appendix, we provide a table summarizing the existing literature since the review paper by Hall and Van Reenen (2000) and list the countries and the datasets that are used in these studies. We argue that the U.K. scheme is by far the simplest and the one that remained the most homogeneous in terms of design throughout the sample period.[9]

In the remainder of the paper, we first describe the policy set up in Section II, followed by a discussion of the conceptual framework for the mechanism through which tax incentives increase R&D spending at the firm level (Section III). Section IV describes the data sources and summarizes the dataset used for the analysis. Section V explains the research design and Section VI reports the main results. Section VII concludes.

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[7] Protecting Americans from Tax Hikes Act of 2015.

[8] The complexity in computing the R&D tax credit is reflected in Equation (2) and Appendix B in Chang (2014). An earlier discussion is available in Eisner and others (1984).

[9] The United Kingdom introduced fundamental design changes, as well as a patent box policy in 2013, which is beyond our sample period.

II. Policy Background

The United Kingdom introduced its first R&D tax incentive scheme in 2000, in an effort to address its "productivity challenge"—a term that features frequently in many government documents and policy papers, referring to the U.K. private sector's modest performance in total factor productivity in comparison to other developed countries such as the United States, France, and Germany.[10]

R&D policy in the United Kingdom currently relies heavily on tax incentives. According to the OECD R&D tax incentive statistics,[11] about half of U.K. funding for business R&D was channeled through tax incentives in 2012. Throughout our sample period of 2002–11, the R&D tax relief schemes were in the form of enhanced deductions. In 2000, the U.K. R&D tax relief was introduced as a scheme targeted to SMEs, which were then defined as companies with fewer than 250 employees, and either a balance sheet size of less than €27 million or sales of less than €40 million.[12] In 2002, the scheme was extended to larger firms, albeit at lower deduction rates.

Until 2008, the SME scheme allowed companies to tax deduct £150 for every £100 spent on qualifying expenditures on R&D and the large company scheme allowed a deduction of £125 for every £100. A cash credit was (and still is) available for SMEs which are in a loss-making position and the amount of cash paid to such SMEs amounted up to 16 percent of the total surrenderable loss of the claimant.[13] In April 2008, the large company deduction rate increased from 125 to 130 percent and the SME deduction rate increased from 150 to 175 percent. The SME deduction rate was further increased to 200 percent in 2011. We present the relevant policy changes for our sample period in Figure 1.[14]

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[10] See, for example, the Budget Report by HM Budget, ed, 1999 for a reference on the U.K. perspective.

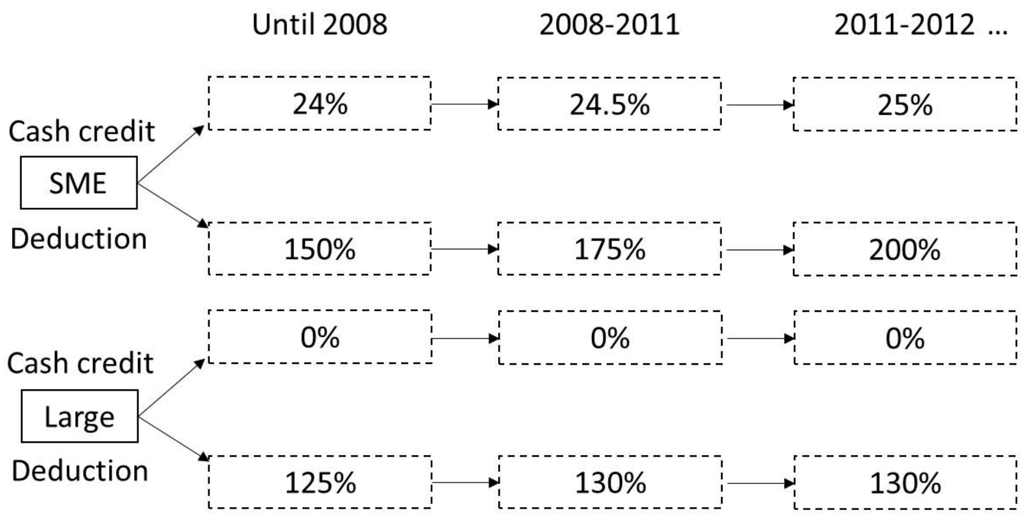
[11] Available at http://www.oecd.org/sti/rd-tax-stats.htm.

[12] The thresholds are defined in Euros as they are determined in accordance with the European Commission's definition of an SME due to EU State Aid regulations. In 2005, the balance sheet size threshold increased to €43 million and the turnover threshold increased to €50 million. Unlike the 2008 reform, the 2005 definition change applied to other tax allowances and benefits for SMEs in addition to the R&D tax breaks, since it was a result of an EU-wide definition change.

[13] See Appendix D for the details on cash benefits for SMEs.

[14] From 2013 onwards, an optional tax credit, which is directly deducted from the final tax liability of companies and is itself taxable, was introduced for large companies at a rate equivalent to the enhanced deduction rates (a taxable credit rate amounting to 10 percent of R&D expenditure). It was also announced that the large company scheme would completely switch to an above-the-line taxable credit from April 2016 onwards, and loss-making large companies are now also eligible for cash refunds.

Figure 1. Evolution of R&D Tax Relief Deduction Rates



The tax price of R&D during this period was also affected by gradual changes in the corporate tax rates summarized in Table 1. While the changes in the R&D enhanced deduction rates and the rates of corporation tax alter the tax price of R&D spending, the most dramatic reduction in the cost of marginal R&D investment for a group of firms was introduced with the August 2008 reform, which changed the definition of a small or medium-sized enterprise (SME) used to determine eligibility for the more generous tax treatment of R&D by doubling all the thresholds for defining an SME. We present the pre-reform and the post-reform size thresholds in Figure 2.

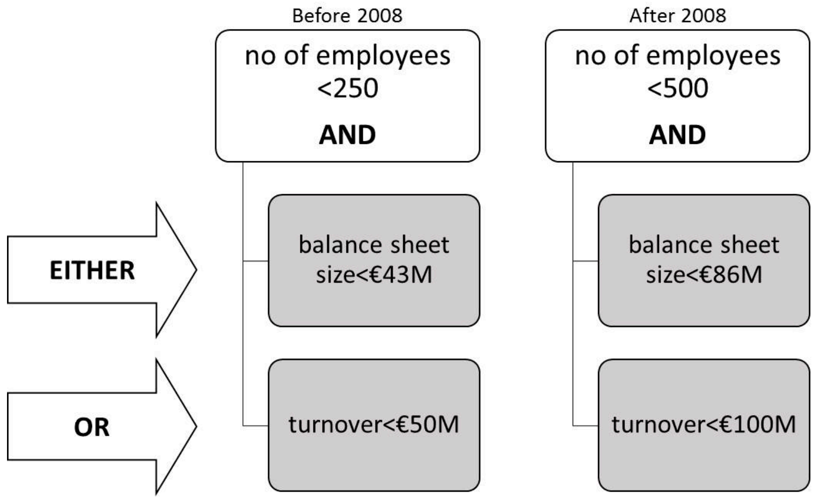
Table 1. Marginal Corporation Tax Rate in the United Kingdom, 2002–14 (Percent)

Taxable Profit (£)	2002–05	2006	2007	2008–10	2011	2012	2013	2014
0–10,000*	0	19	20	21	21	21	21	21
10,001–50,000	23.75	19	20	21	21	21	21	21
50,001–300,000	19	19	20	21	21	21	21	21
300,001–1,500,000	32.75	32.75	32.5	29.75	27.25	24.75	23.5	21
Above 1,500,000	30	30	30	28	26	24	23	21

Notes: In the years 2004 and 2005, the zero marginal tax rate was only available to profits that were retained within the company. For profits paid out to shareholders, the marginal tax rate was 19 percent.

Combining the effect of both the rate increases and the SME definition change, an SME that was previously labeled as "large" before the reform could deduct, for every £100 of qualifying R&D, £125 against its taxable profit in fiscal year 2007/08 and £175 in 2009/10. Newly-qualified SMEs also became eligible to claim cash if they incurred zero or negative taxable profits in the current fiscal year.

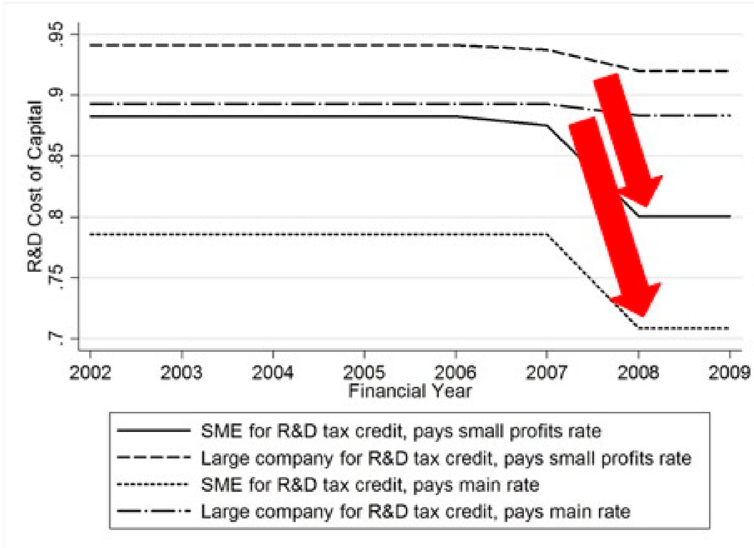
Figure 2. Size Thresholds for the SME Tax Relief



Against the backdrop of all these tax-related reforms, the tax component of the user cost of R&D evolved as depicted in Figure 3. We calculate the tax component of the user cost as $\frac{1-A}{1-\tau}$, where A is the value of tax incentives (all tax credits and deductions) for £1 spending in R&D and τ is the statutory tax rate. This formulation suggests that the value of tax credits and allowances A be obtained by multiplying $1 + d$, where d is the deduction rate, by the statutory tax rate (for example, $A = (1 + 0.5)\tau$ for an SME in the pre-2008 period). The distinction between corporation tax payments at the main rate or the small-profits rate applies to all the companies, independent of whether they perform R&D or not, and the rate applicable to a certain company depends on its taxable profits in a given year.

In Figure 3, a representative company that is eligible for the R&D tax relief for SMEs throughout the sample period experiences a drop in its user cost due to the increase in the deduction rate from 150 percent to 175 percent. The effect of the increase in the deduction rate from 125 to 130 percent for large companies on R&D user cost is partly offset by the decrease in the main statutory tax rate. The arrows indicate the transition for a company that was labeled as "large" before the SME definition change and as "SME" after this reform. A representative company that benefited from the definition change experienced a decrease in the R&D user cost by around 21 percent between 2007 and 2009 if paying at the small profits rate, and around 15 percent if paying at the main rate.

Figure 3. Tax Component of the User Cost of R&D on Current Spending



III. Conceptual Framework

Based primarily on the neoclassical optimal capital accumulation framework presented in Hall and Jorgenson (1967) and Jorgenson (1963), and treating investment in R&D analogously to investment in physical capital, we may consider a simple conceptual background for the response of firms to R&D tax incentives. Bond and Van Reenen (2007) review the literature on investment models of this type, and the notations here follow the convention adopted in their chapter.

We consider a Cobb-Douglas production function with R&D capital as the sole input.[15] Firms maximize the net present shareholder value subject to the law of motion for the accumulation of R&D capital. For each firm the production function is:

$$F(K_t) = AK_t^{\propto} \quad (1)$$

The firms' optimization problem is:

$$V_t(K_{t-1}) = max_{R_t}\{\Pi_t(K_t) + \beta_{t+1}\mathrm{E}_t\big(V_{t+1}(K_t)\big)\} \quad (2)$$

$$\text{subject to } K_t = (1-\delta)K_{t-1} + R_t \quad (3)$$

where δ is the depreciation rate and V_t is the maximised current value of the firm as a function of the knowledge capital accumulated in the firm denoted by K_{t-1}. Knowledge accumulates according to the law of motion expressed in Equation 3, with knowledge capital in time period t determined by the previous period's capital, net of depreciation, plus investment in new R&D, R_t.

[15] Bloom and others (2002), Mulkay and Mairesse (2013) provide applications with constant elasticity of substitution production functions in the R&D context.

$\beta_{t+1} = \frac{1}{1+r_{t+1}}$ is the rate at which the firm discounts future revenue, with r_{t+1} being the risk free interest rate representing the outside option of the firm.

Several simplifications are made in the derivations that follow. We assume no depreciation, and no adjustment costs for simplicity, and the firm finances all R&D by retained earnings. In addition, we assume price-taking firms in both the markets for their input and their output. In the presence of taxes, the current revenue of the firm is:

$$\Pi_t((K_t, R_t) = (1-\tau)[p_t\, F(K_t) - p_t^K R_t] + c p_t^K R_t \tag{4}$$

where τ is the corporation tax rate applied to firm profits and c is the tax credit rate on R&D investment,[16] p_t is the price of output at time t and p_t^K is the input price.

Substituting the constraint in the firms' objective function, we obtain the following firm order condition, yielding that the marginal product of R&D capital is equal to its user cost and pinning down the optimal level of R&D capital:

$$\frac{\partial V_t}{\partial K_t} = (1-\tau)[p_t\, F(K_t) - p_t^K] + c p_t^K + \beta_{t+1}\mathrm{E}_t[(1-\tau)p_{t+1}^K - c p_{t+1}^K] \tag{5}$$

$$F'(K_t) = \frac{p_t^K(1-\tau-c)}{p_t\,(1-\tau)}\left(1 - \beta_{t+1}\mathrm{E}_t\,\frac{p_{t+1}^K}{p_t^K}\right) \tag{6}$$

$$K_t^* = \left(\frac{1}{A\alpha}\frac{p_t^K}{p_t}\frac{(1-\tau-c)}{(1-\tau)}\left[1 - \beta_{t+1}\mathrm{E}_t\,\frac{p_{t+1}^K}{p_t^K}\right]\right)^{\frac{1}{\alpha-1}}, \tag{7}$$

where we denote $\kappa \equiv \frac{1}{A}\frac{p_t^K}{p_t}\frac{1}{(1-\tau)}\left[1 - \beta_{t+1}\mathrm{E}_t\,\frac{p_{t+1}^K}{p_t^K}\right]$.[17]

The response of R&D capital to an increase in the generosity of tax credits is therefore captured by:

$$\frac{\partial K_t^*}{\partial c} = \frac{1}{(1-\alpha)}\left(\frac{\kappa}{\alpha}\right)^{\frac{1}{\alpha-1}}(1-\tau-c)^{\frac{1}{\alpha}-1} \tag{8}$$

Equation 8 shows that firms respond to reductions in their user cost via tax incentives by increasing their R&D capital, as this partial derivative is always positive. In the empirical section, we use the flow variable for R&D instead of generating a conceptual "R&D capital stock." Given a short time series, the steady state assumption commonly used in the literature to initialize the R&D capital of the firm (in the spirit of Griliches 1979 and reviewed in Hall and others 2010) renders the R&D capital stock to be proportional to the flow measure. Hall and Mairesse (1995)

[16] In the United Kingdom, as explained in later sections, the tax incentives for SMEs have been in the form of deductions rather than credits, but accounting for this fact using an equivalent rate of deduction in place of a credit does not alter the results expressed in this section.

[17] We note that κ>0, since $\beta_{t+1}\mathrm{E}_t\,\frac{p_{t+1}^K}{p_t^K}$, following from the definition of the discount factor $\beta_{t+1} = \frac{1}{1+r_{t+1}}$ where r_{t+1} is the nominal interest rate, ruling out negative real interest rates in expectation.

present a comparison of R&D flow and stock variables in the context of estimating production functions and demonstrate that the results do not change between estimates that use stock and flow measures.

IV. Description of Datasets

We link three datasets to create the panel used in this study: (i) the universe of U.K. corporation tax assessments from the HM Revenue and Customs (CT600); (ii) the comprehensive R&D spending data provided by HMRC Specialist R&D Units; and (iii) annual company accounts from Bureau van Dijk's Financial Analysis Made Easy (FAME) Database.

The CT600 dataset includes the population of company tax records and provides information on the precise tax position of a company including its taxable profit loss brought forward, trading profit losses, and turnover. We link the CT600 dataset with a separate R&D spending dataset provided by the HMRC Specialist R&D Units, which form the micro data basis for the National Statistics publication on the R&D tax relief. The micro level R&D dataset contains precise information on, for each firm-year, the amount of R&D tax deductions and cash credits claimed and whether the company claimed under the SME scheme or the large company scheme. For SMEs, there is additional information on whether they claimed cash or carried losses forward and the total amount of subcontracted R&D for an SME.

The key advantage of using the R&D spending dataset is that it allows us to observe precisely the amount of qualifying R&D spending and the status of the company regarding whether it qualifies as an SME or large company for the purpose of the R&D tax relief. We complement the administrative tax records with company accounts in FAME to obtain additional information on company age and ownership structure. The fixed dataset covers years between 2002 and 2011 and includes 30,056 firm-years for companies that have undertaken some positive qualifying R&D spending both before and after the 2008 reform.[18]

According to the HMRC Corporate Intangibles and R&D (CIRD) Manual, there are three main categories of qualifying expenditures that are eligible to claim the R&D tax relief. These include: staffing costs, consumables (such as water and electricity), and software directly used in R&D.

According to the ONS estimates, the total current R&D spending by all U.K. businesses amounted to around £13.7 billion in 2005 and subsequently increased to around £17.4 billion in 2011 (in nominal terms). The ratio of total qualifying R&D spending that is observed in HMRC data to the aggregate current spending in BERD published by the ONS has risen from just over

[18] We use the total qualifying R&D spending numbers provided in the R&D micro datasets that are linked to the CT600. Calculation of qualifying R&D for each company was provided by the HMRC R&D statistics team. Combining information on enhanced R&D expenditure, total amount of subcontracted R&D and whether the company is SME or large, we are also able to back out the total qualifying R&D spending of each company in a given year. Specifically, we scale down the total annual R&D enhanced expenditure for a company by the deduction rate in the corresponding year, in line with the HMRC calculations (See Research and Development Tax Relief Statistics published by the HMRC). For example, an SME that reports £30,000 of enhanced deduction and £25,000 of SME claim under the large company scheme as sub-contractor before the 2008 rate changes must have undertaken a total qualifying R&D of £30,000 $*$ (100/150) + £25,000 $*$ (100/125) = £40,000.

50 percent to 70 percent between 2005 and 2011. Over the same period, the number of beneficiary companies from R&D tax incentives increased from 6,120 to 12,050, manifesting the increased take up of the policy. We do not expect our results to be affected by this increase in take up, as our experiments focus on companies that have already been benefiting from the scheme both before and after the 2008 reforms.

V. Empirical Approach

Throughout the sample period, the tax component of the user cost of R&D capital remained roughly stable for large companies that exceeded both the pre-2008 and post-2008 thresholds for what defines an SME (Figure 3). The group of large companies therefore constitutes a natural control group to benchmark treated firms' behavior.[19] A company is included in the control group if it carried out qualifying R&D in at least one of the years before 2008, and also in at least one of the years after 2008, and (i) is labeled as large in the last of such pre-reform years with positive R&D and, (ii) is also labeled as large in the firm of such post-reform years with positive R&D.[20] This approach therefore addresses an intensive margin question, estimating the policy effect for companies which were already performing qualifying R&D in the pre-reform period.[21]

A. Main Treatment Group: Large Companies that Were Reclassified as SME after 2008

The main policy reform that we exploit is based on the change in the size thresholds for defining an SME, which allows us to compare R&D spending in firm which became eligible to benefit from the more generous SME benefits. These companies therefore enjoyed enhanced deductions of up to £175 for every £100 spent in R&D in the post-reform period. In comparison, companies that remained as large saw an enhanced deduction of £130 for every £100 of R&D spending. In our main analysis, we first define a company as "treated" if it carried out qualifying R&D in at least one of the years before 2008, and also in at least one of the years after 2008, and: (i) is labeled as "large" in the last of such pre-reform years with positive R&D; and (ii) is labeled as "SME" in the first of such post-reform years with positive R&D. We calculate the reduction in the user cost of capital thanks to the 2008 reform for these companies.

If many firms are in a loss-making position, or if they are in different marginal tax rate brackets, then the value of the differential change in the enhanced deduction may vary across the groups. Therefore, in reality, the firms do not necessarily fall into one of the four categories whose user costs are depicted in Figure 3. This could mask the identifying variation in the user cost generated by the policy reform. To examine whether the actual average user cost of the firms' subject to the status change dropped as the theory predicts, we calculate for each company-year

[19] Empirically, companies are classified based on their pre-reform employment size as small (with less than 250 employees), medium (with employees between 250 and 500), or large (with more than 500 employees).

[20] We do not take the 2008 status into account, since the size definition change was introduced in August 2008, which is in the middle of the tax year.

[21] Note that the diff-in-diff approach does not allow us to address the responsiveness of R&D spending at the extensive margin. This is because we do not know the companies' SME or large statuses unless they are already spending in R&D.

observation a measure of the user cost of R&D capital to assess whether variation in the tax component of the user cost of capital indeed resembles the pattern depicted in Figure 3.

Figure 4 verifies the identifying variation in the tax component of the user cost triggered by the SME definition change in 2008. On average, medium-sized (treated) firms experienced a decline in their tax component of the cost of capital from 0.92 in the pre-treatment period to 0.76 in the post-treatment period, whereas that of the large group remained at 0.94 throughout the sample period.

Figure 4. Average User Cost of Capital across Treatment and Control Groups, Tax Component

Notes: The figure captures the user cost of R&D capital for firms that are: (1) "Treated:" claimed R&D tax deductions under the Large Company Scheme in the pre-reform period and under the SME Scheme in the post-reform period; and (2) "Control:" claimed R&D tax deductions under the Large Company Scheme in the pre- and post-reform period. We take into account size in the last pre-reform year and the first post-reform year in which the firm claimed some R&D tax enhancement. In the remainder of the paper, we take an "intent-to-treat" approach to define "Treated" and "Control."

Before proceeding to estimating the model, we refine the treatment definition to account for the fact that the post-reform size may be affected by the reform; because the binding threshold to determine SME status is the employment size, we use the employment size of companies to identify intent-to-treat in the refined version our treatment assignment.[22] We refer to this group of treated firms as the group of "medium sized companies." This group consists of those

[22] In robustness checks, we also include the results based on "actual" treatment, taking into account both the pre- and post-treatment assignment. For these results, see Section VI.4.

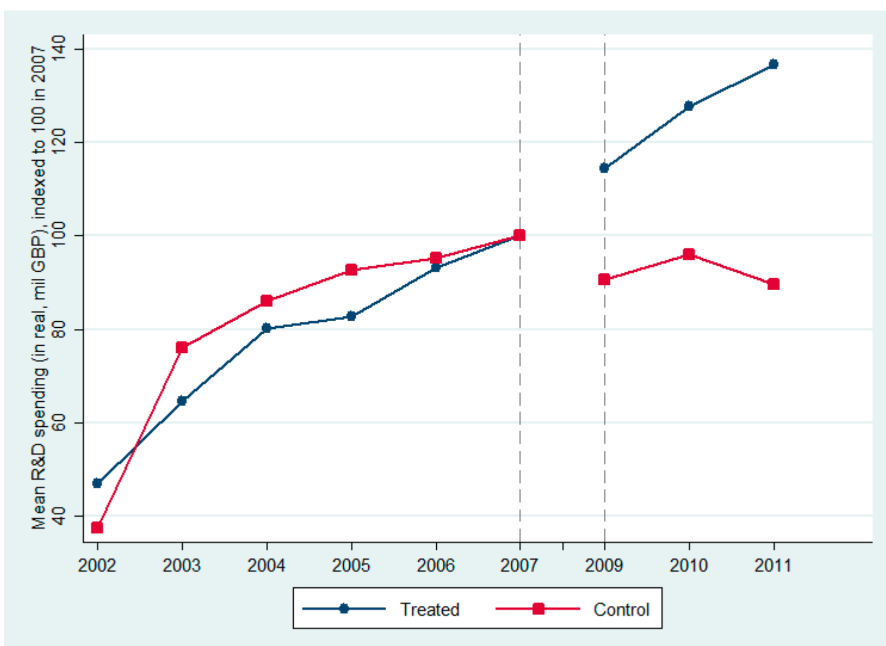
companies that had a size greater than or equal to 250 employees and fewer than 500 employees in the last year of the pre-treatment period.

The dataset for analyzing the 2008 SME definition change is an unbalanced sample that includes 247 firms in the treated group and 335 firms in the control group. Each firm is observed over multiple periods, and at least once before the reform and at least once afterwards. Figure 5 presents average firms spending in R&D by treatment and control groups. Graphically, there is no particular pattern that suggests violation of the common trends assumption in the levels of R&D. In the first year of implementation of the large company scheme, there appears to be a rapid increase in the average qualifying spending of large firms which may be attributable to take up by the larger fi in the fiyear of implementation of the large company relief. If anything, the inclusion of 2002 may work against finding an effect of the policy, but removing this year does not affect the results significantly.

We also present placebo tests to check if there was a differential change in R&D spending in each of the years for the treated group. We show that there were no significant differential increases for the treated group in any period before the reform (Table 2).

Appendix 2 provides further descriptive statistics on the treated and the control groups as defined by their pre-reform employment size groups. We form an alternative treatment group composed of only small companies that had fewer than 250 employees. We discuss this alternative treatment group in Appendix 3.

Figure 5. Average R&D Spending across Groups, Relative to 2007 R&D Spending



Notes: The underlying data used for this figure takes the mean of the real R&D spending (in £million) for each firm, then bases both the treated and control group mean level to 100 for comparability relative to the pre-reform spending.

Table 2. Placebo Reforms. Treatment: Large Companies Reclassified as SMEs after 2008

Placebo reform year	**2003**	**2004**	**2005**	**2006**	**2007**
Diff-in-diff	-0.171	0.079	0.129	0.194	0.19
	(0.237)	(0.166)	(0.135)	(0.128)	(0.117)
Revenue (lag) control?	✓	✓	✓	✓	✓
Revenue (lag) growth control?	✓	✓	✓	✓	✓
Year fixed effects?	✓	✓	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓	✓
N	5,353	5,353	5,353	5,353	5,353

Notes: This table presents regression results of the placebo tests, by replacing the interaction term in Equation 10 with an interaction term between the treated dummy and a dummy indicator for 2004, 2005, 2006, and 2007, respectively. The treated group is composed of companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, diff-in-diff, captures the differential changes in the R&D spending by in the treated group of companies that were reclassified as SMEs in any other years prior to the reform, relative to mature companies in the same treated group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

B. Estimation Strategy

Following the conceptual framework presented in Section III, we attribute the interaction term on our diff-in-diff specification to be capturing the reduction in the user cost of R&D for the treated group of companies in the following model where we identify the causal effect of the 2008 reform on R&D spending:

$$E[R_{it}|D_{it}, \boldsymbol{x}_{it}] = exp(\gamma + \delta_D D_i + \delta_I D_i T_t + \boldsymbol{x}'_{it}\boldsymbol{\beta}_x + \phi_t), \qquad (9)$$

where R_{it} is the level of qualifying R&D spending for company *i* in year *t* in 2009 prices. D_i is a dummy that takes on a value of 1 for the treated observations and 0 for the control observations. T_t is a dummy that takes on a value of 1 for years 2008 onwards and 0 otherwise. The coefficient δ_I on the interaction term D_iT_t captures the differential change in qualifying R&D spending between pre- and post-2008 periods for the treatment group compared to the control group. The null hypothesis of no impact of the change in the generosity of the tax relief on R&D spending in the treated group relative to that in the control group corresponds to $\delta_I = 0$. Importantly, δ_I can be directly interpreted as the percentage change in the qualifying R&D spending with respect to the tax reform (Silva and Tenreyro 2006, Cameron and Trivedi 2013). Time-invariant unobserved firm heterogeneity is captured by the inclusion of firm-fixed effects (later in the estimation stage) and aggregate macroeconomic shocks that are common to all companies, including the effect of the great recession, are controlled for in all specifications by the set of time-fixed effects ϕ_t. Other non-tax determinants of firm-level R&D spending including the firm's growth rate of turnover and measures of firm size can be included in the *x* vector as additional controls. Companies do not claim tax relief continuously every year. There is anecdotal evidence on companies which alternate staff functions between R&D and non-R&D ones depending on the availability of suitable projects.[23] In the CT600 dataset, if we consider all the companies with some R&D spending during the observed period, only 40 percent claim R&D tax relief continuously in all the years and the remaining ones stop claiming at least once. We interpret the instances with zero R&D expenditure as failure to meet ficosts associated with undertaking qualifying R&D and claiming tax incentives on it. For variables of interest characterized with a long right-tail and a mass-point at zero, Silva and Tenreyro (2006) propose a simple Poisson Pseudo-Maximum-Likelihood (PPML) estimator (following Gourieroux and others 1984) to achieve consistency in estimating the parameters of a log-linear model. In particular, Silva and Tenreyro (2006) demonstrate that in the log-linear specification, the OLS estimates are severely biased and inconsistent and that the PPML estimates perform very well on simulated data.[24] In the context of R&D, an application can be found in Agrawal and others (2014). We use standard errors clustered by firm to correct for over-dispersion.

VI. Results

A. Baseline Results from the Main Experiment

We begin by presenting the results from our baseline regression, estimating the specification in Equation 9. We use the sample of large companies with more than 250 employees, with the treated group becoming eligible for more generous benefits in 2008 thanks to the change in the size category of companies with 250–500 employees to "SME." Because the reform was introduced in the middle of the 2008 tax year, we remove this period from all our regressions. In Table 3, Column (1) presents the baseline specification with no controls, capturing the mean differences between treatment and control groups. The row labeled "Diff-in-diff" provides the estimates for the main coefficient of interest which captures the differential effect of the policy reform on average R&D spending in the treated group relative to the counterfactual. The next three columns include additional control variables. First, instead of the pre-/post-reform dummy, we add year fixed effects in Column (2). Column (3) adds a firm size proxy, that is the total company revenues in real terms (lagged), and Column (4) further adds the rate of growth of real revenues (lagged). In all specifications we include firm fixed effects to control for unobserved time invariant firm-specific characteristics that may be correlated with treatment status. In all these regressions, the diff-in-diff coefficient is significant at the 5 percent level, indicating a differential increase in R&D spending for treated firms of at least 26.4 percent.

[23] This argument was put forward by the HMRC and Treasury teams that participated in the seminar on November 6, 2014.

[24] The PPML estimator has been widely used in the empirical international trade literature (see for example, Westerlund and Wilhelmsson 2009, and a survey by Gomez-Herrera 2013).

Table 3. Baseline Results. Treatment: Large Companies Reclassified as SMEs after 2008

	(1)	**(2)**	**(3)**	**(4)**
Diff-in-diff	0.287**	0.286***	0.264**	0.264**
	(0.112)	(0.109)	(0.109)	(0.109)
Post 2008	0.182**			
	(0.075)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	X	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,799	4,799	4,799	4,799
No of Treated Firms	247	247	247	247
No of Control Firms	335	335	335	335

Notes: This table presents regression results of the placebo tests, by replacing the interaction term in Equation 9 with an interaction term between the treated dummy and a dummy indicator for 2004, 2005, 2006, and 2007, respectively. The treated group is composed of companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, diff-in-diff, captures the differential changes in the R&D spending by in the treated group of companies that were reclassified as SMEs in any other years prior to the reform, relative to mature companies in the same treated group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

Next, we test firms' reaction to the early announcement of the policy. Firms may react to the announcement of the policy before its implementation by: (i) postponing their R&D spending to the post-treatment period when it becomes cheaper to do so; (ii) starting to invest early on in preparation for a long term R&D project; (iii) postponing merger and acquisition decisions to until after the policy change; or (iv) strategically adjusting the firm size to keep benefiting from the SME scheme both before and after the policy change. Given our reduced form approach, it is not possible to disentangle these different factors at play, but at least we may be able to limit the effect of such strategic behavior on our estimates. Removing the years 2007–08 would address the issues that may arise from back-loading the R&D investment as in: (i) or front-loading the R&D investment; as in (ii) because of the timing of policy announcement. In Table 4, we observe that the coefficient size in the preferred specification (Column 4) is 28.1 percent, and significant at the 5 percent level.

Table 4. Baseline Results. Treatment: Large Companies Reclassified as SMEs after 2008, Removing Both 2007 and 2008 Fiscal Years

	(1)	**(2)**	**(3)**	**(4)**
Diff in diff	0.305**	0.306**	0.281**	0.281**
	(0.124)	(0.121)	(0.124)	(0.124)
Post 2008	0.231***			
	(0.082)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	✗	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,253	4,253	4,253	4,253
No of Treated Firms	247	247	247	247
No of Control Firms	335	335	335	335

Notes: This table presents regression results of the placebo tests, by replacing the interaction term in Equation 9 with an interaction term between the treated dummy and a dummy indicator for 2004, 2005, 2006, and 2007, respectively. The treated group is composed of companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, diff-in-diff, captures the differential changes in the R&D spending by in the treated group of companies that were reclassified as SMEs in any other years prior to the reform, relative to mature companies in the same treated group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

If there is a strategic timing issue of mergers and acquisitions as in (iii) above, then the acquired firm is not captured by either treatment or control groups, since they will fail to satisfy the intensive margin condition of having been in the dataset and performed R&D at least once both before and after the reform.

The number of companies that grow just after the announcement of the policy is below the HMRC disclosure threshold of 30 observations, not allowing us to present an analysis of the behavior of these companies. These firms would possibly have remained as SMEs both before and after the reform, ruling them out as treated or control group in our fixed experiment. To ensure that our results are robust to potential bunching of firm below the employment threshold of 250, we exclude firms with employment between 240 and 260 in the treated and control groups and repeat the diff-in-diff regressions. The basic findings remain unchanged. Using a wider exclusion band (employment between 230 and 270) also yields similar results.[25]

We check the robustness of these results to outliers in terms of firm size and also in terms of R&D spending amounts. Table 5 removes the top percentile in the size distribution of firms in the control group and check the robustness of the firms to the presence of very large companies that are potentially very different from the medium sized, treated firms. The diff-in-diff coefficient remains significant at the 5 percent level, with a magnitude of 25.4 in the most conservative specification with all controls. In Table 6, we winsorize the top and bottom percentile of R&D spending values to rule out that the results are driven by outliers. Despite losing variation in R&D spending values, we retain a positive and significant effect of the policy at the 10 percent level. The magnitude of the effect is around 20 percent with the winsorized sample.

Table 5. Robustness—Dropping The Largest Percentile of Firms from the Control Group

	(1)	(2)	(3)	(4)
Diff-in-diff	0.275**	0.275**	0.254**	0.254**
	(0.115)	(0.112)	(0.111)	(0.111)
Post 2008	0.193**			
	(0.080)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	X	✓	✓	✓
Firm fixed effects? N	✓	✓	✓	✓
	4,756	4,756	4,756	4,756

Notes: This table presents regression results on the effect of the R&D tax credits on qualifying R&D spending based on Equation 9. The dependent variable is the level of qualifying R&D spending. The main coefficient of interest, diff-in-diff, captures the differential changes in the qualifying R&D spending in the treated group of companies that were relabeled as SMEs following the 2008 tax reform. The control group are companies that remained as Large after the 2008 reform, dropping the largest 1 percent of observations in this group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

In Appendix C, we present results from an alternative treatment group that considers firms with fewer than 250 employees in the pre-reform period and assesses their performance against large firms. There is some evidence that these smaller companies also increased their R&D spending relative to the control group, since they were also eligible for more generous tax incentives through the increase in deduction rates.

[25] We check the validity of the common trends assumption by implementing placebo reforms in each of the pre-reform years in our sample, namely, all the years over 2003–07. We do not find any impact of the policy in these periods, and the results are presented in Table 2.

Table 6. Robustness—Winsorising The Outcome for Highest and Lowest Spenders (Top and Bottom Percentiles) in R&D

	(1)	(2)	(3)	(4)
Diff-in-diff	0.210*	0.210**	0.203*	0.203*
	(0.109)	(0.106)	(0.106)	(0.106)
Post 2008	0.258***			
	(0.070)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	X	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,799	4,799	4,799	4,799

Notes: This table presents regression results on the effect of the R&D tax credits on qualifying R&D spending based on Equation 9. The dependent variable is the level of qualifying R&D spending. The main coefficient of interest, diff-in-diff, captures the differential changes in the qualifying R&D spending in the treated group of companies that were relabeled as SMEs following the 2008 tax reform. The control group are companies that remained as Large after the 2008 reform. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). The top and bottom percentile of R&D spending values have been winsorized to eliminate the effect of outliers. Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

B. Heterogeneous Responses across Firms

Our findings suggest that large, consistent programs which support R&D spending in the form of tax incentives are effective in generating additional private R&D. We identify several reasons for the large elasticity estimate: (i) the U.K. policy is simple for firms to understand and react to quickly; (ii) medium-sized companies may be reacting more to the policy than other sub-groups studied in the existing literature, precisely the reason why the U.K. Government wanted to extend the more generous tax incentives to medium-sized companies; (iii) qualifying spending responds more to the reduction in the user cost of "qualifying R&D," and companies might be increasing their qualifying R&D at the expense of non-qualifying R&D. Because the United Kingdom's legal framework governing micro data does not allow us to match the tax returns to the R&D survey, we are not able to investigate the relationship between qualifying and non-qualifying R&D. If these two categories are substitutes, then we may expect companies to reallocate existing spending, and we would be over-estimating the effect of the R&D tax credit. On the other hand, the qualifying and non-qualifying R&D components are more likely to be complements, as the definition of "qualifying spending," as described in Section IV, defines spending categories rather than activities, such as researcher salaries and supplies.

Anecdotal evidence suggests that there is a degree of heterogeneity in firm responses to R&D tax incentives. We explore various dimensions of possible heterogeneity, such as companies that have continuous positive R&D spending as opposed to those that "stop-and- go," or young or loss-making versus mature or profitable firms. The specification used for each of these dimensions of possible heterogeneity takes the following general form:

$$E[R_{it}|D_{it},\boldsymbol{x}_{it}] = exp\big(\gamma + \delta_D D_i + \delta_T T_t + \delta_I D_i T_t + \delta_D^H D_i H_i + \delta_T^H T_t H_i + \delta_I^H D_i T_t H_i \quad + \boldsymbol{x}'_{it}\boldsymbol{\beta}_x\big), \tag{10}$$

In the specification in Equation 10 each of the key variables "Post 2008" and "diff-in-diff" are interacted with the chosen dimension of heterogeneity, captured by the dummy variable H. More specifically, in each of the diff t regressions (i)–(ii), H is a variable that takes a value of unity if the company: (i) performs strictly positive R&D in all years after it started reporting any R&D and zero otherwise, (ii) is in the lowest age quartile (young firms and zero otherwise. For example, in (i) therefore, the variables that are uninteracted with H capture the coefficients for the companies that are intermittent in their R&D spending, and then the coefficients that are interacted with H capture the surplus for the consistent performers of R&D over intermittent performers of R&D. The triple interaction term $D_i T_t H_i$ captures the differential effect of the policy reform for the firms that are in the group of consistent performers of R&D relative to the intermittent performers of R&D, and δ_I^H.

Table 7. Heterogeneous Responses to the Policy, Consistent Performers of R&D

	(1)	**(2)**	**(3)**	**(4)**
Not consistent, diff-in-diff	0.018	0.005	-0.063	-0.063
	(0.267)	(0.265)	(0.249)	(0.249)
Not consistent, Post 2008	0.191			
	(0.219)			
Consistent * Post 2008	-0.012	-0.017	-0.072	-0.072
	(0.231)	(0.228)	(0.203)	(0.203)
Consistent * diff-in-diff	0.406	0.424	0.480*	0.480*
	(0.289)	(0.284)	(0.266)	(0.266)
Revenue (lag) control? Revenue growth (lag) control?			✓	✓ ✓
Year fixed effects?	✗	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,799	4,799	4,799	4,799
Number of Treated Firms	247	247	247	247
Number of Control Firms	335	335	335	335
Number of Treated, Consistent	116	116	116	116
Number of Treated, Not Consistent	131	131	131	131
Number of Control, Consistent	171	171	171	171
Number of Control, Not Consistent	164	164	164	164

Notes: This table presents regression results on the heterogeneous effect of the R&D tax credits on qualifying R&D spending based on Equation 10. The treated group are companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, Consistent * diff-in-Diff, captures the differential changes in the R&D spending by consistent R&D performers in the treated group of companies that were reclassified as SMEs following the 2008 tax reform, relative to non-consistent R&D performers in the same treated group. "Consistent" performers of R&D are those that had positive R&D in each period after take-up. Additional controls include first lags of real revenue and real revenue growth rate. Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

Perhaps unsurprisingly, these distinctions offer significant differential effects of one group over another, although the estimates come with large standard errors due to limitations related to sample size. The regression results can be found for these separate groups in Tables 7 and 8. We find that consistent performers of R&D respond differentially more to the policy. This may be driven by readily available R&D opportunities for these firms and perhaps indicate a relaxing of cash constraints that previously hindered firms' taking up of profitable R&D projects.

Younger firms identified as the bottom quartile across the firm age distribution also respond to the policy change differentially more. These findings align with anecdotal evidence that innovative firms are often young, high growth start-ups that benefit most from R&D support schemes. A question that arises as a result of this observation is whether the tax incentive works by alleviating cash constraints of younger firms and liquidity constrained firms, rather than working through the user cost channel. Our approach does not allow us to answer this important question.

Table 8. Heterogeneous Responses to the Policy, Young Firms. Treatment: Large Companies Reclassified as SMEs after 2008

	(1)	**(2)**	**(3)**	**(4)**
Not Young, diff-in-diff	0.185	0.185	0.174	0.174
	(0.121)	(0.118)	(0.118)	(0.118)
Not Young, Post 2008	0.255***			
	(0.075)			
Young * Post 2008	-0.430**	-0.377**	-0.352*	-0.352*
	(0.179)	(0.184)	(0.187)	(0.187)
Young * diff-in-diff	**0.608****	**0.608****	**0.586****	**0.586****
	(0.241)	**(0.238)**	**(0.238)**	**(0.238)**
Revenue (lag) control?			✓	✓
Revenue growth (lag) control?				✓
Year fixed effects?	X	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,799	4,799	4,799	4,799
Number of Treated Firms	247	247	247	247
Number of Control Firms	335	335	335	335
No of Treated, Young	41	41	41	41
No of Treated, Not Young	206	206	206	206
No of Control, Young	53	53	53	53
No of Control, Not Young	282	282	282	282

Notes: This table presents regression results on the heterogeneous effect of the R&D tax credits on qualifying R&D spending based on Equation 10. The treated group are companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, Young * diff-in-diff, captures the differential changes in the R&D spending by young companies in the treated group of companies that were reclassified as SMEs following the 2008 tax reform, relative to mature companies in the same treated group. The dummy variable Young takes value of 1 for those in the bottom quartile of the age distribution in 2007. Additional controls include first lags of real revenue and real revenue growth rate. Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

Finally, an important dimension that may lead to heterogeneous responses to tax incentives is the distinction between multinational and domestic firms. There are two important mechanisms at play. First, multinationals may move R&D across jurisdictions based on differentials between the average tax rate on R&D investment (as suggested in Wilson (2009) between U.S. states), even though international relocation may be costlier than inter-state relocations. Second, multinationals may be less responsive to tax reforms if they already engage in profit-shifting activity and hence less sensitive to changes in the headline tax rates. In this study, we do not have sufficient information in the data to analyze either of these effects and leave this important question to future research.

C. Testing for R&D Relabeling

The literature on R&D tax incentives discusses the "relabeling problem," which refers to companies having an incentive to reclassify ordinary spending as R&D to benefit from the preferential tax treatment (See, for example, Griffith and others 1996). To assess the extent of the relabeling problem in the dataset, we analyze whether there is any systematic change in qualifying expenditure for regular capital investment and non-R&D expenses. In the presence of relabeling, we may expect a negative and significant effect of tax incentives on these variables. Note that investment expenditure is only one cost channel through which labelling may take place. If companies systematically relabel ordinary investment expenditure or other current expenses as qualifying R&D to benefit from more tax savings, we may expect to see a decrease in these ordinary expenditure categories following the reform.

Table 9 summarizes the regression results, where Columns (1) and (3) present the diff in-diff coefficient estimates using qualifying investment expenditure and the ratio of non-R&D input costs in turnover as the outcome variable, respectively. In both columns, the coefficient estimate of the interaction term is negative and insignificant effect, not suggesting any sign of relabeling of regular investment expenditure or non-R&D input costs to maximize tax savings. Even if we interpret the negative, albeit insignificant, coefficient on physical investment as an indication of some relabeling, we would expect to observe a larger degree of relabeling in the non-R&D costs, which is not present in our data. The evidence is consistent with Hall (1995), who shows that government auditors (in the United States and Australia) do not find much abuse of the R&D tax incentives.

Table 9. Effect of Policy on Other Outcomes than R&D. Treatment: Large Companies Reclassified as SMEs after 2008

Dependent variable:	Investment (1)	R&D (2)	Non-R&D Cost Ratio (3)	R&D (4)
Diff-in-diff	-0.126	0.255**	0.074	0.262**
	(0.103)	(0.111)	(0.076)	(0.109)
Revenue (lag) control?	✓	✓	✓	✓
Revenue (lag) growth control?	✓	✓	✓	✓
Year fixed effects?	✓	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	4,763	4,763	4,768	4,768

Notes: This table presents regression results on the effect of the R&D tax credits on other outcome variables. These are: physical capital investment in Column (1) and non R-D cost ratio in Column (3). Regressions in Column (2) and (4) check the effect of the R&D tax credits on qualifying R&D spending in the same regression sample in Columns (1) and (3), respectively. The main coefficient of interest, Diff-in-Diff, captures the differential changes in the outcome variables in the treated group of large companies that were classified as SMEs after the 2008 tax reform. The control group are companies that remain as Large after the 2008 reform. Additional controls include first lags of real revenue and real revenue growth rate. In Column (1), the revenue control is significant at 10 percent level. In Column (3), the revenue growth control is significant at 5 percent level. The other coefficients are statistically insignificant at conventional levels. The regression excludes observations in 2007 and 2008 to eliminate any potential anticipation effects. Standard errors are clustered by firm. ***, **, * denotes significance at 1percent, 5 percent, and 10 percent level, respectively.

To make sure that our results are not driven by changes in the sample, we repeat the analysis using R&D spending as the outcome variable on the same subsample with non-missing investment in Column (2) and with non-R&D input-cost ratio in Column (4), respectively. In each subsample the DD coefficient estimate concerning the increase in qualifying R&D spending is positive and significant at 5 percent level. This assures that our results concerning the response of investment expenditure and non-R&D cost ratio are not an artefact of changes in the regression sample.

D. Using Actual Size in the R&D Tax Relief Claim to Define "Treatment"

In this section, we move away from the pre-reform employment size threshold to define "intent-to-treat" and focus on the actual treatment status of fi to identify the treated and control groups. This definition may be prone to strategic downsizing of companies to be included in the treated group in the post-reform period, but also offers a good check on whether our intent-to-treat measure based on accounting data adequately captures the effect on the set of firms that have benefited from the policy.

For the robustness checks in this section, a company is included in the control group if it carried out qualifying R&D in at least one of the years before 2008, and also in at least one of the years after 2008, and: (i) is labeled as large in the last of such pre-reform years with positive R&D; and

(ii) is also labeled as large in the first of such post-reform years with positive R&D.[26] This revised dataset is an unbalanced sample that includes 185 firms in the treated group and 1,102 firms in the control group. Each firm is observed over multiple periods, and at least once before the reform and at least once afterwards.

Table 10 shows the results from diff-in-diff regressions based on this revised sample using the "actual treatment" definition rather than "intent-to-treat." We observe that the point estimate on the diff-in-diff coefficient is higher, with the preferred specification estimate at 39.7 percent and highly significant.

Table 10. Baseline Results. Treatment: Large Companies Reclassified as SMEs after 2008 (Actual treatment based on status declared to HMRC upon receipt of tax relief).

	(1)	(2)	(3)	(4)
Diff-in-diff	0.400**	0.420**	0.397**	0.397**
	(0.192)	(0.186)	(0.185)	(0.185)
Post 2008	0.221***			
	(0.067)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	X	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	10,106	10,106	10,106	10,106

Notes: This table presents regression results on the effect of the R&D tax credits on qualifying R&D spending based on Equation 9. The dependent variable is the level of qualifying R&D spending. The treated group is composed of companies that were reclassified as SMEs after the 2008 reform. The control group are companies that remained as Large after the 2008 reform. The main coefficient of interest, diff-in-diff, captures the differential changes in the R&D spending by in the treated group of companies that were reclassified as SMEs in any other years prior to the reform, relative to mature companies in the same treated group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5percent, and 10 percent level, respectively.

E. Interpreting the Results

Our preferred estimate of the effect of the 2008 SME definition change suggests that on average there is a 26 percent increase in qualifying R&D spending by companies in the 'medium-sized firms treated group. The increase is due to a combination of two policy changes as described in Section II. First, the increase in the generosity of the SME eligibility threshold allows medium-sized companies in the treated group to continue claiming R&D at the 150 percent enhanced deduction rate for SMEs. In the absence of uplift in the eligibility threshold, companies in the

[26] We again do not take the 2008 status into account, since the size definition change was introduced in August 2008, which is in the middle of the tax year.

treated group would only be allowed to claim at the 130 percent rate. Second, the enhanced deduction rate for SMEs has itself increased from 150 to 175 percent in 2008, representing a further decrease in the R&D user cost.

The SME definition change encompasses the rate reduction that applies to the SMEs, and a further rate reduction thanks to the fi switch from being considered as "large" to being considered as "SME." In this context, the 26.4 percent increase in qualifying R&D spending in response to around an average 17 percent drop in the tax component of the user cost translates to an estimate for the elasticity of R&D with respect to its user cost of around -1.55. This is a sizeable effect of the policy, which is on the higher end of the estimates found in the literature. It is, on the other hand, in line with the fi from a recent HMRC evaluation (Fowkes and others 2015). In addition, given the cost of the policy in the form of foregone tax revenue, we find that each £1 foregone in corporation tax generates around £1.30 in R&D for taxpayers at the small profits rate (21 percent in the post-reform period) and around £0.80 in R&D for taxpayers at the main rate (28 percent in 2008–10).[27]

The diff-in-diff coefficient estimate in the alternative experiment that is presented in Appendix C captures the rate change in isolation, as companies in the treated group remain as SMEs throughout the sample period and are not affected by the definition change. Our preferred estimate for the rate-change experiment suggests that on average, there is a 23.4 percent increase in qualifying R&D spending by SMEs in response to 9 percent drop in the tax component of the user cost. The results from the rate-change experiment suggests an R&D user cost elasticity estimate of around -2.9, which is very high, but comparable to the user cost elasticity estimated from the main experiment when the wide confidence intervals are taken into account.

F. Comparing The Diff-In-Diff Results with Direct Estimates of User Cost Elasticity

Finally, as a robustness check, we explore whether the interaction term captures sufficient variation in the user cost of R&D by replacing it with a measure of the actual cost of capital for R&D in Equation 9. We compute the R&D user cost as described in Section II, where the statutory marginal tax rate is firm specific and depends on the current-year taxable profit. The user cost of R&D capital is now the "continuous treatment" variable of interest, which we expect to affect the level of R&D capital within a firm negatively. The relevant sample for estimating the elasticity of R&D spending with respect to its user cost pools all the observations used in this study.

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[27] We calculate the foregone corporation tax revenue by multiplying the corporation tax rate by the change in taxable profit triggered by the change in R&D enhanced deduction rates. For example, for a fixed amount of revenues net of other expenses than R&D (say, an amount X), treated firms experience changes in the enhanced deduction rate $1 + d$, and R&D spending level R, the taxable profit is $X - R(1 + d)$. The difference between the counterfactual scenario and the post-reform rates go through R and $1 + d$, where in the post-reform state, R increases to 1.264R and $1 + d$ increases from 1.25 to 1.75. At the small profits tax rate of 0.21, the foregone tax revenue per firm is then calculated as 0.202R, and at the main rate of 0.28, this value is 0.335R. Dividing the average additional R&D generated by the policy of 0.264R by the foregone tax revenue, we obtain the bang-for-the-buck estimate of £0.80–£1.30.

The amount of R&D spending brings down the current-year taxable profit and marginal tax rate, therefore, the user cost is endogenous to the level of R&D spending. In a regression with R&D spending as the dependent variable and the user cost of R&D capital as explanatory variable, we expect this simultaneity to bias the coefficient on the user cost variable towards zero. In contrast, in our calculation of the user cost variable, we assume that the marginal tax rate for loss-making companies which do not receive cash is zero. This approach is likely to understate the value of the tax incentives for loss-making firms that can carry forward the tax savings to offset future tax liability, potentially causing the magnitude of the coefficient on the user cost to be overestimated (biased away from zero).

The net effect (bias) of the two countervailing forces that we discussed in this section is ambiguous, and we use two approaches to address endogeneity issues. As a first attempt, we construct a measure of the R&D user cost, using the marginal tax rate based on the previous year's taxable profit. Second, we use a "before-R&D spending" marginal tax rate based on companies' taxable profit before undertaking any qualifying R&D investment to construct an alternative R&D user cost of capital measure. In terms of the sign of the coefficient estimate, we nevertheless expect to find a negative relationship between the R&D user cost and level of spending.

Table 11 presents the results from the regressions with the R&D user cost of capital as an explanatory variable. We include year fixed effects, firm-fixed effects, companies' real turnover (lagged), and the real growth rate of turnover (lagged) as controls. In Column (1), the explanatory variable of interest is the user cost variable calculated as described in Section II. The magnitude of the estimated coefficient on the user cost is -2.36, with large standard errors. In Column (2), we replace the actual user cost with the user cost measure calculated based on previous-year marginal tax rate. The magnitude and the significance of the coefficient estimate change only slightly. In Column (3), we replace the user cost variable with one based on 'before-R&D spending' marginal tax rate, and we focus on the tax component of this measure. This modification results in a reduction in the size and standard errors of our user cost elasticity estimates. The findings are in line with our results from the diff-in-diff analysis.

Table 11. Direct Estimates of User Cost Elasticity

	(1)	(2)	(3)
R&D CoC based on profit at t	-2.361		
	(1.602)		
R&D CoC based on profit at $t-1$		-2.395	
		(1.542)	
R&D CoC based on profit at $t-1$, exc R&D			-1.746**
(Tax component)			(0.796)
Revenue (lag) control?	✓	✓	✓
Revenue growth (lag) control?	✓	✓	✓
Year fixed effects?	✓	✓	✓
Firm fixed effects?	✓	✓	✓
N	29,552	29,552	29,552

Notes: This table presents results on the effect of the R&D tax credits on qualifying R&D spending, replacing the discrete interaction term with a direct measure of the *CoC* variable in Equation 9. The dependent variable is the level of qualifying R&D spending. The sample consists of pooled observations from both treated groups and the control group. Additional controls include first lags of real revenue and real revenue growth rate (all statistically insignificant at conventional levels). Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

VII. CONCLUSION

R&D and innovation policy started to increasingly rely on indirect incentives to support business spending in R&D. There has been a global surge in tax incentive schemes for R&D, with limited evidence on the effectiveness of such schemes due to lack of data and problems related to endogeneity in estimation.

In this paper we analyze the effectiveness of tax-based R&D policy in stimulating business spending in R&D. We use a novel and rich administrative dataset for the period 2002–11 on all corporate R&D investors in the United Kingdom, and exploit two exogenous policy reforms to quantify the impact of R&D tax incentives. Both reforms took place in 2008. By increasing the generosity of the R&D tax deduction, the two reforms lowered the user cost of R&D capital for: (i) medium-sized companies; and (ii) small companies, while keeping the user cost stable for larger firms that remain above the eligibility threshold to be qualified as a SME for R&D purposes.

Our findings from the analysis of the two policy experiments suggest that the R&D tax incentives have a strong positive effect on stimulating qualifying R&D spending. In the main experiment based on the change in the criteria used for defining SMEs, identification relies on variation in the R&D user cost for the group of companies that are newly qualified as SMEs following the SME definition change. Our results suggest that the 17 percent reduction in the R&D user cost increased qualifying R&D spending by 26.4 percent, suggesting an elasticity estimate of around

-1.6 and about £1.3 of additional R&D generated per pound foregone in corporation tax revenue. In the second experiment, identification relies on variation in the R&D user cost as a result of an increase in the enhanced deduction rate for the group of companies that are consistent SMEs.

The finding of a strong increase in R&D spending in response to more generous R&D tax incentives is robust to factoring in anticipation effects and controlling for other non-tax determinants of R&D investment. The strong increase in R&D spending is observed in both consistent and intermittent spenders, but more strongly in consistent R&D spenders. We also find that young firms responded very strongly by increasing their R&D spending after the reform. We show that the observed increase in R&D spending is not a mere artefact of relabeling ordinary investment in physical assets or other non-R&D expenses.

Due to the short time period in our dataset, we are unable to analyze the link between R&D spending and long-run productivity growth and R&D spillovers following the policy change. We leave these important research topics to future study.

Appendix 1. Summary of Recent Related Literature

Table 1.1. Related Literature (Since 2000)

Papers	Equation (constants, controls and error terms omitted)	β_1 (SE)	Methodology / Identification	Source of R&D data	Equivalent elasticity of interest
Panel A: Published Work					
Bloom et al. (2002)	$lnR_{it} = \gamma lnR_{it-1} + \beta_0 y_{it} + \beta_1 lnCoC_{it}$	-1.09 (0.02)	First-difference, instrument with lags of lnR_{it} and y_{it} up to date t-2 and lags of $lnCoC^{tax}$ up to $t-1$; country and year FEs	Country-level panel data, 9 OECD countries, 1979-1997	-1.09
Wilson (2009)	$ln(R_{it}^{in}) = \gamma ln(R_{it-1}^{in}) - \beta_1 ln(CoC_{it}^{in}) + \beta_2 ln(CoC_{it}^{out})$	Internal: -2.18 (0.81)	Within-groups (state and year FEs)	US state-level data on industrial R&D from NSF (1981-2004)	-2.18, but implied aggregate-cost elasticity zero
Czarnitzki et al. (2011)	$ln(innovation) = \beta_1 D_i$	N.A.	Mahalanobis distance matching based on observables of beneficiary and non-beneficiary firms in the same year	Canadian Innovation Survey (1999)	N.A.
Mulkay and Mairesse (2013)	$K_{it}^{R\&D} = \beta_0 y_{it} + \beta_1 ln(CoC_{it})$	-0.41 (0.16)	Error-correction model specification; diff GMM; firm and year FEs	French R&D survey (2000-2007)	-0.41
Lokshin and Mohnen (2012)	$K_{it}^{R\&D} = \beta_0 y_{it} + \beta_1 ln(CoC_{it})$	-0.54 (0.20) to -0.79 (0.35) to -0.79	Error-correction model specification; within-groups & IV; instrument with lags of lnK_{it} and y_{it}; policy parameters	Dutch R&D and CIS Surveys (1996-2004)	-0.54
Bøler et al. (2015)	$lnR_{it} = \beta_0 + \beta_1 D_i T_t$	Diff-in-diff: 0.29 (0.25) to 0.54 (0.14)	Diff-in-diff (within-groups), firm and year FEs, firm-specific random trends + structural	Norwegian R&D survey (1997-2005)	N.A.
Rao (2016)	$\frac{R_{it}}{S_{it}} = \beta_1 CoC_{it}$	-1.98 (0.47)	First-diff, instrument with synthetic CoC (under policy at t and t-1 using R_{it-2})	US Tax returns and Compustat (1981-1991)	-1.98

Continued on next page

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Table A.1 – *Continued from previous page*

Papers	Equation (constants, controls and error terms omitted)	β_1 (SE)	Methodology / Identification	Source of R&D data	Equivalent elasticity of interest
Panel B: Working Papers					
Yohei (2011)	$lnR_i = \beta_0 + \beta_1 D_i$	1.18 (0.17)	PS matching; treated firms are R&D tax credit recipients	Cross-sectional firm-level data on SMEs in Japan, 2009 survey data	N.A.
Agrawal et al. (2014)	$E[Rit\|D_{it}, X_{it}] = exp[D_{it} PostPolicy_t \beta_1 + D_{it}\beta_2]$	-0.18 (0.05) Canadian R&D tax credit in year 2004; PQML firm and year FEs	change in eligibility rules for the Canadian firms claiming R&D tax credits, 2000-07	Tax records for all	-1.5
Bozio et al. (2014)	$lnR_{it} = \beta_0 lnR_{it-1} + \beta 1 PostReform_t$	Diff-in-diff: 0.08 (0.03) to 0.07 (0.02)	matching diff-in-diff	French survey data; 2004-2010	N.A.
Chang (2014)	$lnR_{st} = \gamma lnR_{st-1} + \beta_0 y_{st} + \beta_1 ln(CoC_{st})$	2.89 (1.14)	exogenous variation in state-level	US state-level data on	-5.38 to - 6.23
		- 3.78 (1.69)	R&D tax incentives; state and year Fes	industrial R&D, NSF (1981-2006)	
Guceri (2017)	$ln(R_{it}) = \beta_1 D_i T_t$	Diff-in-diff: 0.20 (0.07)	Diff-in-diff (within-groups), exploits change in eligibility rule, firm and year FEs	UK R&D Survey (1999-2013)	-0.88 to -1.18
Dechezlepretre et al. (2016)	$R_{it} = \beta_1 D_i + f(size)$	RD: £75.3 (36.3) (in thou.)	Regression discontinuity, exploits change in eligibility rule, compares firms below and above threshold asset size	UK corporation tax returns	-2.6
Panel C: Review Articles					
Hall and Van Reenen (2000)					
Hall et al. (2010)					

Appendix 2. Sample Characteristics

Year	Group	Freq	Share Loss-making	R&D Spend. Mean (Real £1,000)	R&D Spend. Median (Real £1,000)	Turnover Mean (Real £1,000)	Turnover Median (Real £1,000)
2002–03	Treated	206	25%	940	0	52,970	33,267
2003–04	Treated	210	23%	1,290	70	57,175	37,624
2004–05	Treated	221	27%	1,599	210	58,957	38,836
2005–06	Treated	229	27%	1,650	172	62,444	41,204
2006–07	Treated	229	26%	1,861	295	64,058	45,135
2007–08	Treated	235	33%	1,997	394	70,670	45,630
2008–09	Treated	238	34%	2,230	439	72,458	47,467
2009–10	Treated	242	35%	2,287	511	70,902	42,598
2010–11	Treated	241	28%	2,551	506	83,085	44,542
2011–12	Treated	230	28%	2,727	505	90,055	47,593
2002–03	Control	283	34%	6,504	0	627,664	195,442
2003–04	Control	293	31%	13,208	55	719,594	215,953
2004–05	Control	298	29%	14,916	454	729,263	229,679
2005–06	Control	302	29%	16,076	872	798,555	227,058
2006–07	Control	307	34%	16,518	1,372	833,416	247,221
2007–08	Control	311	40%	17,331	2,214	788,325	246,669
2008–09	Control	316	38%	19,931	2,515	888,841	271,883
2009–10	Control	324	40%	15,724	2,255	819,610	251,526
2010–11	Control	324	34%	16,644	2,522	865,433	271,087
2011–12	Control	314	30%	15,533	2,599	931,359	275,449

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Appendix 3. Treatment II: SMEs that Remained as SMEs after 2008

We form an alternative treated group, which constitutes the group of firms that remained as SMEs after the 2008 definition change and throughout the sample period, to analyze the effect of an increase in enhanced deduction rates on R&D spending. We name the group of treated firms under this second experiment as the group of 'small companies' to avoid confusion with the first experiment, which involves medium-sized firms. Companies in this treated group are smaller compared to the firms that "became" SME as a result of the SME definition change, but focusing on the set of small companies yields a much larger sample than in the previous section, allowing us to evaluate the change in deduction rates in isolation.

The policy experiment summarized in this section is of interest, as it compares the large companies whose tax component of user cost remained at 0.94, to SMEs whose tax component of user cost dropped from around 0.82 to 0.75.

As we have done in Section V.A, in the estimation, we use only pre-treatment period size to determine intent-to-treat. In this alternative treatment group, there are only companies that had fewer than 250 employees in the final year of the pre-treatment period.

It is difficult to make a case for common pre-reform trends for this group. Nevertheless, we present the results from this alternative experiment in Appendix Table 3.1, and observe a positive and significant effect of the policy.

Appendix Table 3.1. Robustness—Treatment: SMEs that Remained SMEs (Rate Increase Experiment), Removing Both 2007 and 2008 Fiscal Years

	(1)	(2)	(3)	(4)
Diff-in-diff	0.317***	0.318***	0.285**	0.286**
	(0.112)	(0.109)	(0.114)	(0.115)
Post 2008	0.238***			
	(0.092)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	✗	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	10,572	10,572	10,572	10,572

Notes: This table presents regression results on the effect of the R&D tax credits on qualifying R&D spending based on Equation 9. The dependent variable is the level of qualifying R&D spending. The main coefficient of interest, diff-in-diff, captures the differential changes in the qualifying R&D spending in the treated group of companies that were classified as SMEs both before and after the 2008 tax reform. The control group are companies that remained as Large after the 2008 reform. Additional controls include first lags of real revenue and real revenue growth rate. The regression excludes observations in 2007 and 2008 to eliminate any potential anticipation effects. Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

Appendix Table 3.2 summarizes the regression results, following the same specifications used for regressions in Table 3. Specifically, Column (1) presents results of the baseline specification with no controls. The diff-in-diff coefficient captures the mean differences in R&D spending between treatment and control groups as a result of the reform and is estimated to be positive and highly significant.

Appendix Table 3.2. Robustness—Treatment: SMEs That Remained SMEs (Rate Increase Experiment)

	(1)	(2)	(3)	(4)
Diff-in-diff	0.260***	0.264***	0.234**	0.234**
	(0.100)	(0.098)	(0.099)	(0.099)
Post 2008	0.190**			
	(0.084)			
Revenue (lag) control?			✓	✓
Revenue (lag) growth control?				✓
Year fixed effects?	✗	✓	✓	✓
Firm fixed effects?	✓	✓	✓	✓
N	11,968	11,968	11,968	11,968

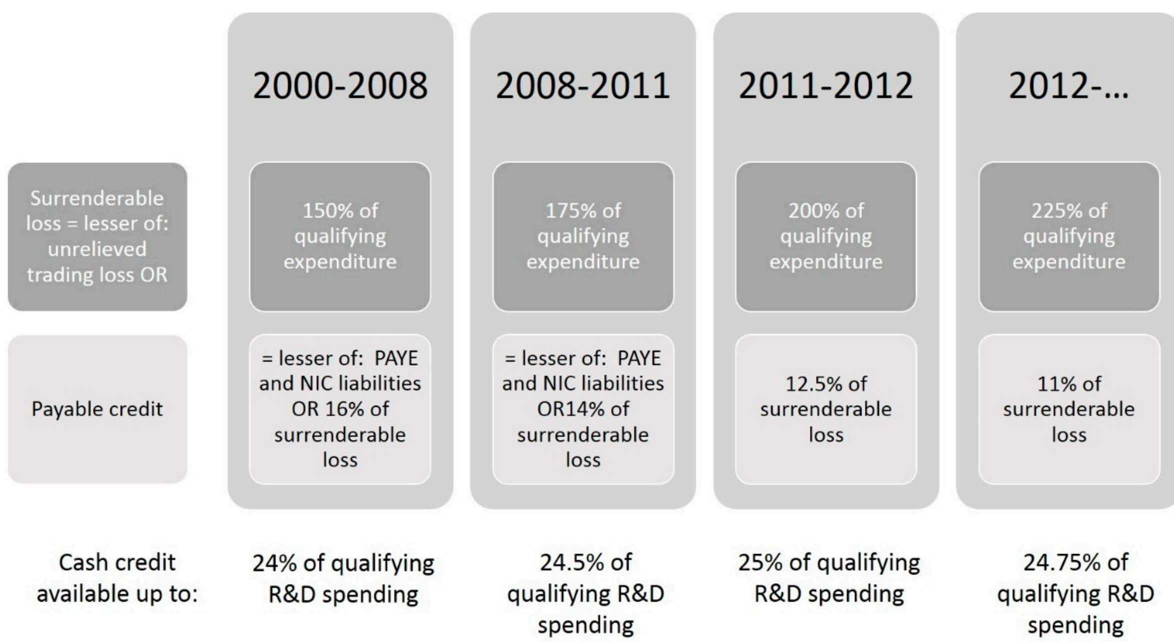
Notes: This table presents regression results on the effect of the R&D tax credits on qualifying R&D spending based on Equation 9. The dependent variable is the level of qualifying R&D spending. The main coefficient of interest, diff-in-diff, captures the differential changes in the qualifying R&D spending in the treated group of companies that were classified as SMEs both before and after the 2008 tax reform. The control group are companies that remained as Large after the 2008 reform. Additional controls include first lags of real revenue and real revenue growth rate. The regression excludes observations in 2008. Standard errors are clustered by firm. ***, **, * denotes significance at 1 percent, 5 percent, and 10 percent level, respectively.

Regression results in Appendix Table 3.1 check the sensitivity of the basic findings to any potential anticipation effect of firms in response to the early announcement of the policy. Following the same specifications as in Appendix Table 3.2, removing observations in years 2007 and 2008 yields similar results. The point estimate of the diff-in-diff coefficient in Column (9) increases slightly to 0.197 and remains significant at the 5 percent level.

Appendix 4. Cash Credits for SMEs

From its inception, the SME scheme has featured a cash component for companies which do not have taxable profits and hence cannot benefit from the enhanced deduction in the year in which the R&D expenditure has been made. HMRC provides a cash refund up to 24 percent of the amount of the total R&D spending of the firm in cash, which is an amount capped by the PAYE or NIC liabilities of the company. If the company is not cash constrained, it has an incentive to carry forward its losses and use the full deduction amount in a future period when it becomes profitable, however, a company with liquidity constraints would choose the cash option which can be claimed immediately. The calculation of the cash amount changed over time, which is depicted in Appendix Figure 4.1, but the total amount of cash available to a company was kept at around 24–25 percent of total R&D spending across periods of different enhanced deduction rates.

Appendix Figure 4.1 Cash Credit Rates for Loss-Making R&D Performers



REFERENCES

Agrawal, Ajay, Carlos Rosell, and Timothy S. Simcoe, "Do Tax Credits Affect R&D Expenditures by Small Firms? Evidence from Canada," Working Paper 20615, National Bureau of Economic Research October 2014.

Bloom, Nicholas, Lucy Chennells, Rachel Griffith, and John Van Reenen, "How Has Tax Affected the Changing Cost of R&D? Evidence from Eight Countries," in H.L.Smith, ed., Regulation of Science and Technology, number W97/03, Macmillan, January 1996.

Bloom, Nick, Rachel Griffith, and John Van Reenen, "Do R&D Tax Credits Work? Evidence from a Panel of Countries 1979-1997," Journal of Public Economics, 2002, 85 (1), 1 – 31.

Boler, Esther Ann, Andreas Moxnes, and Karen Helene Ulltveit-Moe, "R&D, International Sourcing, and the Joint Impact on Firm Performance," American Economic Review, December 2015, 105 (12), 3704–39.

Bond, Stephen and Jing Xing, "Corporate Taxation and Capital Accumulation: Evid- ence from Sectoral Panel Data for 14 OECD Countries," Journal of Public Economics, 2015, 130, 15 – 31.

———, and John Van Reenen, "Microeconometric Models of Investment and Employment," in J.J. Heckman and E.E. Leamer, eds., Handbook of Econometrics, Vol. 6 of Handbook of Econometrics, Elsevier, 2007, chapter 65.

Bozio, Antoine, Delphine Irac, and Loriane Py, "Impact of Research Tax Credit on R&D and Innovation: Evidence from the 2008 French Reform," Working paper 532, Banque de France 2014.

Bronzini, Raffaello and Eleonora Iachini, "Are Incentives for R&D Effective? Evid- ence from a Regression Discontinuity Approach," American Economic Journal: Economic Policy, 2014, 6 (4), 100–134.

Budget, ed., Budget Report March 1999, Her Majesty's Treasury, United Kingdom, 1999.

Caballero, Ricardo J., Eduardo M. R. A. Engel, and John C. Haltiwanger, "Plant- Level Adjustment and Aggregate Investment Dynamics," Brookings Papers on Economic Activity, 1995, 26 (2), 1–54.

Cameron, A. Colin and Pravin K. Trivedi, Regression Analysis of Count Data, 2nd edition, econometric society monograph ed., Cambridge University Press, 2013.

Chang, Andrew C., "Tax Policy Endogeneity: Evidence from R&D Tax Credits," Finance and Economics Discussion Series Divisions of Research & Statistics and Monetary Affairs 2014-101, Federal Reserve Board, Washington D.C. 2014.

Chirinko, Robert S., Steven M. Fazzari, and Andrew P. Meyer, "How Responsive is Business Capital Formation to Its User Cost?: An Exploration with Micro Data ," Journal of Public Economics, 1999, 74 (1), 53–80.

Cordes, Joseph J., "Tax Incentives and R&D Spending: A Review of the Evidence," Research Policy, 1989, 18 (3), 119 – 133.

Cummins, Jason G., Kevin A. Hassett, and R. Glenn Hubbard, "A Reconsideration of Investment Behavior Using Tax Reforms as Natural Experiments," Brookings Papers on Economic Activity, 1994, 25 (2), 1–74.

Czarnitzki, Dirk, Petr Hanel, and Julio Miguel Rosa, "Evaluating the Impact of R&D tax Credits on Innovation: A Microeconometric Study on Canadian Firms," Research Policy, March 2011, 40 (2), 217–229.

Dechezlepretre, Antoine, Elias Einio, Ralf Martin, Kieu-Trang Nguyen, and John van Reenen, "Do Tax Incentives for Research Increase Firm Innovation? An R&D Design for R&D," CEP Discussion Paper 1413, Centre for Economic Performance March 2016.

Edgerton, Jesse, "Investment Incentives and Corporate Tax Asymmetries," Journal of Public Economics, 2010, 94 (11), 936 – 952.

Eisner, Robert, Steven Albert, and Martin Sullivan, "The New Incremental Tax Credit for R&D: Incentive or Disincentive?," National Tax Journal, 1984, 37 (2), 171–183.

Fowkes, Rigmor Kringelholt, Joao Sousa, and Neil Duncan, "Evaluation of Research and Development Tax Credit," HMRC Working Paper 17, HM Revenue and Customs March 2015.

Gomez-Herrera, Estrella, "Comparing Alternative Methods to Estimate Gravity Models of Bilateral Trade," Empirical Economics, 2013, 44 (3), 1087–1111.

Gourieroux, C., A. Monfort, and A. Trognon, "Pseudo Maximum Likelihood Methods: Theory," Econometrica, 1984, 52 (3), pp. 681–700.

Griffith, Rachel, David Sandler, and John Van Reenen, "Tax Incentives for R&D," Fiscal Studies, May 1996, 16 (2), 21–44.

Griliches, Zvi, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," Bell Journal of Economics, Spring 1979, 10 (1), 92–116.

Guceri, Irem, "Will the Real R&D Employees Please Stand Up? Effects of Tax Breaks on Firm-Level Outcomes," International Tax and Public Finance, 2017. Forthcoming.

———, and Li Liu, "Effectiveness of Fiscal Incentives for R&D: Quasi-Experimental Evidence," Technical Report 15/12, Centre for Business Taxation Working Paper Series 2015.

Hall, Bronwyn and John Van Reenen, "How Effective are Fiscal Incentives for R&D?A Review of the Evidence," Research Policy, April 2000, 29 (4-5), 449–469.

Hall, Bronwyn H., "Effectiveness of Research and Experimentation Tax Credits: Critical Literature Review and Research Design," Technical Report 1995.

———, and Jacques Mairesse, "Exploring the Relationship between R&D and Productivity in French Manufacturing Firms," Journal of Econometrics, January 1995, 65 (1), 263–293.

———, ——— , and Pierre Mohnen, "Measuring the Returns to R&D," in Bronwyn H. Hall and Nathan Rosenberg, eds., Handbook of the Economics of Innovation, Volume 2, Vol. 2 of Handbook of the Economics of Innovation, North-Holland, 2010, chapter 24, pp. 1033 – 1082.

———, Pietro Moncada-Paterno Castello, Sandro Montresor, and Antonio Vezzani, "Financing Constraints, R&D Investments and Innovative Performances: New Empirical Evidence at the Firm Level for Europe," Technical Report, mimeo July 2015.

Hall, Robert E. and Dale W. Jorgenson, "Tax Policy and Investment Behavior," The American Economic Review, 1967, 57 (3), pp. 391–414.

Hassett, Kevin A. and R. Glenn Hubbard, "Chapter 20 - Tax Policy and Business Investment," in Alan J. Auerbach and Martin Feldstein, eds., Alan J. Auerbach and Martin Feldstein, eds., Vol. 3 of Handbook of Public Economics, Elsevier, 2002, pp. 1293 – 1343.

Hines, Jr. James R., "On the Sensitivity of R&D to Delicate Tax Changes: The Behavior of U.S. Multinationals in the 1980s," NBER Working Papers 3930, National Bureau of Economic Research, Inc September 1993.

Ientile, Damien and Jacques Mairesse, "A Policy Boost to R&D: Does the R&D Tax Credit Work?," EIB Papers Vol.14 No.1, European Investment Bank 2009.

Jorgenson, Dale W., "Capital Theory and Investment Behavior," The American Economic Review, 1963, 53 (2), pp. 247–259.

Karkinsky, Tom and Nadine Riedel, "Corporate Taxation and the Choice of Patent Location within Multinational Firms," Journal of International Economics, 2012, 88 (1), 176 – 185.

Lokshin, Boris and Pierre Mohnen, "How Effective are Level-based R&D Tax Credits?Evidence from the Netherlands," Applied Economics, April 2012, 44 (12), 1527–1538.

———, and ———, "Do R&D Tax Incentives Lead to Higher Wages for R&D Workers? Evidence from The Netherlands," Research Policy, 2013, 42 (3), 823 – 830.

Mansfield, Edwin, "The R&D Tax Credit and Other Technology Policy Issues," The American Economic Review, 1986, 76 (2), 190–194.

Mulkay, Benoit and Jacques Mairesse, “The R&D Tax Credit in France: Assessment and Ex Ante Evaluation of the 2008 Reform,” Oxford Economic Papers, 2013, 65 (3), 746–766.

OECD, “OECD Science, Technology and Industry Outlook 2014,” Technical Report, Or- ganisation of Economic Co-operation and Development 2014.

Rao, Nirupama, “Do Tax Credits Stimulate R&D Spending? The Effect of the R&D Tax Credit in its First Decade,” Journal of Public Economics, 2016. Forthcoming.

Saez, Emmanuel, Joel Slemrod, and Seth H. Giertz, “The Elasticity of Taxable Income with Respect to Marginal Tax Rates: A Critical Review,” Journal of Economic Literature, March 2012, 50 (1), 3–50.

Silva, J. M. C. Santos and Silvana Tenreyro, “The Log of Gravity,” The Review of Economics and Statistics, November 2006, 88 (4), 641–658.

Slemrod, Joel and Christian I. Gillitzer, Tax Systems, MIT Press, 2013.

Westerlund, Joakim and Fredrik Wilhelmsson, “Estimating the Gravity Model without Gravity Using Panel Data,” Applied Economics, 2009, 43 (6), 641–649.

Wilson, Daniel J, “Beggar Thy Neighbor? The In-State, Out-of-State, and Aggregate Effects of R&D Tax Credits,” The Review of Economics and Statistics, November 2009, 91 (2), 431–436.

Yagan, Danny, “Capital Tax Reform and the Real Economy: The Effects of the 2003 Dividend Tax Cut,” American Economic Review, 2015, 105 (12), 3531–3563.

Yohei, Kobayashi, “Effect of R&D Tax Credits for Small and Medium-sized Enterprises in Japan: Evidence from Firm-level Data,” Discussion papers 11066, Research Institute of Economy, Trade and Industry (RIETI) September 2011.

Zwick, Eric and James Mahon, “Tax Policy and Heterogeneous Investment Behavior,” American Economic Review, 2017. Forthcoming.