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

By Irem Guceri and Li Liu*

We exploit a 2008 UK policy reform that increased the tax incentives for R&D in medium-sized enterprises relative to large ones, to overcome the endogeneity of exposure to such tax credits. We estimate a difference-in-difference design on the universe of corporation tax filings in the United Kingdom, combined with other datasets. We find a positive and significant impact of tax credits for R&D, implying a user-cost elasticity estimate of around −1.6. This magnitude implies around $1 in additional private R&D spending per dollar foregone in tax revenue. (*JEL* H25, H32, K34, L25, O32)

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.[1] In the aftermath of the financial crisis, R&D tax incentives have become more generous in many countries, in the hope of improving competitiveness and stimulating inclusive economic growth.

The literature on tax incentives for R&D has suffered from a lack of exogenous variation in exposure to the policy. We overcome this challenge by exploiting a recent UK policy reform, which increased the generosity of R&D tax incentives for certain medium-sized companies while leaving the cost of R&D capital roughly unchanged for firms above a size threshold. During our sample period of 2002–2011, the UK's R&D tax incentive scheme was in the form of enhanced deductions of

* Guceri: Said Business School, Oxford University Centre for Business Taxation, Park End Street, OX1 1HP, Oxford, UK (email: irem.guceri@sbs.ox.ac.uk); Liu: International Monetary Fund, 1900 Pennsylvania Ave NW, Washington, DC 20009 (email: lliu@imf.org). We thank Miguel Almunia, Steve Bond, Estelle Dauchy, Michael Devereux, Dhammika Dharmapala, Ruud de Mooij, Thomas Pope, Panu Poutvaara, Simon Quinn, Helen Simpson, Michael Stimmelmayr, and participants at the HMRC-Treasury seminars, Bogazici University, Georg-August Universitat Gottingen, the ZEW Public Economics Conference, IIPF Annual Congress 2015, OUCBT Academic Symposium 2016 and Comparative Analysis of Enterprise Data 2015 for helpful comments. We thank the HMRC, especially, Yee Wan Yau, Daniele Bega, Manpreet Khera, and Peter Lumb for providing and facilitating our access to the data. We thank IIPF for awarding the 2015 Young Economists' Prize to an early version of this paper. We gratefully acknowledge financial support from the ESRC under award ES/L000016/1 and from the Oxford University Said Foundation Research Assistantship Fund. Guceri is a British Academy Postdoctoral Fellow and gratefully acknowledges the support of the British Academy. Any errors and omissions are the authors' own responsibility. Disclaimers: This work contains statistical data from the HM Revenue and Customs, which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland, made available for use by the HMRC Datalab. HMRC bears no responsibility for the analysis of the statistical data or the opinions presented in this paper. The views expressed are the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.

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

R&D spending, and was substantially more generous for SMEs than for large companies. The policy reform that we focus on expanded the SME definition, doubling the thresholds measured in employment, 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 under the old system became qualified as SMEs and are entitled to more generous deductions. 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. By generating differential changes in the user cost of R&D for newly classified SMEs compared to companies that remained as large facing relatively stable R&D user cost, this policy reform provides an excellent quasi-experimental setting for us to identify the causal effect of R&D tax incentives by addressing the simultaneous determination of R&D spending and its tax price.

The R&D tax policy in the United Kingdom is relatively simple. The tax benefits that we study are in the form of enhanced deductions and apply to the total amount of R&D every year for all firms investing in R&D. Compared to the R&D tax incentive schemes in the United States, France, and many other OECD countries, the simplicity and transparency of the UK scheme alleviates many of the issues that may interact with the policy evaluation, such as questions about whether firms understand the scheme, salience, or uncertainties regarding policy continuity, and allows us to analyze the effectiveness of the R&D tax incentives in a simpler institutional setting. We analyze this reform with a difference-in-difference approach, exploiting both the cross-section and the time-series variation in the data. We then verify these results with direct estimates of user cost elasticity in a pooled sample. More specifically, we identify the causal effect of R&D tax incentives by relating the changes in the level of R&D spending to the changes in the generosity of tax incentives, controlling for contemporaneous changes in the R&D spending that are unrelated to changes in the tax credits using a control group.

We estimate this difference-in-differences within a large-scale administrative dataset for the universe of UK corporation tax filings that links corporation tax records, qualifying R&D expenditures and financial statements. These data provide precise information on the amount of R&D spending that qualifies for the tax incentive and an indicator of each firm's eligibility for the relevant type of R&D tax incentive. 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 firms' accounting data and their exact position as SME or large based on the information from the tax return. The use of multiple sources to identify treated firms alleviates any measurement errors that may arise from the misclassification of firms. Equally important for identification, we observe non-tax determinants of R&D spending, such as firm size, profitability, and growth rate to disentangle the effect of the tax incentive from other confounding factors.

The key identifying assumption for our difference-in-difference approach is that R&D over time would trend similarly in the treated and control groups in the absence of the policy reform. The policy reform that we use for identification took place in 2008, which coincides with the global recession. Our identifying assumption rules out different time-varying shocks to treated and control firms. We therefore conduct a series of checks to verify that our size groups of interest followed similar pre-reform trends, and also that different size groups in the medium-large range were not differentially affected by the recession in 2008.

Our main finding estimates that companies in the treatment group increased their R&D spending by 33 percent on average in response to the increased generosity of tax incentives in 2008. The positive and significant effect of the R&D tax incentive is robust to controlling for aggregate macroeconomic shocks, other non-tax determinants of R&D investment, and any potential anticipation of companies to early announcement of the policy change.[2] Our preferred difference-in-difference estimates imply that estimate for the elasticity of R&D spending with respect to its user cost is -1.59. This translates to a bang-for-the-buck estimate of around £1 for each pound foregone in corporation tax revenue for a company that pays taxes at the main rate and around £1.5 for a company that pays taxes at the small profits rate.

Our work relates to several strands of literature. First, our paper contributes to the large literature on the impact of fiscal incentives on physical and knowledge capital accumulation. 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 Cummins, Hassett, and Hubbard (1994); Caballero, Engel, and Haltiwanger (1995); Chirinko, Fazzari, and Meyer (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. Hassett and Hubbard (2002) provides a recent survey on this topic.

Second, our study links to the literature on the relationship between financing constraints, R&D and innovation policy, and productivity. The ultimate goal of promoting business R&D spending is to boost productivity. Hall, Mairesse, and Mohnen (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 exists additional spillover effects of R&D that benefit the society via its impact on other firms and consumers (Bloom, Schankerman, and Van Reenen 2013). 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.

Third, our paper relates to recent studies on the effects of fiscal incentives for R&D using administrative data (Rao 2016 and Agrawal, Rosell, and Simcoe 2017). Agrawal, Rosell, and Simcoe (2017) find evidence in support of small firms' responsiveness to R&D tax credits in Canada by exploiting a change in the eligibility threshold for small firm tax credits. In comparison, companies included in the treatment group in our analysis are larger, but our findings support a similar degree

[2] 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.

of responsiveness to R&D tax incentives by medium sized companies. Other studies explore the effects of corporate taxation on related outcomes, such as patent location (Karkinsky and Riedel 2012), headcount and wages of R&D employees (Guceri 2018 and Lokshin and Mohnen 2013), and new or improved products introduced to the market (Czarnitzki, Hanel, and Rosa 2011).

Our findings have important implications for R&D tax policy outside the United Kindom. The current R&D tax scheme in the United Kingdom is permanent, relatively simple, and involves low administrative costs. Overall, in many jurisdictions, the administrative cost borne by R&D investing firms is relatively high, and the exact level of R&D tax benefits available may be hard for them to understand. These complexities are likely to explain partially why the previous papers that use US or French data have found smaller effects of the R&D tax credit in stimulating R&D spending.[3]

In the remainder of the paper, we first describe the main identification challenges and the policy setup in Section I, followed by Section II, which describes the data sources and summarizes the dataset used for the analysis. Section III explains the research design and Section IV reports the main results. Section V concludes.

I. Challenges and the Policy Experiment

A. *Empirical Challenges to Identification*

The rising popularity of R&D tax incentives was accompanied by a surge in the number of descriptive studies that demonstrate strong correlations between generous R&D tax incentives and increased R&D spending by the private sector.[4] Yet the literature still confronts three main empirical challenges in establishing the causal effect of taxes in stimulating R&D spending.

The first main challenge, as described in Hall and Van Reenen (2000, 450), is "… the intractability of finding exogenous variation in the user cost of capital." This identification issue of simultaneity between the user cost of capital and investment shocks arises both in the context of physical and R&D investment. There is, therefore, a recent emphasis on exploiting quasi experiments that generate changes in the tax price of R&D that are exogenous to firm investment decisions (for instance, Bronzini and Iachini 2014, and Guceri 2018, and working papers by Agrawal, Rosell, and Simcoe 2017 and Dechezleprêtre et al. 2016).

The second challenge is the scarcity of large-scale administrative data that accurately reflects the characteristics of the overall population of firms. For many years, R&D surveys that are standardized 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 (Bloom, Griffith, and van Reenen 2002; Lokshin and Mohnen 2013; Mulkay and Mairesse 2013; Guceri 2018). Now, the availability of detailed

[3] The online Appendix table A summarizes the existing literature since the review paper by Hall and Van Reenen (2000) and lists the countries and the datasets that are used in these studies. We argue that the UK scheme is by far the simplest and the one that remained the most homogeneous in terms of design throughout the sample period.

[4] Earlier studies include, among others, Mansfield (1986); Cordes (1989); Hines (1993); Griffith, Sandler, and Van Reenen (1995); and Bloom et al. (2002). Hall and Van Reenen (2000) provides a detailed review.

administrative datasets in particular enables the precise measurement of the firms' marginal tax rates and their R&D user costs, offering an invaluable opportunity for us to carry out an accurate analysis of the impact of tax incentives on R&D spending (Rao 2016).

Third, the elasticity of the R&D user cost, similar to the elasticity of taxable income, depends on the overall tax system (Saez, Slemrod, and Giertz 2012; Slemrod and Gillitzer 2013). There is considerable cross-country heterogeneity in the actual R&D tax incentive schemes. Given that these schemes are often quite complex and difficult to understand, they may present additional issues of salience and compliance for studies that estimate the elasticity of R&D spending in a more complex tax system. For example, 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 firms' improved understanding of the taxes thanks to the publicity generated by the reform.

B. *The Policy Reform*

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 UK private sector's modest performance in total factor productivity in comparison to other developed countries such as the United States (US), France, and Germany.[5]

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).

R&D policy in the United Kingdom currently relies heavily on volume-based tax incentives. According to the OECD R&D tax incentive statistics, about half of UK's funding for business R&D was channeled through tax incentives in 2012. Throughout our sample period of 2002–2011, the R&D tax relief schemes were in the form of enhanced deductions. The UK R&D tax relief was initially introduced in 2000 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 euros or sales of less than 40 million euros. In 2002, the scheme was extended to larger firms, albeit at lower deduction rates. Since the 2000s, both major parties in the United Kingdom expressed a firm commitment to supporting innovation and R&D through tax incentives. Both the government's and the opposition's announcements on the issue helped to eliminate any concerns about a removal of tax incentives in the near future. In the years that followed, there were changes to the R&D tax incentive schemes but these changes were always in the direction of increasing the generosity of the policy.

[5] See, for example, the Budget Report by Her Majesty's Budget (1999) for a reference on the UK's perspective.

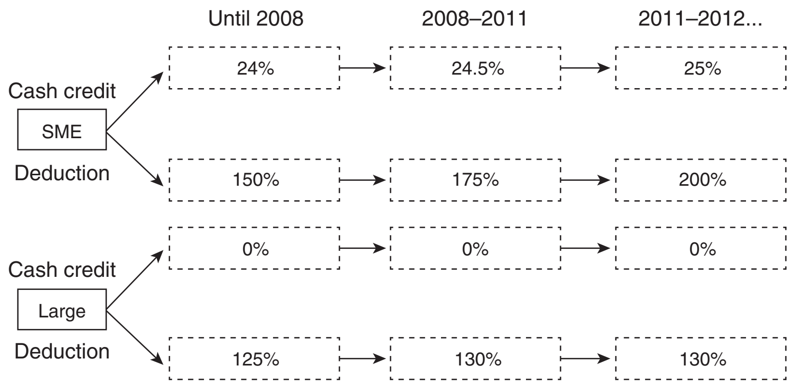

Figure 1. Evolution of R&D Tax Relief Deduction Rates

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. 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.

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 medium-sized firms was introduced with the August 2008 reform. This reform changed the SME definition 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. After a company starts claiming R&D tax incentives, its status as SME or large is valid for one more year even if the company's size changes in a way that affects the company's status as SME or large (See HMRC's Corporate Intangibles Research and Development (CIRD) Manual for details).

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 financial year 2007–2008 and £175 in 2009–2010. Newly qualified SMEs also became eligible to claim cash if they incurred zero or negative taxable profits in the current financial year.

We consider a simple conceptual background for the response of firms to R&D tax incentives based primarily on the neoclassical optimal capital accumulation framework first presented in Hall and Jorgenson (1967) and Jorgenson (1963), and treating investment in R&D analogously to investment in physical capital. We elaborate on the theoretical underpinnings of our empirical framework in online Appendix B.

Table 1—Marginal Corporation Tax Rate in the United Kingdom (*percent*), 2002–2014

Taxable profit (£)	2002–2005	2006	2007	2008–2010	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.

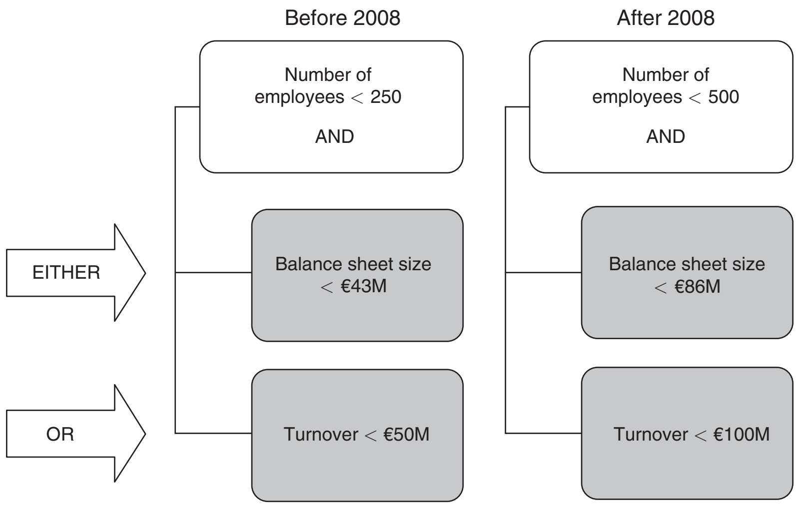

Figure 2. Size Thresholds for the SME Tax Relief

According to this theoretical basis, a reduction in the user cost of capital, through an increase in the generosity of R&D tax incentives, should trigger an increase in the R&D spending of firms to which the policy applies.

II. Description of the Datasets

We link three datasets to create the panel used in this study: (i) the universe of UK 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 tax position of a company including its taxable profit, loss brought forward, trading profit and 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 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. The final 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. In robustness checks, we also use a sample composed of all firms with positive qualifying R&D spending before the 2008 reform and not necessarily after.

According to the HMRC Corporate Intangibles and R&D 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 UK 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 Business Enterprise Research and Development (BERD) data published by the ONS has risen from just over 50 percent to 70 percent between 2005 and 2011. As our paper exploits the differences in generosity between the schemes for medium-sized and large firms, differences in take-up between the two groups can potentially be important for the interpretation of our results. Over the data period (2003–2011), the total number of SME claims increased from 5,160 to 10,030, and the total number of large company claims increased from 1,050 to 2,660, suggesting similar relative increases in take up for the two schemes. This should therefore have a neutral effect on how the intensive margin results extend to the wider group of claimants.

III. Empirical Approach

A. *Main Treatment Definition*

The main policy reform that we exploit introduced changes in the size thresholds for defining an SME. We 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[6] and, (ii) had between 250–500 employees in that particular year. We use the last observed pre-reform employment size to refine the treatment group to account for the fact that the post-reform size may be affected by the reform. Because the primary threshold to determine SME status is the employment size, we

[6] In the corporate tax return, a box is ticked that indicates whether the company is claiming R&D tax credits under the large company scheme or the SME scheme and we use this administrative information on identifying tax credit claims under the large company scheme in the pre-reform period.

use the employment size of companies to identify treatment in the refined version our treatment assignment. We refer to this group of treated firms as the group of "medium-sized companies," as these had between 250 and 500 employees in the last year before the introduction of the policy reform. The dataset for analyzing the 2008 SME definition change is an unbalanced sample that includes 183 firms in the treated group and 280 firms in the control group. Assignment to treatment and control groups by firm size categories is very stable, and we demonstrate the frequency of switches between small, medium, and large size categories in online Appendix D.

Based on our treatment and control definitions as described above, our difference-in-difference strategy allows us to estimate the effect of intention to treat (ITT).[7] Our approach differs from the fuzzy regression discontinuity design of Dechezleprêtre et al. (2016), which provides an estimate of the local average treatment effect (LATE) on companies close to the eligibility thresholds.

Figure 3 compares the average firm spending in R&D by treatment and control groups for each period during 2003–2011. The underlying data used for this figure takes the mean of the real R&D spending (natural logarithm) for each firm, then bases both the treated and control group mean level in 2007 to 100 for comparability relative to the pre-reform spending. Graphically, there is no particular pattern that suggests violation of the common trends assumption in the levels of R&D prior to the implementation of the policy reform. We discuss identification and the comparability of treated and control groups, along with the results of placebo tests in detail in Section IIIC. We also demonstrate the variation in average R&D spending by employment size bins in the pre- and post-reform periods in online Appendix D.

The normalization of each period's R&D spending based on the last pre-reform period (2007) R&D in Figure 3 is useful to compare the two series that have different levels of R&D spending; however, the fact that both medium-sized and large companies experience a drop in their R&D spending in this particular year renders the comparison between the two groups difficult. We therefore show the trend in log R&D spending in the two groups in Figure 4, panel A.

In order to demonstrate the extent of the differences between the two groups, Figure 4, panel B displays the predicted difference between the treated and control group averages from yearly Poisson regressions of R&D spending on the treatment dummy. Figure 4, panel C controls for firm size (measured by lagged turnover in log), firm growth rate (measured by lagged turnover growth in log), and two-digit sector dummies. Similarly, Figure 4, panel D displays the predicted difference between the treated and control group averages from yearly Poisson regressions of R&D spending on the treatment dummy, controlling for firm size (measured by lagged turnover), growth rate (measured by lagged turnover growth rate), and sector.

Panel D of Figure 4, the inclusion of controls appear to tighten the confidence bands, but they do not fully explain the level differences between the treated and

[7] There are several ways in which we can conceptualize "treatment" in this context. We consider treatment as taking up the subsidy at the lower SME rate in the first post-reform period. Alternatively, if we defined treatment as a reduction in the user cost of R&D capital even if the company does not perform R&D in the first post-reform period, then the estimate would have been the effect of treatment on the treated (TOT). This conceptualization does not change the interpretation of the results.

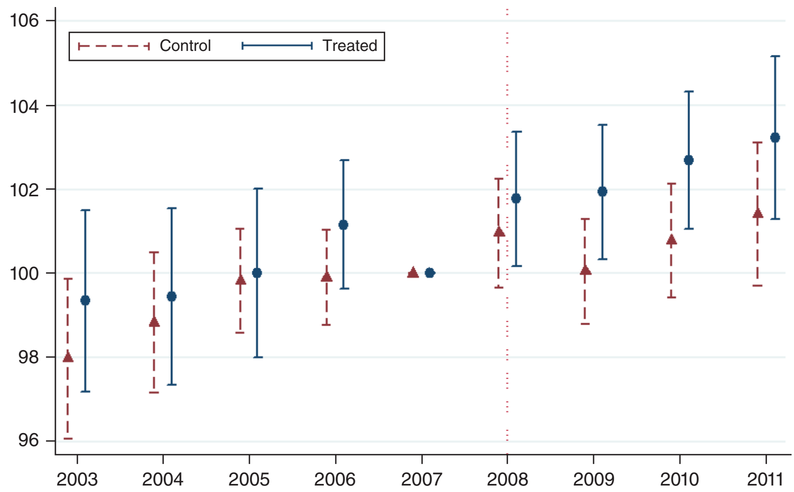

FIGURE 3. AVERAGE R&D SPENDING ACROSS GROUPS, RELATIVE TO 2007 R&D SPENDING

Notes: This figure shows treated and control group mean levels of real R&D spending (natural logarithm). The treated group is composed of companies that claimed R&D relief under the large company scheme and had between 250 and 500 employees in the last pre-reform year in which they performed R&D. These companies were reclassified as SMEs after the 2008 reform. The control group are companies that claimed R&D relief under the large company scheme and had more than 500 employees in the last pre-reform year in which they performed R&D. Therefore, the control group companies are those that remained as large after the 2008 reform. Treatment status is time-invariant for each company. For ease of comparability between the treated and the control groups, both the treated and the control group means are normalized to 100 in 2007, which is used as a base due to 2008 being a partial treatment year (the policy was adopted in August). The blue straight bars represent the 95 percent confidence intervals for the treated group means, and the red dashed bars represent the 95 percent confidence intervals for the control group means. The values in this figure are in logs because in the analysis that we present in Section III, the main specification is: $E[R_{it} | D_{it}, \mathbf{x}_{it}] = \exp(\gamma + \delta_D D_i + \delta_I D_i T_t + \mathbf{x}'_{it}\beta_x + \phi_t)$, where R_{it} is the level of real qualifying R&D spending for company i in year t, D_i is a dummy that captures treatment, and T_t is a dummy that captures pre-/post-reform periods. A version of this figure in levels can be drawn using the R&D data for treated and control groups that we present in Table C1.

control groups. In the estimation stage, we include firm fixed effects to control for time-invariant unobserved heterogeneity.

Overall, Figure 4 shows that the difference in R&D spending by firms in the treatment group relative to spending by firms in the control group has been stable over the pretreatment period, and then treated firms' R&D spending increases in the post-treatment period.

For a company that pays tax at the large profits rate, the drop in the user cost of R&D capital thanks to the change in the size definition for eligibility to the SME scheme should trigger about a 21 percent reduction in the tax component of the user cost of R&D capital. For a company that pays tax at the small profits rate, this reduction is around 15 percent. For each firm, we compute the user cost of capital, taking into consideration their taxable profit and the applicable R&D deduction.

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

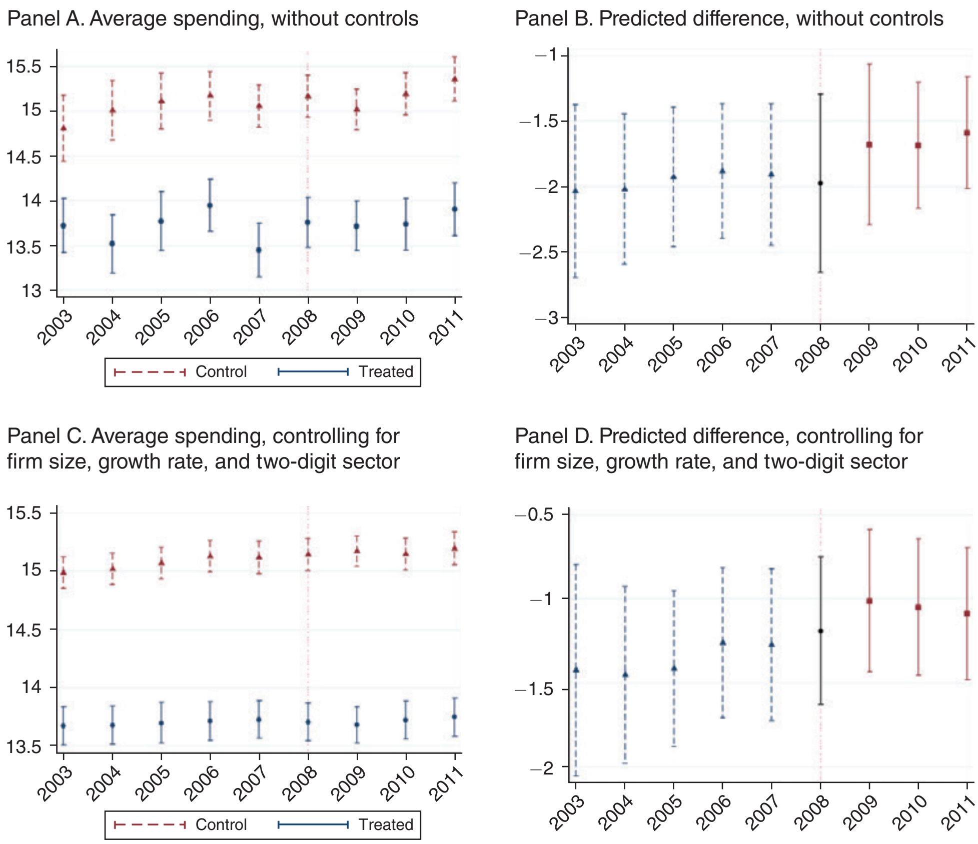

Figure 4. Average R&D Spending across Groups, Actual and Predicted Differences

Notes: Panel A shows the mean of real R&D spending (natural logarithm) for each firm, by treated and control groups. The blue straight bars represent the 95 percent confidence intervals for the treated group means, and the red dashed bars represent the 95 percent confidence intervals for the control group means. Panel B presents the predicted difference between the treated and control groups, where we obtain the predicted values using a year-by-year Poisson regression of R&D spending on a dummy that takes the value unity for the treated group and zero for the control group. Panel C plots the predicted values from an OLS regression of R&D spending (in log) on a set of controls (lagged turnover in log, lagged turnover growth rate in log, two-digit sector dummies) separately for the treated and the control groups, along with their 95 percent confidence intervals. As in the top panel, the blue straight bars capture the patterns for the treated group and the red dashed bars capture the patterns for the control group. Panel D presents the predicted difference between the treated and control groups, where we obtain the predicted values using a year-by-year Poisson regression of R&D spending on the treatment group dummy and control variables, namely, firm size (captured by lagged turnover), firm growth (captured by lagged turnover growth), and two-digit sector dummies. The year 2008 is a partial treatment year (the policy was adopted in August).

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. Figure 5 shows the change in the user cost of R&D (in log) over time across treated and control firms in panel A. Because R&D spending affects the taxable income of firms, we also present a measure of the tax component of the user cost of capital, which is not affected by the change in tax position due to the increase in R&D after the reform. This measure is calculated as

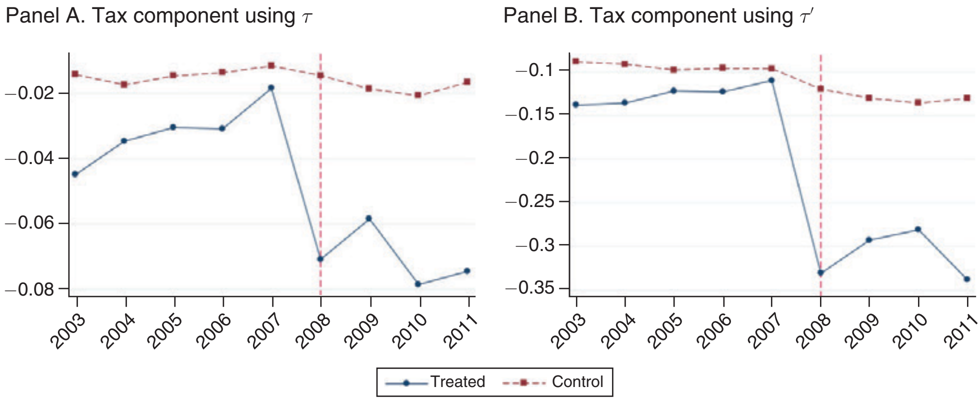

Figure 5. Average R&D User Cost over Time across Groups

Notes: Panel A depicts the evolution of the tax component of user cost of R&D (in log) across treated and control groups over time. This measure is calculated as $\frac{1-(1+d)\tau}{1-\tau}$, where d is the R&D super-deduction rate and τ is the statutory tax rate based on a company's current taxable income. Panel B refines the user cost measure to exclude the effects of changes in R&D spending as a result of the reform on the applicable statutory tax rate. This measure is calculated as $\frac{1-(1+d)\tau'}{1-\tau'}$, where the applicable tax rate τ' is based on prior year's income excluding the firms' R&D spending.

$\frac{1-(1+d)\,\tau'}{1-\tau'}$, where the applicable tax rate τ' is based on prior year's income excluding the firms' R&D spending. We show the changes in this alternative user cost measure (in log) in panel B of Figure 5. Consistent with the policy reform, there is a sharp reduction in the user cost of R&D capital for the treated group. In contrast, the user cost of R&D capital for the control group remained relatively stable over the sample period.

In Table 2, we present the mean and median levels of firm size measures and R&D across treated and control firms. Treated firms are on average smaller, and they spend less on R&D. As a share of different firm size measures (turnover and number of employees), median R&D is comparable across treated and control firms. Online Appendix C provides further descriptive statistics on the treated and the control groups.

B. *Estimation Strategy*

Based on the conceptual framework in online Appendix B, we attribute the interaction term on our difference-in-difference specification to be capturing the reduction in the user cost of R&D for the treated group of companies in the following model:

$$E[R_{it} \mid D_{it}, \mathbf{x}_{it}] = \exp(\gamma + \delta_D D_i + \delta_I D_i T_t + \mathbf{x}_{it}' \beta_x + \phi_t), \tag{1}$$

where R_{it} is the level of qualifying R&D spending for company i in year t in 2009 prices. The variable 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

Table 2—Summary Statistics

	Freq.	Turnover (real, £1,000)	Assets (real, £1,000)	R&D (real, £1,000)	Number of employees	R&D/ turnover	Assets/ turnover	R&D per worker
Control, mean	1,926	797,775	921,657	14,567	3,135	0.09	5.3	6,525
Control, median	1,926	259,221	233,227	1,551	1,253	0.01	0.9	1,194
Treated, mean	1,239	68,636	59,904	2,368	347	0.05	2.7	6,653
Treated, median	1,239	47,981	40,590	416	332	0.01	0.8	1,378

Notes: This table presents summary statistics for the key variables in the main sample, which includes companies that were reclassified as SMEs (medium-sized companies) and companies that remain as large (large control) after the 2008 tax reform. R&D, assets, and turnover values are reported in thousands, real (2008) GBP.

for years 2008 onward, and 0 otherwise. The coefficient δ_I on the interaction term $D_i T_t$ captures the differential change in qualifying R&D spending between pre- and post-2008 periods for the treatment group relative to the control group. Importantly, δ_I can be directly interpreted as the percentage change in the qualifying R&D spending with respect to the tax reform (Santos Silva and Tenreyro 2006; Cameron and Trivedi 2013). Time-invariant unobserved firm heterogeneity is captured by additional firm-fixed effects 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 $\mathbf{x}$ vector as additional controls.

Companies do not claim tax relief continuously every year. There is anecdotal evidence on companies that alternate staff functions between R&D and non-R&D ones depending on the availability of suitable projects.[8] In the CT600 dataset, among all companies with some R&D spending during the sample 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 fixed costs associated with undertaking qualifying R&D and claiming the relevant tax benefits. For variables of interest characterized with a long right-tail and a mass-point at zero, Santos Silva and Tenreyro (2006) propose a simple Poisson Pseudo-Maximum-Likelihood (PPML) estimator (following Gourieroux, Monfort, and Trognon 1984) to achieve consistency in estimating the parameters of a log-linear model. In particular, Santos 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.[9] In the context of R&D, an application can be found in Agrawal, Rosell, and Simcoe (2017). We use standard errors clustered by firm to correct for over-dispersion.

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

[9] The PPML estimator has been widely used in the empirical international trade literature (see, for example, Westerlund and Wilhelmsson 2011 and a survey by Gómez-Herrera 2013).

C. *Identification*

In an ideal experiment, we would assess the impact of the R&D tax incentives by randomly assigning some firms a low user cost of R&D capital and other comparable firms a higher user cost of R&D capital, and then comparing differences in the R&D spending between the two groups of firms. In the absence of such a randomized controlled experiment, we instead rely on the firm size thresholds for eligibility to the more generous SME scheme to establish treatment status. Determining treatment by firm size calls for a thorough check of the comparability of treated and control groups. By construction, the control group is larger than the treated group, and any unobserved shock to the expected returns from R&D that co-varies with firm size, and time may constitute a potential threat to identification. While we expect differences in the levels of R&D spending for the two groups, we should rule out differential trends between treated and control groups prior to the policy reform for identification.

We conduct a test of the null hypothesis that there is no difference in pre-reform trends between the treated and the control group companies.[10] Specifically, we first estimate the model: $E[R_{it}|D_{it}] = \exp(\alpha_i + \sum_{t=2003}^{2011} \phi_t + \sum_{k=2003}^{2011} \beta_k D_i T_k)$, where α_i represent firm fixed effects, ϕ_t represent year fixed effects; D_i is a dummy variable that takes the value unity for treated firms and zero otherwise; T_t is a dummy variable that takes the value unity only for one period, that is, year k, and zero otherwise. Without loss of generality for our test of parallel trends, we normalise $\beta_{2007} = 0$. We present the coefficients for this regression in Figure 6 and the full set of regression results in, Table E.1 in the online Appendix. In this estimation, the null hypothesis that there is no difference in pre-reform trends is equivalent to the null hypothesis that all pre-reform β_k coefficients are equal to each other. We run this test and obtain a p-value of 0.341; our parallel trends assumption therefore passes comfortably.

IV. Results

A. *Baseline Results*

We begin by presenting the results from our baseline regression, estimating the specification in equation (1). 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 this section, we summarize our findings on point estimates along with standard errors (s.e.) in parentheses.

In Table 3, column 1 presents the baseline specification with no controls, capturing the mean differences between treatment and control groups. The row labeled "Treated Firm × Post-reform" provides the estimates for the main coefficient of interest that captures the differential effect of the reform on average R&D spending

[10] We thank an anonymous referee for this suggestion.

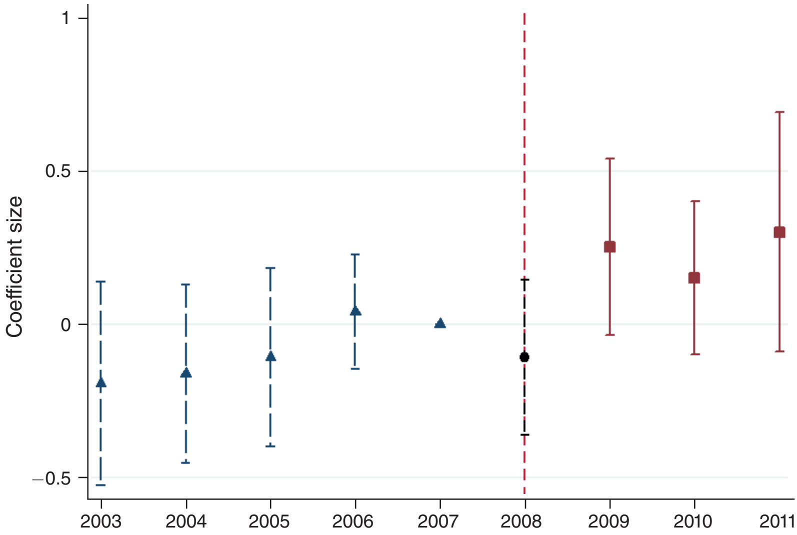

Figure 6. Common Pre-reform Trends between Treated and Control Groups

Notes: This figure presents the point estimates with 95 percent confidence intervals for the β_k coefficients from the regression specification: $E[R_{it} | D_{it}] = \exp(\alpha_i + \sum_{t=2003}^{2011} \phi_t + \sum_{k=2003}^{2011} \beta_k D_i T_k)$, where α_i represent firm fixed effects, ϕ_t represent year fixed effects, D_i is a dummy variable that takes the value unity for treated firms and zero otherwise, T_t is a dummy variable that takes the value unity only for one period, that is, year k, and zero otherwise. We normalize $\beta_{2007} = 0$. In online Appendix E, we present the result from this regression.

Table 3—Baseline Results

	(1)	(2)	(3)	(4)	(5)	(6)
Treated Firm × Post-reform	0.308	0.309	0.303	0.302	0.275	0.298
	(0.119)	(0.118)	(0.112)	(0.112)	(0.117)	(0.141)
Post-reform	0.080					
	(0.079)					
Revenue (real, lag) control?	No	No	Yes	Yes	No	Yes
Revenue (real, lag) growth control?	No	No	No	Yes	No	Yes
Revenue × Post–2008	No	No	No	No	No	Yes
Revenue (real, lag, in log) control?	No	No	No	No	Yes	No
Revenue (real, lag, in log) growth control?	No	No	No	No	Yes	No
Firm fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects?	No	Yes	Yes	Yes	Yes	Yes
Observations	3,165	3,165	3,165	3,165	3,159	3,165

Notes: This table presents regression results for the effect of the R&D tax credits on qualifying R&D spending based on equation (1). The dependent variable is the level of qualifying R&D spending (in real, thousand GBP). The treated group is composed of companies that claimed R&D relief under the large company scheme and had between 250 and 500 employees in the last pre-reform year in which they performed R&D. These companies were reclassified as SMEs after the 2008 reform. The control group are companies that claimed R&D relief under the large company scheme and had more than 500 employees in the last pre-reform year in which they performed R&D. Therefore, the control group companies are those that remained as large after the 2008 reform. "Treated Firm" is a dummy variable that takes the value unity for all firms that are in the treated group and zero for all firms in the control group. This is a time-invariant dummy. "Post-reform" is a dummy variable that takes the value unity for all the periods after 2008. The treatment status for 2008 is unclear because the reform was introduced in the middle of the year. We drop the year 2008 for this reason. The main coefficient of interest, which is the interaction term between being in the treatment group and in post-reform period (labeled Treated Firm × Post-reform), captures the differential changes in the R&D spending by the treated group of companies relative to that of the control group. Additional controls include first lags of real revenue, real revenue growth rate, an interaction term to capture the differential changes in size between pre- and post-reform periods, and the natural logarithm of lagged real revenues and its growth rate. Standard errors are clustered by firm.

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 difference-in-difference coefficient is significant at the 5 percent level, indicating a differential increase in R&D spending for treated firms of at least 30 percent (s.e. 0.11). In column 5, we additionally check for any substantial changes to the magnitude and significance of the "Treated Firm $\times$ Post-reform" interaction term after the inclusion of the logs of lagged real revenues and lagged real revenue growth rate. We observe a 3 percentage point drop in the magnitude, which still maintains a sizable 28 percent (s.e. 0.12) differential increase in the treated group's R&D spending.

Finally, in column 6, we add an interaction term between revenues and the post-reform dummy indicator to capture any differential changes in firm size between the pre- and post-treatment periods, given that the timing of the reform coincided with the global recession, which may cause firms of different sizes to be impacted differently. As discussed in Section IIIC, the inclusion of this variable does not affect the results significantly. The reform impact of interest, captured by the interaction term, is still estimated to be 30 percent (s.e. 0.14) and statistically significant at the 5 percent level.

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,[11] 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 2007–2008 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, column 1, we observe that the coefficient size from a regression that excludes observations in 2007 is 33 percent (s.e. 0.13) and significant at the 5 percent level.

We check the robustness of these results to outliers in terms of firm size in Table 4, column 2, which removes the top percentile in the size distribution of firms in the control group and checks the robustness of the findings to the presence of very large companies that are potentially systematically different from the medium sized, treated firms. The difference-in-difference coefficient is 25 percent (s.e. 0.13) and remains significant at the 5 percent level.

[11] 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.

Table 4—Robustness Checks

	Exclude all observations in 2007 (1)	Exclude largest 1 percent (2)	Alt. treatment: No post-treat R&D required (3)	Alt. treatment: Domestic only (4)	Alt. treatment: SME rate change (5)
Treated Firm × Post-reform	0.329	0.247	0.279	0.279	0.193
	(0.125)	(0.128)	(0.115)	(0.134)	(0.094)
Revenue (real, lag) control?	Yes	Yes	Yes	Yes	Yes
Revenue (real, lag) growth control?	Yes	Yes	Yes	Yes	Yes
Firm fixed effects?	Yes	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes	Yes
Observations	2,767	3,133	3,361	2,664	7,323

Notes: This table presents the results from three robustness checks for the effect of the R&D tax credits on qualifying R&D spending based on equation (1). The dependent variable is the level of qualifying R&D spending (in real, thousand GBP). The treated group, unless otherwise specified, is composed of companies that claimed R&D relief under the large company scheme and had between 250 and 500 employees in the last pre-reform year in which they performed R&D (except in column 5). These companies were reclassified as SMEs after the 2008 reform. The control group are companies that claimed R&D relief under the large company scheme and had more than 500 employees in the last pre-reform year in which they performed R&D. Therefore, the control group companies are those that remained as large after the 2008 reform. "Treated Firm" is a dummy variable that takes the value unity for all firms that are in the treated group and zero for all firms in the control group. This is a time-invariant dummy. "Post-reform" is a dummy variable that takes the value unity for all the periods after 2008. The treatment status for 2008 is unclear because the reform was introduced in the middle of the year. We drop the year 2008 for this reason. Column 1 excludes observations in 2007 to eliminate any potential anticipation effects. Column 2 excludes from the control group the largest 1 percent of observations. The treatment and control definitions that we use in column 3 do not require firms to carry out R&D both before "and after" the reform. Column 4 removes all observations that reported "overseas income" in their tax return. Column 5 uses an alternative treated group, which is composed of companies that claim R&D relief under the SME scheme and had fewer than 250 employees in the last pre-reform year in which they performed R&D. The performance of the revised treatment group is measured against the same control group as in the baseline specification, which uses large companies as 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.

In columns 3, 4, and 5 of Table 4, we check robustness to alternative treatment definitions. The treatment and control definitions that we use in column 3 do not require firms to carry out R&D both before and after the reform, thereby alleviating the risk of sampling on the outcome variable. The revised treatment group includes firms that perform R&D in at least one year before (but not necessarily after) the policy reform. The difference-in-difference coefficient is 28 percent (s.e. 0.12) and remains significant at the 5 percent level. In column 4, we focus only on the firms with domestic operations, by removing all the observations that have overseas income, and the results are similar to those in column 3. Finally, in column 5, we present results from an alternative experiment that includes only the smallest companies in the treatment group and excludes medium-sized companies. These small companies were eligible for an increase in the generosity of tax incentives through the increase in deduction rates in the same year as the size definition change. The control group is the same as before, and is composed of large companies with more than 500 employees. There is some evidence that small companies also increased their R&D spending relative to the control group (by around 19 percent s.e. 0.09, significant at the 5 percent level). We explore this dimension further in online Appendix G.

The timing of the global recession coincided with the reform that we exploit in the paper, so it is critical to show that the impact of the recession does not vary by firm

Table 5—Impact of the Recession on Treated and Control Groups

Outcome: Turnover growth, in log	(1)	(2)	(3)
Post-2008 × (Emp < 750)	−0.100	−0.221	−0.169
	(0.035)	(0.054)	(0.044)
Post-2008 × (Emp ≥ 750 & Emp < 1,000)	−0.103	−0.222	−0.171
	(0.033)	(0.063)	(0.049)
Post-2008 × (Emp ≥ 1,000 & Emp < 1,500)	−0.075	−0.194	−0.142
	(0.028)	(0.054)	(0.044)
Post-2008 × (Emp ≥ 1,500)	−0.017	−0.136	−0.085
	(0.033)	(0.061)	(0.049)
Year 2004		−0.078	
		(0.059)	
Year 2005		−0.016	
		(0.056)	
Year 2006		−0.039	
		(0.058)	
Year 2007		−0.120	
		(0.076)	
Year 2010		0.101	0.101
		(0.070)	(0.070)
Year 2011		0.105	0.105
		(0.054)	(0.054)
Year fixed effects?	No	Yes	Yes
Firm fixed effects?	Yes	Yes	Yes
R^2	0.003	0.007	0.004
Observations	1,903	1,903	1,903
Results of joint test with H_0: equal interaction terms across sizes			
p-value	0.245	0.235	0.238

Notes: This table presents within-groups ordinary least squares estimates from regressions with output growth rate (as measured by the natural logarithm of turnover growth rate) as the outcome variable, and with interactions between "Post-2008", which is a dummy variable that takes a value of zero for all the periods before 2008 and unity for all the periods after 2008, and size group dummies, which take a value of unity if the pre-2008 average employment of a company falls between the sizes indicated in the table and zero otherwise. "Emp" represents the pre-2008 average employment for each company. F-stat and p-value present the results of an F-test of equal interaction terms for each of the four interaction coefficients of interest. "Year 2004–Year 2007" represent the coefficient estimates on the pre-2008 year dummies of interest. "Year 2008" is dropped in all our regressions as treatment status for this year is unclear due to the mid-year introduction of the policy reform. "Year 2009" drops in the regressions for which the results are presented in column 2 and column 3 due to collinearity. In column 3, only post-2008 year dummies have been included in the regression. Standard errors are clustered by firm.

size for our groups of interest. That is, there is no differential impact of the recession within the control group for different size bands. Specifically, Table 5 shows that the change in output growth rates between pre- and post-2008 outcomes for four different size groups of companies were not statistically different from each other. The four groups that we focus on are companies that on average have: (i) 500–750 employees, (ii) 750–1,000 employees, (iii) 1,000–1,500 employees, and (iv) more than 1,500 employees prior to the 2008 policy reform.

In Table 5, regressions in all three columns include company fixed effects, in addition, interaction terms between the post-reform period dummy and the average size group of the firm. All these interactions indicate a negative and significant impact of the recession on output growth rate, however, this drop is statistically similar across the different size groups. We report p-values for the joint test of all size group interactions with the post-2008 dummy to be the same across the different groups. In Table 5, column 1 only includes the interaction terms of interest and company fixed effects, and then column 2 introduces year dummies to capture the time-specific shocks that are common to all groups, and column 3 only focuses on time-specific shocks in the post-2008 period.[12]

The ultimate goal of governments in their support to private R&D is boosting aggregate productivity and innovation. We explore the impact of the policy reform on firm-level labor productivity as measured by real turnover per worker using our difference-in-difference specification.[13] Perhaps owing to the short time period for which we have post-reform observations, we do not find a significant positive effect of the policy on labor productivity. We do not rule out that a longer time series may be needed to observe such effects.[14]

B. *Alternative Specifications*

We now explore heterogeneities in R&D investment responses across observed characteristics using triple interaction terms as in equation (2):

$$(2) \quad E[R_{it} | D_{it}, \mathbf{x}_{it}] = \exp(\gamma_i + \phi_t + \delta_I D_i T_t + \delta_T^H T_t H_i + \delta_I^H D_i T_t H_i + \mathbf{x}_{it}' \beta_x).$$

In addition to including all the key variables as in equation (1), we interact each of the key variables ("Post-reform" variable T_t and "Treated Firm $\times$ Post-reform" variable $D_i T_t$) in equation (2) with a time-invariant dummy variable H. Note that H takes the value unity for all firms if they fall in the category of interest. The coefficient estimate of the triple interaction term alone $D_i T_t H_i$ captures the differential effect of the policy reform for the firms that are in the category of interest, relative to the firms for which $H_i = 0$.

We explore differences of the impact of the policy for younger firms as opposed to older firms and for consistent performers of R&D as opposed to those that "stop-and-go." Perhaps unsurprisingly, these distinctions reveal some differential effects of the policy reform on one group over another, albeit with low power.[15] First, we find that consistent performers of R&D respond more to the policy (albeit insignificantly), with a magnitude of 0.45 (s.e. 0.30) estimated for the coefficient on the triple interaction term ($\hat{\delta}_I^H$), and an estimate of the baseline coefficient $\hat{\delta}_I$ insignificantly different from zero. 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.

[12] We carried out a separate test of equal postcrisis growth rates on the whole population of corporate tax returns, including all the non-R&D companies in the corporate sector. We split these companies into five different size categories according to their turnover levels. We run an OLS regression of the 2008–2010 growth rate on the firm size in 2008. Based on this analysis, for the medium-sized and large firms, we cannot reject equal post-crisis growth rates. This holds for all size groups except micro enterprises, which experienced significantly different growth rates than the rest. This requires us to exercise caution when interpreting the results in column 5 of Table 4. R&D-performing small companies in our data are usually not small enough to fall within the "micro enterprise" category.

[13] These results are available upon request.

[14] For example, Chen et al. (2018) find some productivity effect for firms in China.

[15] Full regression results are available upon request.

Second, younger firms, identified as the bottom quartile across the firm age distribution also respond to the policy change differentially more. The magnitude of the estimated coefficient on the triple interaction term $(\hat{\delta}_I^H)$ is 0.48 (s.e: 0.33), with an estimate of the baseline coefficient $\hat{\delta}_I$ of 0.23 (s.e: 0.12). This finding aligns with anecdotal evidence that innovative firms are often young, high-growth start-ups that benefit most from R&D support schemes. A potential explanation for this finding is that R&D tax incentives, by leaving more after-tax profits in the hands of private companies, may further alleviate cash constraints of younger and liquidity constrained firms.[16]

Finally, as a comparison with the existing literature, we directly estimate the elasticity of R&D with respect to its user cost. We compute the R&D user cost as described in Section I, 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.

Because the SME tax relief is more generous, companies may have an incentive to adapt their size to remain within the "SME definition" applicable to this particular policy. Strategic sizing by firms may cause the user cost of R&D capital measure to be correlated with the unobserved error terms in a regression relating the user cost as a continuous treatment variable to R&D spending. This was not a problem in our difference-in-difference approach, since we only took into account the pre-reform size, but the pooled approach uses both the pre- and the post-reform user cost of capital. Figure 7 explores whether companies bunch just below the employment thresholds (in 20-employee bins). We use the employment thresholds as our primary indicator since the employment size constitutes the primary criterion in determining eligibility to the SME scheme.[17] We verify that the firms in our groups of interest did not frequently adapt their size to remain an "SME" for R&D tax credit purposes.

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 upward; in fact, we may even expect to observe a positive coefficient on the user cost of capital.

In contrast, in our calculation of the user cost variable, we assume that the marginal tax rate for loss-making companies that 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).

[16] A third important dimension that may lead to heterogeneous responses to tax incentives is the distinction between multinational and domestic firms. In this study, we do not have sufficient information in the data to provide a full analysis of these effects apart from the robustness check that we present in Section IV, Table 4 and leave this important question to future research.

[17] We have also verified that there is no bunching at the turnover or asset thresholds.

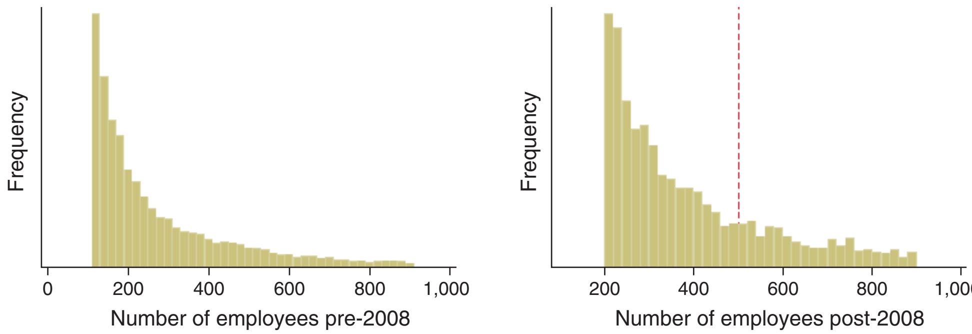

Figure 7. Distribution of Employment in the Pre- and Post-Reform Periods

Notes: The underlying data used for this figure uses 20-employee bins to examine the existence of strategic sizing by firms to remain within the more generous SME relief scheme. The left panel shows the distribution of employment in the pre-2008 period. The right panel shows the distribution of employment in the post-2008 period. The thresholds are marked with red dashed lines. Due to HMRC's disclosure requirements, the narrowest bin size that could be used for these graphs was 20, which leaves at least 30 observations in each bin. Bars further away from the thresholds have been dropped to comply with the HMRC disclosure requirements.

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 "before-R&D spending" marginal tax rate based on companies' taxable profits before undertaking any qualifying R&D investment to construct an alternative R&D user cost of capital measure. We base this marginal tax rate calculation on the previous year's "before-R&D spending" profits. In terms of the sign of the coefficient estimate, we expect to find a negative relationship between this measure of the R&D user cost and level of spending.

Table 6 presents the results from ordinary least squares regressions with the R&D user cost of capital (in log) as an explanatory variable. In these regressions, we pool the observations from the main treatment group with medium-sized companies, the alternative treatment group with smaller firms that experienced a more modest drop in their user cost, and the control firms. We include year fixed effects, firm fixed effects, companies' real turnover (in log, lagged), and the real growth rate of turnover (in log, lagged) as controls. In column 1, the explanatory variable of interest is the user cost variable calculated as described in Section I. The magnitude of this biased coefficient estimate for the user cost is 0.29 (s.e. 0.11). In column 2, we replace the actual user cost with the user cost measure calculated based "before-R&D spending" marginal tax rate, and we focus on the tax component of this measure. This modification results in a significant negative coefficient estimate of -0.61 (s.e. 0.18). Finally, we employ an instrumental variable regression strategy and instrument the R&D user cost of capital with the difference-in-difference interaction terms, along with the user cost measure calculated based on the "before-R&D spending" marginal tax rate. The findings are in line with our results from the difference-in-difference analysis, but we do find a larger elasticity estimate in absolute value, of -2.74 (s.e. 1.38).[18]

[18] This point estimate, along with standard errors of 1.38, does not reject an elasticity estimate of -1, which is a benchmark finding of the existing literature.

TABLE 6—DIRECT ESTIMATES OF USER COST ELASTICITY

	OLS (1)	OLS (2)	IV (3)
User cost of capital (log)	0.294		−2.744
	(0.107)		(1.379)
Before-R&D user cost of capital (log)		−0.606	
		(0.181)	
Revenue (real, lag, in log) control?	Yes	Yes	Yes
Revenue (real, lag, in log) growth control?	Yes	Yes	Yes
Firm fixed effects?	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes
Observations	6,801	6,801	6,801

Notes: This table presents results of ordinary least squares (columns 1 and 2) and two-stage least squares regressions that relate the user cost of R&D capital to the R&D spending at the company level. The specification here is linear, and replaces the discrete interaction term in equation (1) with a direct measure of the R&D user cost of capital variable (in natural logarithm). The dependent variable is the natural logarithm of qualifying R&D spending. The sample consists of pooled observations from both treated groups and the control group. In column 3, the user cost of R&D capital is instrumented by the "Treated Firm × Post-reform" interaction term and the "Before R&D user cost of capital." "Before-R&D user cost of capital" is a user cost of capital measure based on the marginal tax rate that corresponds to companies' taxable profits in the preceding period before undertaking any qualifying R&D investment. Additional controls include first lags of real revenue and real revenue growth rate. Standard errors are clustered by firm in columns 1 and 2 and bootstrapped in column 3.

C. *Discussion and Interpretation of the Results*

Our preferred estimate of the effect of the 2008 SME definition change (taking into account anticipation effects a year prior to the implementation of the policy) suggests that on average there is a 33 percent (s.e. 0.13) 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 I. First, the increase in the generosity of the SME eligibility threshold allows medium-sized companies in the treated group to continue claiming R&D deductions at the 150 percent enhanced deduction rate for SMEs. In the absence of the uplift in the eligibility threshold, companies in the 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 all SMEs, and a further rate reduction thanks to medium-sized firms' switch from being considered as "large" to being considered as "SME." In this context, the 33 percent increase in qualifying R&D spending in response to a 21 percent drop in the tax component of the user cost (for main rate tax payers) translates to an estimate for the elasticity of R&D with respect to its user cost of around −1.59. For tax payers in the small profits tax rate bracket, the elasticity estimate is −2.25. These are sizable effects of the policy, which is on the higher end of the estimates found in the literature. Our point estimates for user cost elasticity are in the same ballpark as the findings from a recent HMRC evaluation (Fowkes, Sousa, and Duncan 2015).

We calculate the foregone corporation tax revenue triggered by the policy change and the associated return in terms of additional private R&D spending under two scenarios: (i) for firms that pay corporation tax at the "main rate" (28 percent in 2008-2010), and (ii) for firms that pay corporation tax at the "small profits rate" (21 percent in 2008–2010). We take these tax rates as exogenous for the purpose of calculating the foregone tax revenue. We consider a treated firm that regularly incurs a fixed amount X of revenues net of non-R&D operating expenses. The pre-reform annual R&D spending of this firm is R, which then increases to $R' = 1.33R$ in the post-reform period. The pre-reform enhanced deduction rate $1 + d$, with $d = 0.25$, increases to $1 + d'$, with $d' = 0.75$ in the post-reform period. The pre-reform taxable profit of this treated firm is $X - R(1 + d)$. In the post-reform state, the taxable profit becomes $X - R'(1 + d')$. For a firm that pays taxes at the small profits tax rate of 0.21, the foregone tax revenue per firm is calculated as $0.23R$, and at the main rate of 0.28, this value is $0.30R$. Dividing the average additional R&D generated by the policy of $0.33R$ by the foregone tax revenue, the estimates imply £1–1.5 in additional private R&D spending per £1 foregone in tax revenue.

Our findings suggest that large, consistent programs that support R&D spending in the form of tax incentives are effective in generating additional private R&D. We offer evidence suggesting that the results are not driven by relabeling of ordinary spending as R&D (online Appendix F). We do not rule out cross-country differences in this observation. For example, Chen et al. (2018) provide empirical evidence supporting the presence of relabeling in China. According to our findings, the increase in R&D spending in the United Kingdom in response to the increased generosity of tax incentives is not merely a relabeling effect, possibly owing to the strong institutional setup.

We identify several reasons for the large elasticity estimate: (i) the UK policy is simple for firms to understand and react to quickly, (ii) medium-sized companies may be reacting more to the policy than other subgroups studied in the existing literature, (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.[19]

The difference-in-difference coefficient estimate (labeled "Treated Firm × Post-reform") in the alternative experiment that we present in online Appendix G 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 19 percent (s.e. 0.09) increase in qualifying R&D spending by SMEs in response to an 8–10 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 -1.96 for the main rate tax payers and -2.27 for the small profits tax payers. The point estimates are comparable to the user cost elasticity estimated from the main experiment when the wide confidence intervals are taken into account, and these are close to the instrumental variable regression estimates based on the "continuous treatment" that we have discussed at the end of Section IVB.

[19] 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 currently unable to investigate the relationship between qualifying and non-qualifying R&D.

V. 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 2002–2011 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 reforms lowered the user cost of R&D capital for medium-sized companies, while keeping the user cost stable for larger firms that remain above the eligibility threshold to be qualified as SME for R&D purposes.

Our findings from the analysis of the policy experiment suggest that R&D tax incentives have a strong positive effect on average qualifying R&D spending. In the experiment, which is 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. We find that the 21 percent reduction in the R&D user cost increased qualifying R&D spending by 33 percent, suggesting an elasticity estimate of around -1.6 and about £1 of additional R&D generated per pound foregone in corporation tax revenue.

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. We observe the strong increase in R&D spending in both consistent and intermittent spenders, but more strongly in consistent R&D spenders. We also find that young firms responded strongly by increasing their R&D spending after the reform. We provide evidence which suggests that the observed increase in R&D spending is not a mere artifact 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.

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