ONLINE APPENDICES FOR:

Do Tax Incentives Increase Firm Innovation? An RD Design for R&D, Patents, and Spillovers

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Appendix A: Institutional details of the UK R&D Tax Relief Scheme

A.1 Features of the R&D Tax Relief Scheme

The R&D Tax Scheme includes an SME Scheme and a Large Company (LCO) component.[1] Between its introduction in 2000 and 2012, more than 28,500 different companies had made claims under the SME Scheme, and over 7,000 under the Large Company Scheme, claiming more than £9.5bn in total R&D support. The annual amount of R&D support had risen to over £1bn by 2008, reaching £1.4bn in 2012, and covered qualifying R&D expenditure worth £13.2bn (HMRC, 2014).

Enhanced tax deduction. Both SME and Large Company Schemes are volume-based, i.e., the tax relief accrues on the total R&D spending rather than the incremental R&D over a prior base (the main US R&D tax relief scheme is incremental). It works mostly through enhanced deduction of current R&D expenditure from taxable income, thus reducing R&D-performing companies' corporate tax liabilities. The *enhancement rate* is always more generous under the SME Scheme than under the Large Company Scheme.

Example: If a company is allowed an enhancement rate of 75% and spends £10,000 spend on R&D; it can deduct an additional £7,500 (on top of the standard £10,000) for a total of £17,500 from its taxable income before calculating its tax liability.

Payable tax credit. In addition, under the SME Scheme, a company that has taxable loss after the additional deduction can also claim payable tax credit up to the amount of *payable credit rate* × enhanced qualifying R&D expenditure. This payable tax credit can only be used to reduce the company's employers' payroll tax (National Insurance Contributions, NIC) liabilities. Alternatively, the company (either as an SME or as a large company) can choose to carry the loss forward as normal.[2]

Example: If a company is allowed an enhancement rate of 75% and payable credit rate of 14%, spends £10,000 in R&D, and has no taxable income before the additional deduction, it can claim payable tax credit of $0.14 \times £10{,}000 \times (1 + 0.75) = £2{,}450$. If instead the company has £1,500 in taxable income before the additional deduction, it can first use £2,000 of its R&D to reduce its taxable income to zero (i.e., £1,500 = 75% × £2,000, then claim payable tax credit of $0.14 \times £8{,}000 \times (1 + 0.75) = £1{,}960$. This latter case is called a combination claim.

To be eligible for R&D tax relief, a company must also spend at least £10,000 a year on qualifying R&D expenditure in an accounting period (see Appendix A.3 for details on what constitutes qualifying R&D expenditure). If an SME works as a subcontractor for a large company, only the subcontractor SME can claim R&D tax relief, under the Large Company Scheme. There is also an upper limit of €7.5m on the total amount of aid a company can receive for any one R&D project under the SME Scheme.[3]

[1] For further details, see http://www.hmrc.gov.uk/manuals/cirdmanual/CIRD90000.htm (SME Scheme) and http://www.hmrc.gov.uk/manuals/cirdmanual/CIRD85050.htm (Large Company Scheme).

[2] A large company that has taxable loss before the additional deduction therefore may still benefit from R&D tax relief by carrying the enhanced loss forward to further reduce its taxable income in the next period. However, this reduction is only meaningful when the company has enough taxable income in this next period.

[3] Furthermore, an SME already receiving another form of notified state aid for a project cannot claim R&D tax relief for that same project under the SME Scheme (which is also a notified state aid), as total state aid intensity cannot

A.2 SME definition

The UK R&D Tax Relief Scheme's SME (Small and Medium Sized Enterprise) definition is based on total assets ("balance sheet total"), employment ("staff headcount"), and sales ("turnover") as described in Section 2. We summarize the key elements of the definition rules below but for further technical details on these rules see http://www.hmrc.gov.uk/manuals/cirdmanual/CIRD91400.htm.

Ceiling tests and two-year rule. An enterprise passes the SME ceiling tests if (i) its staff headcount and (ii) either its aggregated assets or its aggregated sales fall below the respective ceilings. An enterprise loses (acquires) its SME status if it fails (passes) the ceiling tests over two consecutive accounting periods (two-year rule). The SME ceilings were set according to the European Commission (EC)'s recommendation at the introduction of the R&D Tax Relief Scheme in 2000, which were revised upward (also by the EC) effectively from January 2005. From August 2008, the UK government only for the purpose of the R&D Tax Relief Scheme (see Table A1 and Appendix A.4) doubled the SME ceilings again.

Measurements for ceiling tests. Total assets is the gross amount of assets shown in the company accounts. The staff headcount of an enterprise represents the number of full-time person-years attributable to people who have worked within or for the enterprise during the year under consideration.[4] The staff headcount and financial data used for the ceiling tests are those relating to the latest accounting year, yet financials from previous accounting years also matter due to the two-year rule. Total assets and sales converted to Euros using the exchange rate on the last day of the relevant accounting period, or the average exchange rate throughout that accounting period, whichever is more beneficial for the enterprise.

Account aggregation rules. In the case of an autonomous enterprise, the staff headcount and financial data are determined exclusively based on the consolidated accounts of the enterprise itself. An autonomous enterprise is one that is not a linked enterprise or a partner enterprise. Generally, an enterprise is autonomous if it has holding of less than 25% of the capital or voting rights in one or more enterprises and/or other enterprises do not have a stake of 25% or more of the capital voting rights in the enterprise.

In the case of a linked enterprise, the ceiling tests are applied to the aggregates of the figures in its own accounts and those from the accounts of all other enterprises to which it is linked (including non-UK ones), unless the account data of those enterprises are already included through account consolidation. Linked enterprises are those in which one is able to control, directly or indirectly, over the affairs of the other(s).

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exceed 25% under European Commission's State Aid rules. However, from April 2003 onward, SMEs could claim R&D tax relief for such projects under the Large Company Scheme.

[4] The contributions of part-time workers, or those who work on a seasonal or temporary basis count as appropriate fractions of a full-time person-year. The term staff includes employees, persons seconded to the enterprise, owner-managers, partners (other than sleeping partners); it excludes apprentices or students engaged in vocational training with an apprenticeship or vocational training contract, and any periods or maternity or parental leave.

A.3 Qualifying R&D expenditure

The definition of R&D expenditure that qualifies for the R&D Tax Relief Scheme has been stable over time. Qualifying R&D expenditure must be allowable as a deduction in calculating trading profits, which includes all flow costs, employee costs, materials, utilities, software, or subcontracted R&D expenditure (but only if the contractor is an SME).[5] Formally, the costs must be consistent with the UK accounting definition of R&D under GAAP (accounting standards FRS102 s18, IAS38, FRS105 s13 and SSAP13). In addition, "to quality for R&D, a company must be undertaking a project to seek an advance in science or technology through the resolution of scientific or technological uncertainties. The advance being sought must constitute an advance in the overall knowledge or capability in a field of science or technology, not a company's own state of knowledge or capability alone." More details on what constitutes qualifying R&D expenditure are available at https://www.gov.uk/hmrc-internal-manuals/corporate-intangibles-research-and-development-manual/cird81300 and https://www.gov.uk/hmrc-internal-manuals/corporate-intangibles-research-and-development-manual/cird81900.

A.4 Evolution of the R&D Tax Relief Scheme

2000-02 introduction. Table A1 summarized the evolution of the UK R&D Tax Relief Scheme. It was first introduced in April 2000 only for SMEs (Finance Act 2000, Chapter 17, and Schedule 20), then later extended to large companies starting from April 2002 (Finance Act 2002, Chapter 23, Schedule 12). Between April 2000 and December 2004, the ceilings for staff headcount, assets, and sales were 249, €27m, and €40m respectively. From January 2005, they were raised to 249, €43m, and €50m. This followed European Union guidelines for SME definitions. Throughout the period from April 2000 (April 2002) to March 2008, the enhancement rates were set at 50% for SMEs and 25% for large companies, and the payable credit rate for SMEs was 16%.[6]

2008 changes. As discussed in Section 2, various changes to the scheme became effective at different points in 2008. First, from April 2008, the enhancement rate for large companies was increased from 25% to 30%. Then from August 2008, the enhancement rate for SMEs was increased from 50% to 75% and the payable credit rate for SMEs was reduced from 16% to 14%. That is, the effective state aid intensity in the payable tax credit case increased from 24% (= 1.5 × 0.16) to 24.5% (= 1.75 × 0.14). [7]

Also from August 2008, the SME Scheme was extended to "larger" SMEs as the SME ceilings were doubled to 499, €86m, and €100m for staff headcount, total assets, and sales respectively. This change in

[5] Qualifying R&D expenditure could include R&D performed outside of the UK by *foreign branches* of UK holding companies, as foreign branches' revenues and costs are directly consolidated into their UK holding companies' tax revenues and costs for UK tax purpose. Qualifying R&D expenditure is unlikely to include R&D performed outside of the UK by *foreign subsidiaries* of UK holding companies, as foreign subsidiaries' net profits are indirectly incorporated into their UK holding companies' tax revenues as dividends for UK tax purpose instead.

[6] One exception to this differential treatment of SMEs and large companies was the Vaccine Research Relief Scheme (VRR) launched in April 2003, which extended the higher 50% additional allowance to cover specific areas of vaccine and drug research conducted in large companies (Finance Act 2003, Chapter 14, Schedule 31). The VRR enhancement rate was later reduced to 40% from August 2008 onward.

[7] The reduction in payable credit rate form 16% down to 14% is to ensure that effective state aid intensity does not exceed the limit of 25% imposed by the European Commission.

SME definition is applicable only for the purpose of the R&D tax relief and therefore is the focus of our paper, as it allows us to separate the impacts of the R&D Tax Relief Scheme from those of other programs. It should also be noted that even though these new SME ceilings were announced in Finance Act 2007, the date on which they became effective (August 1st, 2008) was announced much later, on July 16th, 2008, less than a month before the effective date.[8]

Later changes. There were tweaks to the system in 2011 and 2012. From April 2011, the SME enhancement rate was increased to 100% and the SME payable credit rate was reduced to 12.5%. From April 2012, the SME enhancement rate was again increased to 125%. However, the SME definition as announced in Finance Act 2007 and the large company enhancement rate of 30% remained unchanged throughout this period.

[8] Finance Act 2007, Section 50 (Appointed Day) Order 2008 of July 16th, 2008.

Appendix B: Data sources and sample construction

B.1 PATSTAT dataset

Overview of the dataset. Our patent data are drawn from the World Patent Statistical Database (PATSTAT) maintained by the European Patent Office (EPO).[9] PATSTAT is the largest international patent database available to the research community and includes nearly 70 million patent documents from over 60 patent offices, including all of the major offices such as the United States Patent and Trademark office (USPTO), the Japan patent office (JPO) and the Chinese Patent and Trademark Office (SIPO) in addition to the EPO. Patents filed with the UK Intellectual Property Office are also included. PATSTAT data thus cover close to the population of all worldwide patents between 1900-2015.

PATSTAT reports the name and address of patent applicants, which allows matching individual patents with company databases. The matching between PATSTAT and FAME is implemented by Bureau Van Dijk and was available to us as part of the ORBIS online platform through a commercial agreement. The quality of the matching is excellent: over our sample period, 94% of patents filed in the UK and 96% of patents filed at the EPO have been matched with their owning company.

Patent family count. A patent in country *c* grants a holder an exclusive right to commercially exploit the invention in that country. Accordingly, she will patent her invention in country *c* if she plans to either market there directly or license to another firm who will sell it there. The set of patents in different countries related to the same invention is called a *patent family*. The vast majority of patent families include only one patent (usually in the home country of the inventor). Importantly, PATSTAT reports not only the unique identifier of each patent application, it also indicates a unique patent family indicator for each patent (we use the DOCDB patent family indicator). This allows us to identify all patent applications filed worldwide by UK-based companies and to avoid double-counting inventions that are protected in several countries.

Our primary measure of innovation is the *number of patent families*, irrespective of where the patents are filed. This proxies for the number of inventions a firm makes. This means that we count the number of patents filed anywhere in the world by firms in our sample, be it at the UK Intellectual Property Office, at the European Patent Office, at the USPTO or anywhere else, but we use information on patent families to make sure that any invention patented in several places is only counted once. Patents are sorted by their first application year (the priority year). We use fractional counts to account for multiple applicants. For example, if two firms jointly apply for a patent, then each firm is attributed one-half of a patent. In practice, only 8% of patents filed by UK-based companies are filed jointly by at least two companies.

Patent quality measures. There are many well-known issues with patents as a measure of innovation. As noted above, not all inventions are patented, although it is reasonable to assume the most valuable ones are, so counting patents screens out many of the low value inventions. Nevertheless, since patents are of very heterogeneous importance we use several approaches to examine how our results change when looking at patent quality.

First, we distinguish between patents filed at the UK patent office and patents files at the European

[9] For further details see http://www.epo.org/searching/subscription/raw/product-14-24.html.

Patent Office (EPO), US Patent and Trademark Office (USPTO), or Japan Patent Office (JPO). Since the financial and administrative cost is about six times higher at the EPO than UK patent office, EPO, and similarly USPTO and JPO, patents will on average be of higher private value. We also consider a related measure of patent quality which is the number of jurisdictions in which each patent is filed, i.e., patent family size. There is evidence that the number of jurisdictions in which a patent is filed is an indicator of its economic value as patenting is costly (see Guellec and Van Pottelsberghe, 2000, and Harhoff et al., 2003).

Second, we use patent citations, also available from PATSTAT. For each patent in the database, we know how many times it was cited by subsequent patents (excluding self-citations). We use the number of subsequent citations (referred to as forward citations) as a measure of value. Again, this measure is well rooted in the patent literature (Hall et al., 2005, Lanjouw and Schankerman, 2004). The disadvantage for our purposes is that we only have a short window of time for future citations causing a truncation problem. To address this issue, we benchmark a patent's citations against the distribution of citations to patents in the same patent sector-by-filing office-by-filing year cohort.

Third, another measure of quality is to distinguish by technology class, as some classes (e.g., pharmaceuticals) are likely to be more valuable than others (e.g., business process methods). In addition, patents in PATSTAT are categorized based on the International Patent Classification (IPC). We use this to compute the technological scope of a patent. Information on citations and patent technology class additionally allows us to compute the originality index, a more sophisticated measure of patent quality that measures the patent-class diversity of a patent's backward citations. Similar to forward citation count, we also benchmark a patent's scope and originality index against other patents in the same patent sector-by-filing office-by-filing year cohort.

Finally, we also use patent IPC codes (at three-digit level) to determine a firm's primary technology class, and construct measures of technological proximity and connectedness between firms, which are used to investigate R&D technology spillovers.

B.2 CT600 and RDTC datasets

Overview of the datasets. The CT600 dataset is constructed by the UK tax authority (HMRC) and is a confidential panel dataset of corporate tax returns or assessments made from the returns for the universe of companies that file a corporate tax return in the UK. We can only access the dataset from within an HMRC facility (similar to a US Census Bureau Research Data Center) and merging with other datasets requires approval from HMRC. It is currently not possible to merge CT600 with other government secured datasets available at different facilities.[10] The CT600 dataset covers all accounting periods whose end dates fall between April 1st, 2001 and March 31st, 2012 (we denote the fiscal year ending in March 31st, 2012 by "2011" as most of the data will fall in this calendar year) and consists of all information on the UK Company Tax Return form (which is called the CT600 form). Specifically, an extension of CT600, the Research and

[10] For example, it is currently not possible to merge CT600 with the BERD firm survey which is used to build the national estimate of R&D. Since BERD is a stratified random sample that puts large weight on the biggest R&D performers, we would likely only have a small overlap with firms around the threshold.

Development Tax Credits (RDTC) dataset, provides detailed information on tax relief claims. However, CT600 contains little information on financial statement variables (e.g., assets and employment are not included) as they are not directly required on corporate tax forms.[11]

We convert the original observation unit of firm by accounting period in CT600 to firm by financial year by aggregating all accounting periods the end dates of which fall in the same financial year.[12] This conversion affects a very small number of observations as only 3% of our firm by year observations are aggregates of multiple accounting periods. Our converted dataset then contains 15.7 million firm by year observations over 12 financial years from 2000 to 2011 (covering 3.2 million firms), including 9.1 million firm by year observations over our study period from 2006 to 2011 (covering 2.5 million firms).

Key variables used. Our key variables of interest are those related to firms' R&D tax relief claims from CT600's RDTC dataset, which include the amount of qualifying R&D expenditure each firm has in each year and the scheme under which it makes the claim (SME vs. Large Company Scheme). These variables, originally self-reported by firms on their CT600 forms, have been further validated and corrected by HMRC staff using additional tax processing data available only within the tax authority. It should also be noted that R&D tax relief variables are only available for R&D-tax-relief-claiming firms for the years in which they make the claims. While we believe it is reasonable to assume that non-claiming firms have zero qualifying R&D expenditure, it is not possible to construct their precise SME eligibility without full information on employment, total assets, sales, and ownership structure.

Table B1 shows that over the study period of 2006-11, we observe claims in 53,491 firm by year observations (by 20,730 firms), 81% of which are under the SME Scheme. The total qualifying R&D expenditure and estimated Exchequer costs under the SME Scheme are in nominal terms £11.2bn and £1.8bn respectively; the corresponding figures under the Large Company Scheme are £48.5bn and £3.9bn (excluding claims by SME subcontractors). These figures are in line with the official R&D Tax Relief Scheme statistics released in HMRC (2014).

We also use the data on sales and on investment in plant and machinery from CT600. Sales are annualized to account for different accounting period lengths. CT600 tax-accounting sales, which is calculated using the cash-based method, is not the same as financial-accounting sales (reported in the FAME data – see below), which is calculated using the accrual method and used to determine SME eligibility.[13] However, CT600 sales provides a good measure for firms' growth and performance, given its relatively wide coverage.

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[11] The CT600 dataset was further extended to cover up to the end of financial year 2014 in late 2017. However, the corresponding RDTC dataset has not been made available as of the writing of this paper. As a result, we focus on the period between 2009 and 2011, for which we have reliable R&D data, as our post-policy period for R&D analyses. In addition, it is unlikely that our key running variable – total assets in 2007 – has strong predictive power of firm's SME status after 2011. We do use data on sales up to 2013 from this extended CT600 dataset in our firm performance analysis (see Table A13).

[12] Financial year *t* begins on April 1st of year *t* and ends on March 31st of year *t+1*.

[13] The cash-based method focuses on actual cash receipts rather than their related sales transactions. The accrual methods records sale revenues when they are earned, regardless of whether cash from sales has been collected.

B.3 FAME dataset

Overview of the dataset. FAME is a database of UK companies provided by Bureau Van Dijk (BVD), a private sector company. The panel dataset contains companies' balance sheet and income statement data from companies' annual accounts filed at the UK company registry (Companies House), together with additional information on addresses and industry codes. Like other countries, UK regulations for reporting accounting variables vary with company size, so some balance sheet and income statement variables are missing. We discuss the implications of this below.[14] Our FAME dataset also covers 14 financial years from 2000 to 2013 and contains 23.9 million firm by year observations (covering 4.4 million firms), including 11.5 million firm by year observations over our study period of 2006-11 (covering 3.1 million firms).

Key variables used. Our key SME-eligibility variable from FAME (for R&D tax relief purpose) is total assets (i.e., balance sheet total). As almost all UK companies are required by the Companies House to send in their balance sheets for their annual accounts regardless of their size, total assets coverage in FAME is close to complete, at 97% over our study period of 2006-11. On the other hand, sales (financial-accounting sales used to determine SME eligibility) is available for only 15%, as smaller firms are not required to provide their income statements.[15] The proportion of firms that reported employment is even lower, at 5%, as employment reporting is not mandatory. Even in our baseline sample of relatively larger firms (i.e., firms with total assets in 2007 between €61m and €111m); the proportion of firms that reported sales is 67% and employment 55%. For this reason, while we do use FAME sales and employment as running variables in some alternative specifications, our baseline sample and key results are derived using total assets as the running variable.

Besides total assets, sales, and employment, other FAME variables used in our paper include primary industry code, address, capital investment, profits, wagebill, and other financial information.

B.4 Merging datasets and sample construction

Baseline patent sample. To construct our baseline sample for patent outcomes, we merge PATSTAT with FAME using Bureau Van Dijk's matching. As PATSAT comprehensively covers all UK patenting firms, we can safely infer that non-matched firms have zero patents. From the merged dataset, we define our baseline sample based on our key running variable – total assets in 2007. Specifically, we employ a baseline bandwidth of €25m around the new SME threshold of €86m (see subsection 3.2 for details), which gives a baseline sample of 5,744 firms, 60% of which are below the threshold.

Complementary R&D sample. To also consider R&D outcomes, we further merge CT600 with

[14] All UK limited companies, public limited companies (PLC), and limited liability partnerships (LLP) are required to file *annual accounts* with the Companies House. An annual account should generally include a balance sheet, an income statement, a director's report, and an audit report. However, smaller companies may be exempt from sending in income statement, director's report, or audit report. All UK registered companies are required to file *annual returns* with the Companies House, which contain information on registered address and industry codes.

[15] Small companies (those having any 2 of the following: (1) sales of £6.5m or less, (2) assets of £3.26m or less, (3) 50 employees or less) are only required to send in balance sheets. Micro-entities (those having any 2 of the following: (1) sales of £632,000 or less, (2) assets of £316,000 or less, (3) 10 employees or less) are only required to send in simplified balance sheets.

FAME using an HMRC-anonymized version of company registration number (CRN), which is a unique regulatory identifier in both datasets. 95% of CT600 firms between 2006 and 2011 also appear in FAME, covering close to 100% of R&D performing firms and 100% percent of patenting firms in this period (Panel C of Table B1).[16] Unmatched firms are slightly smaller but not statistically different from matched ones across different variables reported in CT600, including sales, gross trading profits, and gross and net corporate tax chargeable.[17] Furthermore, that the match rate is less than 100% is due to CRN entering error in FAME, which happens more often among firms that are much smaller than those around SME-eligibility thresholds.[18] For these reasons, we believe sample selection due to incomplete matching between CT600 and FAME is unlikely to be an issue for us.[19]

As CT600 is only accessible within the HMRC Datalab, this merging was done using the Datalab's own version of FAME, which is slightly different from ours (most likely due to differences in times of download). As a result, the in-lab version of the baseline sample (similarly defined based total assets in 2007 and a €25m bandwidth around the SME threshold of €86m) is slightly larger, with 5,888 firms. Despite this, the two samples are near identical to each other in all observable characteristics (e.g., share of firms below the threshold, average patent count and patent quality, coverage of firm financials). The same patterns also hold for the wider sample based on a €35m bandwidth around the SME threshold that we also consider throughout the paper.

Due to restricted access to the Datalab, we use the baseline out-of-lab sample as the baseline for all patent analyses, which are also the focus of this paper, and turn to the complementary in-lab sample only for R&D-related analyses.[20] Sample descriptive statistics are summarized in Table 1 and discussed in detail in subsection 3.2.

B.5 Further notes on variable construction

Converting sterling to euros. As FAME total assets and sales are reported in sterling while the corresponding SME ceilings are set in euros, we convert sterling to euros using the exact same rule used by HMRC for tax purposes. That is, the conversion should be done using the exchange rate on the last day of the relevant accounting period or the average daily exchange rate throughout that accounting period, whichever is more beneficial for the enterprise. The daily exchange rate is obtained from the OECD, using the exact the same method as used by HMRC.

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[16] Out of 2,495,944 firms present in CT600 between 2006 and 2011, 2,358,948 firms are matched to FAME (94.5% match rate). Over the same period, 20,627 out of 20,730 R&D-performing firms and 9,376 out of 9,420 patenting firms are matched to FAME (99.5% match rate).

[17] Differences (standard errors) between matched and unmatched firms in sales (£'000), gross trading profits (£), gross corporate tax chargeable (£) and net corporate tax chargeable (£) are 970 (3,286), 8,969 (13,703), 3,497 (3,898) and 1,961 (2,291) respectively. None of these differences are statistically significant at conventional level.

[18] Because of confidentiality concerns, we do not get to work directly with CRNs but an anonymized version of CRNs provided by the HMRC Datalab for both FAME and CT600 datasets. This prevents us from further cleaning and matching of initially unmatched firms due to above issue.

[19] The correlation between ln(sales) from CT600 and ln(sales) from FAME is 0.90. As noted above, the variables are not measured in the same way, but the fact that their correlation is high is reassuring that the match is well performed.

[20] Some patent regressions are implemented on both samples and yield quantitatively similar results, as reported in Tables 3 and A4 (see Appendix C.4 for details).

Qualifying R&D expenditure. For qualifying R&D expenditure, we do not include the amounts claimed by SME subcontractors, which do not benefit from more generous reliefs under the SME Scheme. Since SME subcontracting makes up only a small portion of the overall R&D Tax Relief Scheme, we confirm excluding SME subcontracting does not materially affect our key findings. To account for price differences across years, we also convert nominal values of R&D expenditure to their real values in 2007 price, using UK annual CPI as reported in the World Bank Economic Indicators database.[21]

Winsorizing key variables. We address the presence of outliers in patenting and R&D spending by winsorizing our key outcome variables, which include qualifying R&D expenditure and number of all patents as well as number of EPO patents, UK patents, and US patents. Specifically, for each variable, the top 2.5% of non-zero values in each year within the sample of firms with 2007 total assets between €46m and €126m are set to the corresponding 97.5 percentile value (i.e., winsorization at 2.5% of non-zero values). This translates into "winsorizing" the R&D of top 5 to 6 R&D spenders and the number of patents of top 2 to 4 patentees in the baseline sample in each year. It should be noted that our key findings are robust to alternative choices of winsorization window (e.g., 1% or 5% instead of 2.5%), or to excluding outliers instead of winsorizing outcome variables (see Tables A4 and A5).

Financial constraint measures. We construct an industry-level measure of financial constraints as the average cash holdings to capital ratio in each three-digit US SIC industry. This ratio is computed using FAME data for the universe of UK firms over 2000-05. Cash holding is the amount of cash and cash equivalents on the balance sheet; capital is proxied by fixed assets. We first (i) average cash holdings and capital within firm over 2000-05, then (ii) calculate the cash holding to capital ratio at the firm level, and finally (iii) average this ratio across firms by industry. Constructing the measure at the two- or four-digit industry level, or using cash flow or current assets instead, yields qualitatively similar results (Table A11).

Total factor productivity (TFP). TFP is calculated as $\ln(value\ added) - \propto_k \ln(capital) - \propto_l \ln(Wagebill)$, in which (i) value added is sales minus imputed materials, (ii) capital is proxied by fixed assets, (iii) Wagebill is the total payroll (wage weighted employment as a measure of labor service inputs) as reported in FAME, and (iv) $\propto_k$ and $\propto_l$ are estimated separately for each two-digit UK SIC industry across all UK firms in FAME over the 2000-05 period, using Olley-Pakes (1996) production function estimation.

Construction of other variables is generally detailed in the notes to tables.

[21] Ratios of current-£ to 2007-£ derived using UK annual CPI are 1.023 for 2006, 1.000 for 2007, 0.965 for 2008, 0.945 for 2009, 0.915 for 2010, and 0.875 for 2011.

Appendix C: Robustness checks and supplementary analyses

C.1 Relationships between RD, Diff-in-Diff, and Diff-in-Disc Designs

To see formally the relationship between the different empirical models, we consider a simplified case where there are three periods $t \in \{0,1,2\}$. In the main empirical models these are averages across years, so period t = 2 is 2009-13, period t = 1 is 2006-08, and period t = 0 is 2002-05. Thus $\mathbb{1}_{\{t>2008\}}$ in the main text is equivalent of $\mathbb{1}_{\{t=2\}}$ below.

Dynamic Regression Discontinuity Design. Our baseline model (equation (1) in the main text) is an RD Design with a lagged dependent variable, so we label it here dynamic RD Design (in the main text we abbreviate this to "RD Design"):

$$PAT_{i2} = \alpha + \beta^{RD} E_{i1} + f(z_{i1}) + \mu PAT_{i1} + \varepsilon_i. \quad \text{(C1)}$$

With a slight abuse of notation E_{i1} here represents E_i^{2007} in the main text. Note that in our baseline $f(z_{i1}) = \gamma^-(z_{i1} \times E_{i1}) + \gamma^+(z_{i1} \times (1 - E_{i1}))$. We can write this in quasi-differenced form as:

$$PAT_{i2} - \mu PAT_{i1} = \alpha + \beta^{RD} E_{i1} + f(z_{i1}) + \varepsilon_i. \quad \text{(C2)}$$

Static Regression Discontinuity Design. We also consider static RD Design without a lagged dependent variable:

$$PAT_{i2} = \alpha + \beta^{RD} E_{i1} + f(z_{i1}) + \varepsilon_i. \quad \text{(C3)}$$

The static RD model is a restricted version of the dynamic RD model with the restriction $\mu = 0$.

Difference-in-Differences Design. The general form of the Diff-in-Diff Design (equation (2) in the main text) is:

$$PAT_{it} = \beta^{DiD}(E_{i1} \times \mathbb{1}_{\{t=2\}}) + \theta_i + \delta_t + \varepsilon_{it}. \quad \text{(C4)}$$

In our two-period $t \in \{1, 2\}$ case:

$$PAT_{i2} - PAT_{i1} = \beta^{DiD} E_{i1} + \delta + \Delta\varepsilon_i,$$

or

$$PAT_{i2} = \delta + \beta^{DiD} E_{i1} + PAT_{i1} + \Delta\varepsilon_i. \quad \text{(C5)}$$

Equation (C5) shows that the Diff-in-Diff model is a restricted version of our baseline dynamic RD model in equation (C1) with the restrictions $f(z_{i1}) = 0$ and $\mu = 1$.

Difference-in-Discontinuities Design. The Diff-in-Disc estimator (equation (3) in the main text) is the difference between the static RD estimators in pre- and post-policy periods:

$$PAT_{it} = \beta^{Disc}(E_{i1} \times \mathbb{1}_{\{t=2\}}) + f_{\mathbb{1}_{\{t=2\}}}(z_{i1}) + \theta_i + \delta_t + \varepsilon_{it}. \quad \text{(C6)}$$

In our two-period $t \in \{1, 2\}$ case:

$$PAT_{i2} - PAT_{i1} = \delta + \beta^{Disc} E_{i1} + f(z_{i1}) + \Delta\varepsilon_i,$$

or $$PAT_{i2} = \delta + \beta^{Disc} E_{i1} + f(z_{i1}) + PAT_{i1} + \Delta\varepsilon_i. \tag{C7}$$

Equation (C7) shows that this Diff-in-Disc model is also a restricted version of our baseline dynamic RD model in equation (C1) with the restriction $\mu = 1$. If this structural restriction of the Diff-in-Disc model (i.e., $\mu = 1$) were satisfied or the additional restriction of the Diff-in-Diff model (i.e., $f(z_{i1}) = 0$) were also satisfied, equations (C6) and (C3) would be more efficient than our baseline equation (C1). Empirically, we find that this is not the case.

Dynamic Difference-in-Discontinuities Design. We further generalize Diff-in-Disc Design based on the dynamic RD model instead of the static RD model, using data back to 2002:

$$PAT_{it} = \beta^{DDisc}\left(E_{i1} \times \mathbb{1}_{\{t=2\}}\right) + f_{\mathbb{1}_{\{t=2\}}}(z_{i1}) + \mu_t PAT_{i,t-1} + \theta_i + \delta_t + \varepsilon_{it}, \tag{C8}$$

or $$PAT_{i2} = \delta + \beta^{DDisc} E_{i1} + f(z_{i1}) + (1 + \mu_1) PAT_{i1} - \mu_0 PAT_{i0} + \Delta\varepsilon_i. \tag{C9}$$

Equation (C9) is a generalized version of our baseline dynamic RD model in equation (C1) with the addition of a 2-period lagged dependent variable PAT_{i0}.

Adjusted Difference-in-Differences Design. Finally, note that the key assumption in the Diff-in-Diff Design is that there are parallel trends between treatment and control. But if small firms do worse in recessions, then this will be violated, since 2009-13 started with a major downturn. One way to tackle this is to allow for a break in how firm size affects firm's performance, i.e., patents in our specific context.

$$PAT_{it} = \beta^{ADiD}\left(E_{i1} \times \mathbb{1}_{\{t=2\}}\right) + \pi\left(z_{i1} \times \mathbb{1}_{\{t=2\}}\right) + \theta_i + \delta_t + \varepsilon_{it}, \tag{C10}$$

or $$PAT_{i2} = \delta + \beta^{ADiD} E_{i1} + \pi z_{i1} + PAT_{i1} + \Delta\varepsilon_i. \tag{C11}$$

Equation (C10) is a restricted version of the Diff-in-Disc model in equation (C6) with the restriction that $f(z_{i1}) = \pi z_{i1}$, or $\gamma^- = \gamma^+$.

C.2 Estimation models for event study plots

Diff-in-Diff event study plot. Panel A of Figure 3 plots the β_t^{DiD} coefficients for $t \in [2002, 2015]$ from estimating the following equation using our baseline sample:

$$PAT_{it} = \sum_{t=2002}^{2015} \beta_t^{DiD} \times E_i^{2007} + \theta_i + \tau_t + \varepsilon_{it}. \tag{C12}$$

Diff-in-Disc event study plot. Panel B of Figure 3 plots the β_t^{Disc} coefficients for $t \in [2002, 2015]$ from estimating the following equation using our baseline sample:

$$PAT_{it} = \sum_{t=2002}^{2015} \beta_t^{Disc} \times E_i^{2007} + f_{\mathbb{1}_{\{t>2008\}}}\left(z_i^{2007}\right) + \theta_i + \tau_t + \varepsilon_{it}. \tag{C13}$$

Spillover Diff-in-Disc event study plot. Panel A of Figure 6 plots the δ_t^{Disc} coefficients for $t \in [2002, 2015]$ from estimating the following equation using our baseline sample:

$$PAT_{jt} = \sum_{t=2002}^{2015} \delta_t^{Disc} \times E_i^{2007} + f\left(z_i^{2007}\right) \times \mathbb{1}_{\{t>2008\}} + \theta_j + \tau_t + \varepsilon_{ij}. \quad \text{(C14)}$$

C.3 IV estimation of innovation production function

IV Design. In Section 3, besides estimating the policy's direct effects on R&D and patents, we also estimate an "innovation production function" (equation (4) in the main text):

$$PAT_i^{Post} = \alpha + \gamma^{IV} R_i^{Post} + f\left(z_i^{2007}\right) + \varepsilon_i, \quad \text{(C15)}$$

which can be interpreted as a "knowledge production function" as in Griliches (1979), using E_i^{2007} as the instrument for R_i^{Post}(firm i's annual average R&D over 2009-11). Appendix E.1 shows that this equation can be derived from optimizing behavior of a firm with a R&D augmented CES production function and Cobb-Douglas knowledge production function. With homogenous treatment effects, the IV estimate delivers the causal effect of R&D on patents; with heterogeneous treatment effects, it captures the causal marginal effect of policy-induced R&D on innovation outputs. Both frameworks require the exclusion restriction that the discontinuity induced exogenous fluctuations in $E_{i,2007}$ did not affect patents through any channel other than qualifying R&D.

Under the identification assumptions discussed earlier, the RD Design guarantees that $E_{i,2007}$ (conditional on appropriate running variable controls) affected innovations only through a firm's eligibility for the SME Scheme, which directly translated into qualifying R&D expenditure. It is possible that firms benefitting from the SME Scheme (i) also increased complementary investment spending in capital or managerial capabilities (even though they would want to classify as much of this spending as qualifying R&D expenditure if possible); or (ii) relabeled existing non-R&D spending as qualifying R&D expenditure in order to claim R&D tax relief. The first channel would bias our estimate of γ^{IV} upward, while the second channel would bias it downward.

Policy effect on non-qualifying expense categories. To assess whether these other channels through which $E_{i,2007}$ could affect innovations are a first order concern, we estimate the RD Design analogous to equation (1) in the main text with various non-R&D expense categories as the outcome variables. Table A12 reports statistically insignificant discontinuities across these expenses, among both all baseline firms (columns (1)-(5)) and only R&D-performing firms (columns (6)-(10)). These categories include: (i) total administrative expenses (columns (1) and (5)), (ii) total administrative expenses minuses qualifying R&D expenditure (columns (2) and (6)), (iii) total expenses minuses qualifying R&D expenditure (columns (3) and (8)), (iv) imputed capital expenditure (columns (4) and (9)), and (v) qualifying machinery and plant investments for capital allowance tax relief purpose (columns (5) and (10)). The magnitudes of the coefficients (either positive or negative) are immaterial compared to firms' average spending in the corresponding expense categories. This suggests that firms benefitting from the SME Scheme did not also increase complementary non-R&D investments when they increased R&D spending in response to the policy. The results also imply that relabeling is unlikely a first order concern in our context, as it should lead to decreases in non-qualifying expense categories (as found in Chen et al., 2019, in the context of China), which we do not observe. Furthermore, relabeling, had it happened, could not explain the effect the policy had on patents.

Patent returns to R&D. Column (2) in Panel B of Table 3 estimates equation (C15) using our baseline sample. Column (3) additionally controls for PAT_i^{Pre} as in equation (1) in the main text, which only slightly reduces the IV estimate of the returns to R&D. Table A6 reports these same IV estimates in columns (2) and (4), together with their corresponding OLS estimates in columns (1) and (3). The IV coefficients, which are considerably larger than their OLS counterparts, imply that one additional patent costs on average $2.4-3.1 million (1/0.563-1/0.434 using a $/£ exchange rate of 1.33) in additional R&D. Unlike β^{RDD} this IV estimate (γ^{IV}) is not subject to the fuzziness of our RD Design but instead captures the true marginal effect of policy-induced R&D on patents. At the pre-policy means of R&D and patents of £0.074m and 0.064 respectively, it implies an elasticity of patents with respect to R&D of about 0.50-0.65 ((0.434/0.064)/(1/0.074)-(0.563/0.064)/(1/0.074)).

The fact that the IV estimates are larger than OLS ones is consistent with the LATE interpretation, which implies that the IV specification estimates the impact of additionally induced R&D on patents among complier firms (i.e., those increased their R&D because of the policy). These firms were more likely to be financially constrained, thus also more likely to have higher-return R&D projects which they could not have taken without the policy. Table 7 presents some direct evidence supporting this hypothesis (see subsection 5.2 for details).

Columns (5) to (8) of Table A6 extend the sample to firms within a €35m bandwidth around the SME assets threshold of €86m and report estimates quantitatively comparable to those in columns (1) to (4). Finally, despite the weak adjusted first-stage F-statistics, the Anderson-Rubin weak-instrument-robust inference tests indicate that all IV estimates reported in Table A6 are statistically different from zero even in the possible case of weak IV.

C.4 Placebo threshold tests and alternative specifications

C.4.1 Placebo threshold tests

To examine if the discontinuity in post-policy patents is unique to the SME assets threshold of €86m, we run a series of placebo tests at all possible integer thresholds between €76m and €96m using the same RD specification in equation (1) in the main text and the same €25m sample bandwidth. Figure A3 shows that the estimated discontinuities in post-policy patents (average over 2009-13) peak at €86m and are statistically significant only near this true SME threshold (due to effect contamination from the true threshold). Panel B of Figure A4 presents the analogous plot for R&D, which also exhibits the same pattern.

In fact, if we adjust the placebo-threshold estimation samples to not overlap with the true threshold, then *all* resulting coefficients are small and not statistically different from zero. For example, using a placebo threshold of €76m with as an upper bound the true threshold of €86m and as a lower bound €51m (€25m below the placebo threshold) yields a discontinuity estimate (standard error) of -0.007 (0.028) for patent outcome, and using a placebo threshold of €96m with as a lower bound the true threshold of €86m and as an upper bound €121m (€25m above the placebo threshold) yields -0.003 (0.035). These coefficients are small in magnitude compared to that estimated at the true threshold of 0.052 (0.019). These results further confirm that the discontinuities in patents and R&D exist only the true SME threshold, as results of the more generous SME Scheme after the 2008 policy change.

C.4.2. Alternative specifications

Table 3's results on the policy's direct effects on patents and R&D are robust a wide range of robustness tests, as reported in Tables A4 (for patent outcome) and A5 (for R&D outcome). As the tests presented in Table A4 are a superset of those in Table A5, the column reference below is based on Table A4 unless noted otherwise.

In-lab R&D sample. First, we replicate our main patent results using the in-lab sample of 5,888 firms used in all R&D analyses. Column (1) employs main-text equation (1)'s baseline RD Design and column (2) main-text equation (3)'s Diff-in-Disc Design. Both columns report estimates quantitatively similar to their equivalent in Table 3 (columns (2) and (4) in Panel A respectively). In column (3), we implement Calonico, Catteneo, and Titunik's (CCT) (2014) robust bias-corrected optimal bandwidth RD Design (using the default triangular kernel weights). The CCT selected optimal bandwidth for patent outcome is €31.2m and for R&D outcome is €20.3m (column (9) of Table A5), which guides our baseline sample bandwidth choice of €25m.

Alternative weights and bandwidths. Second, we explore alternative kernel weights for both the baseline sample based on a bandwidth of €25m around the threshold and the wider sample based on a €35m bandwidth, using main-text equation (1)'s baseline RD Design. Columns (4) and (5) employ triangular and Epanechnikov kernel weights with a €25m bandwidth and columns (6) and (7) uniform and Epanechnikov kernel weights with a €35m bandwidth. All four columns yield statistically significant RD estimates of comparable magnitude to Table 3's baseline results.

Next, in columns (8) and (9), we consider *all* firms that were not SMEs from before the policy change (i.e., firms with 2007 assets above the old SME threshold of €43m). Column (8) implements main-text equation (3)'s Diff-in-Disc Design and column (9) main-text equation (2)'s Diff-in-Diff Design. Although the estimates from this much larger sample are smaller, they remain of sizeable magnitude and are statistically significant. This further strengthens Figures 4 and A2's evidence that our key finding of the policy's effect on patents is not driven by sample bandwidth choice, and that it is likely not limited to only firms around the policy threshold.

Similarly, columns (5) to (8) in Table A5 explore narrower (€15m and €20m in columns (5) and (6)) and larger (€30m and €35m in columns (7) and (8)) bandwidths for R&D outcome, using main-text equation (1)'s RD Design. We further add a second order polynomial of assets in columns (7) and (8) to improve the fit given the larger bandwidths (the coefficients on the second order assets terms are statistically significant for both bandwidths). All four columns report statistically significant RD estimates, similarly indicating that the policy's effect on R&D is robust to sample bandwidth choice.

Only firms below employment threshold. Third, we expect that the effects of being below the SME assets threshold on patents and R&D exist only among firms for which the assets criterion is binding. In column (10), we restrict the sample to only firms whose 2007 employment did not exceed the SME employment threshold of 499.[22] This results in a statistically significant RD estimates that are much larger than those from the full baseline sample, especially after accounting for firm's pre-policy patents and R&D. We also further explore the interactions between the different SME criteria in Table A14 and Appendix C.6.

Alternative data trimming rules. Fourth, we examine winsorizing R&D and patent data at 1% (column (11)) or 5% (column (12)) instead of 2.5% as for the baseline sample. We also explore dropping outliers in patents (or R&D in Table A5) as an alternative way to address outliers (column (13)). These expectedly affect the magnitude of RD estimates, but not the qualitatively finding of the presence of statistically significant discontinuities in patents (and R&D) at the SME assets threshold.

Higher order polynomial controls. Fifth, we add second (column (14)) and third (column (15)) order polynomials to main-text equation (1)'s RD Design and obtain estimates comparable in magnitude to the baseline results, although they are not always statistically significant. Importantly, in all specifications, the coefficients on the higher order assets terms are not statistically significant, and we cannot reject that the higher order terms are jointly zero. This supports our choice to use first order polynomial controls as per Gelman and Imbens's (2018) advice. In addition, the RD estimates are also quantitatively similar to our baseline results when we add industry fixed effects (column (16)), or location and industry-by-location (columns (11) and (12) in Table A5) fixed effects, as expected in an RD Design.

Other estimation models. Sixth, we obtain similarly positive and statistically significant estimates when using count data models, i.e., Poisson (column (17)) and Negative Binomial (column (18)), instead of OLS, to allow for a proportional effect of being below the SME threshold on patents and R&D (as in a semi-log specification). Alternatively, we apply the inverse hyperbolic sine transformation to both firm's pre- and post-policy patents to estimate the policy's proportional effect using main-text equation (1)'s RD Design. This also yields a positive and statistically significant RD estimate, albeit of smaller magnitude.

Alternative pre-/post-policy periods. Next, we consider alternative constructions of the lagged dependent variable control. Column (19) only controls for firm's patents in 2007, while column (20) pre-policy patents in 2006, 2007, and 2008 separately, both using main-text equation (1)'s RD Design. These tests also generate estimates quantitatively similar to Table 3's baseline results.

Finally, as different elements of the policy change were introduced at different times in 2008, it is not perfectly clear whether 2008 should be considered a pre- or post-policy year. In columns (21) to (27), we replicate all key specifications in Panel A of Table 3 counting 2008 as a post-policy year instead (i.e., pre-policy period is 2006-07 or 2002-07 and post-policy period is 2008-13 or 2008-15). Column (21) corresponds to column (2) and columns (22) to (27) correspond to columns (4) to (9) in Panel A of Table 3 respectively. The resulting estimates are all statistically significant. In terms of magnitude, they are

[22] Note that the SME ceiling tests require that firms must first meet the employment criterion before either assets or sales criterion could be considered. However, information on employment is available for only slightly more than half of the firms in our baseline sample, and missing employment is unlikely to be random. Therefore, we do not exclude firms whose 2007 employment exceeded 499 from the baseline sample in our main analyses to avoid potential selection issues.

comparable if not slightly larger than those in Table 3, consistent with the pattern shown in Figure 3. This suggests that our decision to consider 2008 as a pre-policy year, if anything, is on the conservative side.

C.5 Bunching at the SME thresholds in 2007 and later years

Assets, sales, and employment distributions in 2007. Figure 1 shows that firms' 2007 assets distribution was continuous around the 2008 new SME threshold of €86m. The corresponding McCrary test, which estimates the discontinuity in firms' 2007 assets distribution at the threshold, yields a discontinuity estimate (log difference in density height at the threshold) (standard error) of -0.026 (0.088), which is not statistically different from zero. Using available data on sales and employment, similar McCrary tests also suggest that in 2007, there was no bunching below the new SME sales threshold of €100m or employment threshold of 499. Furthermore, there was no bunching below the assets threshold among firms for whom the assets threshold was binding (firms that met the employment criterion but did not meet the sales one). The evidence further confirms that firms had not immediately manipulated their financials in response to the news of the policy change as laid out in the Finance Act 2007, especially when the new policy's effective date was only announced a year later, in July 2008.

Assets distributions in pre- and post-policy periods. As discussed in Sections 2 and 3, we focus on the 2007 value of total assets as our primary running variable to avoid potential endogenous sorting of firms across the threshold once the policy effective date was announced in mid-2008. We test the validity of our choice by estimating firms' assets distribution at the SME threshold of €86m in each year from 2006 to 2011 using the McCrary test. For 2006 and 2007, the tests confirm that firms did not manipulate their total assets to benefit from the SME Scheme before 2008. The log differences in density height at €86m are not statistically different from zero, with coefficients (standard errors) of 0.029 (0.065) in 2006 and -0.026 (0.088) in 2007. On the other hand, there is some graphical evidence of firms' bunching right below €86m from 2009 onward, consistent with rational responses to the policy, although they are small and insignificant.[23]

Panel A of Figure A1, which pools together the two years before the policy change (2006-07), shows a discontinuity estimate (standard error) of 0.013 (0.056), while Panel B of Figure A1, which pools together the three years after the change, shows a discontinuity estimate (standard error) of -0.072 (0.045). Endogenous sorting did seem to happen, but only after the policy became effective. If knowledge production benefits from economy of scale, then firm's attempt to "stay small" to benefit from the SME scheme could lead to an underestimation of the true returns to R&D on patents using equation (4) in the main text (and vice versa). However, the small difference in firm size between those right below and above the threshold is unlikely to generate bias large enough to be of first order concern.

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[23] We exclude 2008 as the increase in deduction rate for large companies became effective before the effective date for the changes in the SME Scheme (including increase in deduction rate for SMEs and SME definition change) was announced much later in the year. As such, it is hard to predict which way the bunching would happen in this year, or if it would happen at all.

C.6 Exploiting other elements of the SME definition

C.6.1 Using and combining with other SME criteria

In Table A14, we estimate the baseline RD Design specification in equation (1) in the main text using other elements of the SME definition, particularly employment (also in 2007), to estimate the effect of likely-eligibility for the SME Scheme on patents.

Employment criterion. The first two columns of Panel A consider the sample of firms around the SME employment threshold of 499 based on firm's 2007 employment and a bandwidth of 250. Column (1) exploits only the employment threshold (using 2007 employment as the running variable) while column (2) additional controls for whether the firm is also below the SME assets and sales thresholds (using 2007 assets and sales as additional running variables). Similar to our baseline results in Table 3, both columns suggest that firms below the employment threshold filed significantly more patents than those above the threshold, although the magnitude of this effect is smaller than our baseline when taking into consideration the pre-policy patent means of the respective samples.

The next two columns further restrict the employment-based sample to firms that already meet either the assets or the sales criterion (i.e., 2007 assets below €86m or 2007 sales below €100m), for which the employment criterion is then binding. Unsurprisingly, the coefficients associated with being below the employment threshold are both larger and more precisely estimated in this subsample. Finally, it is worth highlighting that in both employment-based samples, being below the assets threshold has as large an effect on firm's patents as being below the employment threshold (see columns (2) and (4)) (while being below the sales threshold does not have any effect). This strengthens our case for focusing on the assets criterion, given not only its data coverage but also its predictive power.

Assets vs. sales criterion. The last four columns of Panel A of Table A14 further explore the predictive power of the assets and sales criteria. Columns (5) and (6) study the assets criterion among firms that are above the sales threshold of €100m (for which the assets criterion binds) and within a €25m or €35m bandwidth around the assets threshold. Conversely, columns (7) and (8) study the sales criterion among firms that are above the assets threshold €86m (for which the sales criterion binds) and within a €40m or €50m bandwidth around the sales threshold. The coefficients associated with being below the assets threshold in columns (5) and (6) are considerably larger than those associated with being below the sales threshold in columns (7) and (8), even after scaling by pre-policy patent mean (although they are not always precisely estimated due to small samples). This is consistent with the results reported in columns (2) and (4) that being below the assets threshold is much stronger instrument for firm's eligibility for the SME Scheme, and the evidence in the subsection below that the assets criterion is more binding than the sales criterion.

Combining the criteria. In Panel B of Table A14, we examine whether combining the different SME criteria could increase the efficiency of our estimates. Columns (1) and (2) consider the employment and assets criteria in the sample of firms close to *both* thresholds (i.e., firms with 2007 employment between

250 and 750 *and* 2007 assets between €51m and €121m).[24] Column (1) includes the below-employment-threshold and below-assets-threshold indicators as separate variables (together with their corresponding running variables). Column (2) combines the two indicators into one indicating whether the firm meets both criteria, which makes it eligible for the SME Scheme. To control for the running variables associated with this two-dimensional threshold, we fully interact firm's 2007 employment, separately on each side of the threshold, with firm's 2007 assets, also separately on each side of the threshold. Column (2)'s coefficient suggests that combining the indicators indeed does improve efficiency in this sample of firms close to both thresholds.

Columns (3) to (6) of Table A14 then go on to consider all three criteria in the sample of firms close to *all* thresholds (i.e., firms with 2007 employment between 250 *and* 750 and 2007 assets between €51m *and* €121m and 2007 sales between €50m and €150m). Columns (3) and (4) replicate columns (1) and (2) with the addition of the below-sales-threshold indicator and its corresponding running variable. Similar to previous results, combining employment and assets criteria yields a more precisely estimated coefficient, while the below-sales-threshold coefficients are always small and statistically insignificant.

Next, columns (5) and (6) examine alternative ways of combining the criteria based on the policy terms, i.e., a firm is considered an SME if it meets both (i) the employment criterion and (ii) either the assets or the sales criterion. Column (5) considers conditions (i) and (ii) separately while column (6) combines them into a single indicator. Compared to columns (3) and (4), further combining the sales criterion with the assets or assets and employment criteria does not help increase the efficiency of the estimates, if not the opposite, consistent with previous evidence of the weak predictive power of the sales criterion.

Finally, columns (7) and (8) replicate columns (3) and (4) using the sample of firms close to *one* of the thresholds (i.e., firms with 2007 employment between 250 and 750 *or* 2007 assets between €51m *or* €121m and 2007 sales between €50m and €150m). In this larger sample that also includes firms far away from the either employment or asset threshold (or even both), the assets criterion turns out to be a stronger instrument for firm's SME eligibility (column (7)), and combining the criteria does not lead to efficiency gain (column (8)) as in columns (3) and (4) with the much smaller "intersection" sample. Given this, the tradeoffs between gain in efficiency and loss in sample size and generalizability (employment coverage is both sparse and selected) tilt towards using only the assets criterion as we do throughout the paper.

We must interpret these results with caution because, as emphasized in subsection 2.2, there are many missing values on sales and especially employment, and these are unlikely to be random. Yet Table A14 presents ample evidence that the paper's key finding on the effect of the policy on innovation outputs is not limited to the sample of firms around the assets threshold based on the assets criterion. On the other hand, the assets criterion is a strong predictor of firm's SME eligibility across different types of samples, and the best one if we also take into account data coverage.

[24] As we consider the intersection of employment-based and assets-base samples, larger sample bandwidths allow us to have sufficient sample size.

C.6.2. SME criterion binding ratio

We find evidence that the assets criterion is more binding than the sales one. A firm is considered an SME if it meets either one of the criteria, thus the assets criterion is binding only when the firm already fails the sales one and vice versa. We define the binding/non-binding ratio for a criterion as the number of firms for which the criterion binds divided by the number of firms for which the criterion does not bind.

Specifically, we calculate the binding/non-binding ratio for the *assets* criterion as the number of firms with 2007 sales in [€100m, €180m] (firms for which the assets criterion binds), divided by the number of firms with 2007 sales in [€20m, €100m] (firms which also meet the sales criterion), conditioned on firms' 2007 total assets being in [€36m, €136m] (+/-€50m window around the SME assets threshold of €86m).

Similarly, the same ratio for the *sales* criterion is the number of firms with 2007 assets in [€86m, €166m] (firms for which the sales criterion binds), divided by the number of firms with 2007 assets in [€6m, €86m] (firms which already meet the assets criterion), conditioned on firms' 2007 sales being in [€50m, €150m] (+/-€50m window around the SME sales threshold of €100m).

The binding/non-binding ratio for the assets criterion is 0.34, considerably higher than that for the sales criterion of 0.21, as visually presented in Figure A10. This implies that the below-assets-threshold indicator is a more precise instrument for firm's SME status than the below-sales-threshold indicator, consistent with the results reported in Table A14 and discussed above. Finally, the qualitative results that the assets criterion is more binding than the sales criterion does not change when we pick different windows to calculate the binding/non-binding ratios.

Appendix D: R&D technology spillovers

D.1 Framework for estimating R&D technology spillovers

We start with a general system of spillover equations in which each firm *j*'s innovation output (patents) depends on (i) its own R&D, (ii) all connected firms' R&D, and (iii) all connected firms' innovation outputs, as specified by:

$$PAT_j = \kappa R_j + \psi \frac{\sum_{i \neq j}^{N} R_i}{N-1} + \pi \frac{\sum_{i \neq j}^{N} PAT_i}{N-1} + \nu_j, \tag{D1}$$

where N is the number of firms in firm *j*'s technology class, and $\frac{\sum_{i \neq j}^{N} R_i}{N-1}$ and $\frac{\sum_{i \neq j}^{N} PAT_i}{N-1}$ denote average R&D and patents among $N-1$ firms in the same technology class to whom firm j is connected. Parameter κ reflects the direct own R&D effect of R_j; $\frac{\psi}{N-1}$ is the direct spillover effect of other firms' R&D, and $\frac{\pi}{N-1}$ is the direct spillover effect of other firms' patents. Within this system, an increase in own R&D R_j impacts PAT_j via both (i) a direct effect from R_j to PAT_j and (ii) an *indirect* effect from R_j to PAT_i to PAT_j. Similarly, an increase in R_i impacts PAT_j via both (i) direct spillover from R_i to PAT_j and (ii) indirect spillover from R_i to PAT_i to PAT_j.

Solving equation system (D1) by substitution gives the following equation:

$$PAT_j = \gamma R_j + \xi R_i + \xi \sum_{k \neq j,i}^{N} R_k + \eta_j, \tag{D2}$$

where

$$\gamma = \frac{\kappa + \pi\psi + (N-2)(1-\pi)\kappa}{(1-\pi)(N-1+\pi)}, \tag{D3}$$

and

$$\xi = \frac{\psi + \pi\kappa}{(1-\pi)(N-1+\pi)}. \tag{D4}$$

Here, γ captures the *net* own R&D effect of R_j on PAT_j, where $\frac{\kappa+(N-2)(1-\pi)\kappa}{(1-\pi)(N-1+\pi)}$ and $\frac{\pi\psi}{(1-\pi)(N-1+\pi)}$ are the direct and indirect own effects respectively. Similarly, ξ captures the *net* R&D spillover effect of R_i on PAT_j, where $\frac{\psi}{(1-\pi)(N-1+\pi)}$ and $\frac{\pi\kappa}{(1-\pi)(N-1+\pi)}$ are respectively the direct and indirect spillover effects.

Estimating $\boldsymbol{\gamma}$. Equation (D2) can be rewritten as equation (4) in the main text by absorbing $\xi R_i + \xi \sum_{k \neq j,i}^{N} R_k + \eta_j$ (after partialling out the running-variable polynomial controls) into main-text equation (5)'s error term. As E_j^{2007} is as good as random in the RD Design, it is also conditionally uncorrelated with R_i and R_k under mild sufficient conditions (discussed in subsection D.2 below). Then it remains the case that E_j^{2007} satisfies the exclusion restriction that E_j^{2007} affects PAT_j only via R_j and equation (4)'s IV specification thereby consistently estimates γ, the net own R&D effect of R_j on PAT_j.

Estimating $\boldsymbol{\xi}$. Equation (D2) can also be rewritten as equation (5) in the main text by absorbing $\kappa R_j +$

$\xi \sum_{k\neq j,i}^{N} R_k + \eta_j$ (after partialling out the running-variable controls) into equation (5)'s error term. Similarly, as E_i^{2007} is as good as random in the RD Design, it is also conditionally uncorrelated with R_j and R_k. Then E_i^{2007} satisfies the exclusion restriction that E_i^{2007} affects PAT_j only via R_i and equation (5)'s IV specification thereby consistently estimates ξ, the net R&D spillover effect of R_i on PAT_j.

ξ as a function of *N*. Equation (D1) specifies R&D and patent spillovers as a function of *average* R&D and patents of all connected firms. For fixed values of ψ and π, the *net* spillover effect of a single firm *i*'s R&D on firm *j*'s patents $\xi = \frac{\psi+\pi\kappa}{(1-\pi)(N-1+\pi)}$ quickly decreases with their technology class size N. This reflects the observation that in large technology classes, a single firm has relatively small impact on the field's average technology (as measured by average R&D and patents in equation (D1)) and thereby other firms' innovations. Indeed, the data show evidence consistent with this hypothesis (as discussed in Section 4 in the main text). Furthermore, Figure 5, which plots the reduced-from coefficient $\hat{\delta}$ as a function of N, closely tracks how ξ is expected to evolve with N based on the above formula (note that empirically, the first-stage coefficient δ/ξ does not vary with N, see columns (17) and (18) of Table A7).

Direct versus indirect effects. It is not possible to separately identify three parameters κ, ψ, and π from only two estimates $\hat{\gamma}$ and $\hat{\xi}$. However, κ and ψ *are* identified for a given value of π (provided that N is also known). Conceptually, π captures the spillovers from patents that are beyond the spillovers from R&D knowledge creation. It is therefore reasonable to think that π is small, as it is difficult to think of a channel for such spillover.[25] When $\pi = 0$, $\gamma = \kappa$ and $\xi = \psi$. That is, both own R&D and R&D spillover indirect effects are zero, thus the net effects equal the direct effects. On the other hand, at the other extreme, when $\pi = 1$ (which is highly unlikely),[26] ψ is negative under the reasonable assumption that $\gamma > \xi$. Furthermore, for given values of γ and ξ, both κ and ψ are decreasing in π. (That is, for given values of the net effects, the direct effects are smaller when π, and thus the indirect effects, is larger.)

Using our empirical estimates of $\hat{\gamma} = 0.563$ (column (2) in Panel B of Table 3) and $\hat{\xi} = 0.222$ (column (6) of Table 6) and equations (D3) and (D4), we find that the $\bar{\pi}$ threshold at which ψ becomes negative increases extremely quickly with N and reaches 0.9 at $N < 20$ (Figure A5). That is, ψ is positive for most combinations of π and N. Relatedly, Figure A6 plots κ and $\frac{\psi}{N-1}$ as a function of π at the "average" value of N in the small-technology class sample used to estimate ξ.[27] It is shown that $\frac{\psi}{N-1}$ is positive for any

[25] One possible passage could be that patents allow for knowledge disclosure, which then facilitates technology spillovers.

[26] Note that it is not possible for π to be greater than 1, as the system will then explode.

[27] To derive the "average" value of N among a sample of heterogenous technology class size, we employ the following bounding approace. First, we rewrite equation (D2) with γ and ξ themselves being functions of N:

$$PAT_j = \gamma(N_j)R_j + \xi(N_j)R_i + \xi(N_j)\sum_{k\neq j,i}^{N} R_k + \eta_j.$$

Under the assumption that R_i and R_j are orthogonal to $N_i = N_j$, it can be shown that:

$$\hat{\xi} = \mathbb{E}(\xi(N)) = \frac{\psi + \pi\kappa}{1-\pi}\mathbb{E}\left(\frac{1}{N-1+\pi}\right).$$

reasonable value of π (i.e., π smaller than 0.98), implying that while we cannot precisely identify the direct R&D spillover effect ψ, it is highly likely to be positive given our $\hat{\gamma}$ and $\hat{\xi}$ estimates.

D.2 Orthogonality between E_i^{2007} and firm j's characteristics

We argue that for any characteristic U_j of firm $j(i)$ connected to firm i, the distribution of $U_{j(i)}$ is smooth as firm i's size crosses the threshold of €86m, therefore $\lim_{z_i \to 86-} \mathbb{E}\left[U_{j(i)} | E_i = 1\right] = \lim_{z_i \to 86+} \mathbb{E}\left[U_{j(i)} | E_i = 0\right]$, and δ^{RDD} could be correctly identified in equation (6) in the main text. In this case, the standard "local randomization" result from Lee and Lemieux (2010, pp. 295-6) is extended to connected firms under three (sufficient) conditions: (i) there are some (possibly very small) perturbations so that firms do not have full control of their running variable (assets size) (Lee and Lemieux's (2010) standard RD Design condition), (ii) the size distribution of connected firms $\{j(i)\}$ is smooth for each firm i, and (iii) for each firm i, this size distribution changes smoothly with firm i's size. Conditions (ii) and (iii) warrant that the set of connected firms $\{j(i)\}$ does not change abruptly when firm i's size crosses the threshold. This condition holds naturally given our definition of connected firms. It could fail under certain extreme cases, e.g., when $\{j(i)\}$ comprise all firms with exactly the same size as i, in which case all connected firms $j(i)$ abruptly switch side when firm i crosses the threshold.

Given the above, controlling for $g\left(z_j^{2007}\right)$ (or E_j^{2007}) as in equations (5) and (6) is not needed for identification, although it helps improve precision as connected firm j's are drawn from a wide support in terms of firm size (as captured by z_j^{2007}). All of our results are robust to dropping this inessential $g\left(z_j^{2007}\right)$ polynomial control, or adding E_j^{2007} as an additional control variable (as discussed below in D.5).

D.3 Technological connectedness definition

We consider two firms to be technologically connected if (i) most of their patents are in the same three-digit IPC technology class and (ii) the Jaffe (1986) technological proximity between them is above median (0.75). Both criteria are determined based on firms' pre-policy patent portfolios over 2000-08, thus technological connectedness is defined only among firms which patented during this period. For criterion (i), we define a firm's primary technology class as the three-digit IPC technology class single in which the firm filed the most patent applications. Two firms satisfy criterion (i) if they have the same primary technology class. The size of a technology class is the number of firms whose primary technology class is the said technology class.

For criterion (ii), we follow Jaffe (1986) in defining proximity as the uncentered angular correlation

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Notice that $\mathbb{E}\left(\frac{1}{N}\right) < \mathbb{E}\left(\frac{1}{N-1+\pi}\right) < \mathbb{E}\left(\frac{1}{N-1}\right)$, which allows us to construct empirical lower and upper bounds for $\mathbb{E}\left(\frac{1}{N-1+\pi}\right)$ when π is not known. The bounds constructed for small-technology class sample imply that the "average" N should fall between 108.7 and 109.3 for $\mathbb{E}\left(\frac{1}{N-1+\pi}\right)$ to fall between these bounds. We thus use 109 as the "average" value for N.

between the vectors of the proportion of patents taken out in each technology class $\omega_{ij} = \frac{F_i F_j'}{(F_i F_i')^{\frac{1}{2}}(F_j F_j')^{\frac{1}{2}}}$, where $F_i = (F_{i1}, \dots, F_{i\Upsilon})$ is a $1 \times \Upsilon$ vector where $F_{i\tau} = \frac{n_{i\tau}}{n_i}$ is firm i's number of patents in technology field τ as a share of firm i's total number of patents. The Jaffe technological proximity equals 1 if firms i and j have identical patent technology class distribution and 0 if the firms patent in entirely different technology classes. It has been shown that this Jaffe measure delivers similar results to more sophisticated measures of proximity (Bloom, Schankerman, and Van Reenen, 2013). The 25th-75th percentile range of Jaffe technological proximity among firm pairs sharing the same primary technology class is 0.65-0.95, with a median/mean of 0.75. We thus pick 0.75 as the cut-off for criterion (ii), yet our qualitative results are not sensitive to this cut-off choice (see Appendix D.5 for details).

D.4 Semi-parametric estimation of spillovers by technology class size

We modify the spillover regression in equation (6) in the main text by modelling the potentially heterogeneous effect of baseline firm i's likeliness of eligibility for the SME scheme on connected firm j's average patents over 2009-13 as a non-parametric function of the primary technology class size (measured in percentile and denoted as x):

$$PAT_j^{Post} = \alpha(x) + \delta^{RDD}(x)E_i^{2007} + f(z_i^{2007}, x) + g(z_j^{2007}, x) + \mu(x)PAT_j^{Pre} + \varepsilon_{ij}. \qquad \text{(D5)}$$

Figure 5 plots the estimated function $\delta^{RDD}(x)$ of the spillover effect based on primary technology class size percentile. It is estimated from semi-parametric local linear regressions of equation (6) at each value of x, weighted by a Gaussian kernel with a bandwidth of 25% (with x ranging from 1 to 100). The observed pattern is similar across a wide range of bandwidths.

D.5 Robustness of R&D technology spillover estimates

Table A7 reports a wide range of robustness tests for Table 6's results on the policy's spillover effects.

Alternative clustering schemes. First, columns (1) to (3) show that our key result of positive technology spillovers in small technology classes (column (4) of Table (5)) remains statistically significant under alternative clustering schemes (i) by treated firm i, (ii) by connected firm j, or (iii) two-more clustering by firm i and firm j.

Alternative polynomial controls. Second, this result is robust to employing different $g(z_j^{2007})$ controls (controls for connected firm j's 2007 assets z_j^{2007}), including:

i. Dropping $g(z_j^{2007})$ polynomial control, as it is not needed in the RD Design (column (4)),
ii. Employing first-order polynomial of z_j^{2007} or $\log(z_j^{2007})$ for $g(z_j^{2007})$ in place of second-order polynomial, and
iii. Additionally controlling for E_j^{2007} (whether firm j's 2007 assets is at or below €86m), together with either a first- or second-order polynomial of the running variable z_j^{2007} separately on each side of the SME assets threshold (column (5)).

Alternative technological connectedness definitions. Third, we consider alternative definitions of technological connectedness. Column (6) extends the definition of technological connectedness to all firm pairs patenting primarily in the same three-digit IPC technology class while column (7) tightens this definition by raising the Jaffe (1986) technological proximity cutoff from 0.75 (median among all firm pairs sharing the same technology class) to 0.95 (75^{th} percentile). In both columns we observe the same pattern of larger spillovers in smaller technology classes, as indicated by the negative and statistically significant interaction terms and shown in Figure A7. We also obtain the same results from extending the definition of technological connectedness to all firm pairs whose Jaffe technological proximity is above 0.75 (technology class size is then determined by the size of treated firm i's primary technology class).

Other estimation models. Fourth, columns (8) and (9) employ count models, Poisson and Negative Binomial respectively, instead of OLS. Table 6's key findings remain intact: the spillover effect is positive and significant in the smallest technology classes, whereas the negative and statistically significant interaction terms imply that this effect is close to zero in the largest ones.

Alternative pre-/post-policy periods. Fifth, we examine the evolution of spillovers among firms in small technology classes over alternative post-policy periods. Considering only 3 years (2009-11, column (10)) or up to 7 years (2009-15, column (12)) after the policy change generate statistically significant spillover RD estimates of comparable magnitude among firm pairs in small technology classes. On the other hand, the corresponding estimate for the pre-policy years (2006-08) are not statistically significant. Relatedly, column (13) implements main-text equation (7)'s spillover Diff-in-Disc Design over the extended 2002-15 period, which yields similar finding to that presented in column (5) of Table 6. These results again reflect the pattern plotted in Panel A of Figure 6, as discussed in subsection 4.3.

We also consider alternative constructions of connected firm j's pre-policy patent control, including controlling only for firm j's patents in 2007 (column (14)) or separately for firm j's patents in 2006, 2007, and 2008. Both tests generate estimates comparable to the baseline in column (11). On the other hand, column (15) excludes this lagged dependent variable control to be comparable to the corresponding in-lab spillover RD specification presented in column (16). Columns (15) and (16)'s estimates are similar to each other in magnitude, and both are larger than the baseline estimate.

Spillovers on R&D. Finally, it should be noted that we do not find similarly robust spillover estimates on connected firm j's R&D, especially after controlling for firm j's pre-policy R&D. This is consistent with Bloom, Schankerman, and Van Reenen's (2013) theoretical finding that the sign of the spillovers on technologically connected firms' R&D is ambiguous.

D.6 Alternative approach to estimate R&D technology spillovers

In this appendix, we discuss a complementary approach to estimate R&D technology spillovers using a monadic specification, following Bloom, Schankerman, and Van Reenen (2013), instead of the dyadic specification discussed in Section 6. We calculate the knowledge spillover pool available to firm j as $spilltechR_j = \sum_{i,i\neq j} \omega_{ij} R_i$ where (i) R_i is the average R&D of firm i over 2009-11 and (ii) ω_{ij} is the Jaffe (1986) measure of technological "proximity" between firms i and j (see Appendix D.3), computed based on the distribution of technology classes in which the firms patent. We extend our RD Design approach of using E_i^{2007}, firm i's below-assets-threshold indicator, as instrument for R_i to construct $spilltechE_j = \sum_{i,i\neq j} \omega_{ij} E_i^{2007}$ as instrument for $spilltechR_j$. The exclusion restriction requires that the discontinuity-induced random fluctuations in firm i's eligibility would only affect technologically connected firm j's R&D and innovation through R&D spillovers.

Our monadic spillover IV regression estimates the impact of the aggregate R&D spillover pool available to firm j, $spilltechR_j$, on firm j's average patents over 2009-13, PAT_j, controlling for firm j's E_j^{2007} as an instrument for its own R&D, as specified by the following equation:

$$PAT_j = \alpha + \psi spilltechR_j + F_j(Z^{2007}) + \zeta E_j^{2007} + g\left(z_j^{2007}\right) + \mu techconnect_j + \varepsilon_j, \qquad \text{(D6)}$$

where $F_j(Z^{2007}) = \sum_{i,i\neq j} \omega_{ij} f(z_i^{2007})$ and Z^{2007} is a vector comprising of the 2007 assets for all firms; $f(z_i^{2007})$ and $g(z_j^{2007})$ are polynomials of firms i and j's 2007 total assets; and $techconnect_j = \sum_{i,i\neq j} \omega_{ij}$.[28] We instrument $spilltechR_j$ with $spilltechE_j$. $F_j(Z^{2007})$ and $g(z_j^{2007})$ are polynomial controls for $spilltechE_j$ and E_j^{2007} respectively while $techconnect_j$ additionally controls for spillover-receiving firm j's level of "connectivity" in technology space. We estimate the equation (D6) on the sample of firm j's with total assets in 2007 between €51m and €121m. This is a larger bandwidth than in the baseline sample as the policy-induced R&D can have spillovers on firms well beyond the policy threshold.[29] Standard errors are bootstrapped using 1,000 replications over firms.

Column (1) of Table A15 reports the first stage for the R&D spillover term and column (2) the first stage for spillover-receiving firm j's own R&D. As expected the instrument $spilltechE_j$ significantly predicts $spilltechR_j$ (column (1)) and the instrument E_j^{2007} significantly predicts connected firm j's own R&D (column (2)). The instruments $spilltechE_j$ and E_j^{2007} are jointly statistically different from zero in both columns, with F-statistics of 26.9 and 6.4 respective. Interestingly, we see that in the reduced-form patent model of column (3) the R&D spillover instrument, $spilltechE_j$, has a large and significant positive

[28] Consider the RD equation for firm i's R&D as $R_i = \alpha + \beta^R E_i^{2007} + f(z_i^{2007}) + \varepsilon_i$, aggregating across all firm i's around the SME asset threshold and using ω_{ij} as weights gives:

$$\sum_{i,i\neq j} \omega_{ij} R_i = \alpha \sum_{i,i\neq j} \omega_{ij} + \beta^R \sum_{i,i\neq j} \omega_{ij} E_i^{2007} + \sum_{i,i\neq j} \omega_{ij} f(z_i^{2007}) + \sum_{i,i\neq j} \omega_{ij} \varepsilon_i$$

$$\Rightarrow spilltechR_j = \alpha techconnect_j + \beta^R spilltechE_j + F_j(Z^{2007}) + \upsilon_j$$

This equation shows that $F_j(Z^{2007})$ is the appropriate polynomial control when using $spilltechE_j$ as instrument for $spilltechR_j$. The key condition that $\nu_j = \sum_{i,i\neq j} \omega_{ij} \varepsilon_i$ is mean independent of $spilltechE_j$ conditional on $F_j(Z^{2007})$ follows from RD Design results. To address non-trivial serial correlation among the error term υ_j, we correct the standard errors using 1,000 bootstrap replications over firms.

[29] Note that $spilltechR_j$ is calculated using the population of all possible firm i's, while $spilltechE_j$ and $F_j(Z^{2007})$ are calculated using all firm i's with 2007 total assets between €51m and €121m (same as the sample on which we nomadic spillover equation), as the RD Design works best in samples of firms around the relevant threshold. Our key results are robust to using different sample bandwidths around the threshold to calculate $spilltechE_j$ and/or to estimate the monadic spillover equation. In addition, in all reported results, we use second order polynomial controls separately on each side of the threshold for $f(z_i^{2007})$ and $g(z_j^{2007})$. In this larger sample we found that higher order terms were significant. However, using different orders of polynomial controls does not change our qualitative findings.

effect on firm j's patents. This is consistent with the hypothesis that policy-induced R&D has sizeable spillover effect on technologically-connected firms' innovation.

Turning to the IV results, column (4) suggests that there is no significant R&D spillover effect on technologically connected firms' R&D, as already suggested by the R&D regression in column (2). By contrast, columns (5) and (6) report that the aggregate R&D spillover pool available to firm j, $spilltechR_j$, *does* have a causal impact on firm j's patenting, consistent with the patent regression in column (3). This spillover effect is robust after controlling for the policy's direct effect on firm j's R&D, either by (i) including E_j^{2007} as a control in addition to the instrumented spillover term (column (5)), or (ii) including R_j as a control and using E_j^{2007} as the corresponding instrument (column (6)). The latter is a very demanding specification, and even though the corresponding spillover coefficient is no longer significant,[30] its magnitude is almost identical in both specifications.

In terms of magnitudes, the last two columns suggest that a £1m increase in R&D by a firm i with an identical technological profile will increase firm j's patenting by 0.014, which is 3.4% of the direct effect of an equivalent R&D increase by the firm itself (= 0.014/0.412). Combining this with the mean level of connectivity among firms in the sample gives us the total spillover effect of 0.616 (= 0.014 x 44). In other words, the total spillovers of an £1m increase in R&D on all technology-connected firms' patenting is about 1.5 times (= 0.616/0.412) the direct effect on own patenting.[31]

This presence of positive R&D spillovers on innovations is robust to a wide range of robustness tests. The reduced-form spillover coefficient capturing effect of $spilltechE_j$ on firm j's patents (column (3)'s specification) is robust to (i) limiting firm j sample to only patenting firms, (ii) using EPO, UK, and US patent outcomes, (iii) employing the more sophisticated Mahalanobis generalization of the Jaffe proximity measure to allow for between field overlap (see Bloom, Schankerman, and Van Reenen, 2013), (iv) reconstructing the standard Jaffe measure of technological proximity using only information on patents filed up to 2008, and (v) using alternative samples to calculate the instrument $spilltechE_j$ or to estimate the monadic spillover equation.

Besides spillovers in technology space, there may be some negative R&D spillovers through business stealing effects among firms in similar product markets. To address this concern, we follow Bloom, Schankerman, and Van Reenen (2013) and construct $spillsicR_j = \sum_{i,i \neq j} \phi_{ij} R_i$ that captures the aggregate R&D spillovers pool in product market space, where ϕ_{ij} is a measure of product market distance between

[30] If we use robust standard errors instead of bootstrapped standard errors, the estimated coefficient (standard error) for $spilltechR_j$ from column (6)'s specification is 0.014 (0.007), statistically significant at 5% level.

[31] Consider a firm i that increases its R&D by £1m. The spillover of this R&D increase on a firm j's patenting, as estimated by the monadic spillover equation, is $\psi \omega_{ij}$. Summing this spillover over all spillover-receiving firms j' patenting gives total spillovers of $\psi \sum_{j,j \neq i} \omega_{ij} = \psi techconnect_i$, which is the product of the spillover coefficient and firm i's level of connectivity. The estimated total spillover effect for an average firm i is then $\widehat{\psi}\, \overline{techconnect_i} = 0.014 \times 44 = 0.616$.

firms i and j.[32] We also construct $spillsicE_j = \sum_{i,i \neq j} \phi_{ij} E_j^{2007}$ as instrument for $spillsicR_j$. We found no significant effects of $spillsicR_j$ on either firm j's R&D or firm j's patents.

In summary, these findings provide evidence that policy-induced R&D have sizable positive impacts on not only R&D performing firms but also other firms in similar technology areas, as measured by patents. This further supports the use of R&D subsidies in the UK context.

[32] $\phi_{ij} = 1$ if firm i operates in the same industry as firm j and $\phi_{ij} = 0$ otherwise. To calculate ϕ_{ij}, we use firms' primary industry codes at three-digit SIC level. These data are available from FAME.

Appendix E: Magnitude of effects and tax-price elasticities

E.1 A simple model of patents and R&D demand

Consider a CES production function in R&D capital (G) and non-R&D capital (Z). If input markets are competitive, we can write the long-run static first order condition for factor demand of the firm as:

$$\ln G = -\sigma \ln \rho + \sigma \ln U + \ln Z + B, \tag{E1}$$

where ρ is the user cost of R&D capital, U is is the user cost of non-R&D capital and B is a technological constant reflecting factor bias terms in the production function. Assume that G can be described by the perpetual inventory formula $G_t = (1-\delta)G_{t-1} + R_t$ where R is the R&D expenditure in period t. Since in steady state, the R&D just offsets the depreciated part of the R&D stock $\delta G = R$, we can re-write the first order condition in steady state as:

$$\ln R = -\sigma \ln \rho + \sigma \ln U + \ln Z + \ln \delta + \mathrm{B}. \tag{E2}$$

We also consider a knowledge production function:

$$\ln PAT = \mu + \alpha \ln G. \tag{E3}$$

Substituting the R&D first order condition into this "structural" patent equation generates our key reduced form patent equation:

$$\ln PAT = -\alpha\sigma \ln \rho + \alpha \ln Z + \alpha\sigma \ln U + \alpha \ln \delta + \alpha\mathrm{B} - \mu. \tag{E4}$$

This is essentially what we estimate in equation (1) in the main text. Around the R&D SME threshold the user cost of non-R&D capital and technology are assumed to be smooth. Non-R&D capital (assets) is the running variable so we have a polynomial approximation to $\ln Z$. Furthermore, replacing patents with R&D in equation (1) similarly allows us to estimate equation (E2).

The main departure from the R&D and patent equations above is that the presence of firms with zero patents and/or R&D means we cannot take logarithms. Therefore, we use levels instead of logs as dependent variables. To obtain the logarithmic (proportional) changes we use the empirical averages of the dependent variable in the pre-policy period. We also show that the calculations are robust to using a Poisson regression whose first moment is the exponential log-link function and so is equivalent to estimating in logarithms.

E.2 Estimating the instrument's sharpness using a subsample

Our approach is a fuzzy RD Design. Equations (1) and (4) are the reduced form and structural form of a knowledge (patent) production function. But as discussed in subsection 5.2 we may also be interested in the elasticity of patents (and R&D) with respect to its tax-adjusted use cost. To do this we need to scale the estimate in equation (1) in the main text by the "sharpness" of the IV. Consider equation (E5) (equation (8) in the main text):

$$SME_i^{Post} = \alpha + \lambda E_i^{2007} + f\left(z_i^{2007}\right) + \varepsilon_i. \tag{E5}$$

Recall that E_i^{2007} is a binary indicator of firm i's being below the new assets threshold in 2007 and SME_i^{Post} is a binary indicator of the firm's true SME eligibility post policy change (which is observable only for R&D performing firms). Let $\lambda_E = \Pr(SME = 1|E, Z)$ for $E \in \{0,1\}$ in the *full baseline sample* of both R&D performing and non-R&D performing firms. For the sharpness of E_i^{2007} as an instrument for firm's SME-scheme eligibility, we would like to estimate $\lambda \equiv \lambda_1 - \lambda_0$. The problem is that we only observe SME_i for the subsample of R&D performing firms as (a) this data is not in HMRC datasets for non-R&D performers and (b) we cannot calculate eligibility status with precision from the accounting variables. Thus, we can only estimate equation (E5) on the R&D performers subsample. Under the RD Design identification assumptions discussed in subsection 3.1, the resulting $\widehat{\lambda}$ from this regression is a consistent estimate for $\tilde{\lambda} \equiv \widetilde{\lambda_1} - \widetilde{\lambda_0}$, where $\widetilde{\lambda_E} = \Pr(SME = 1|E, Z, R > 0)$ for $E \in \{0,1\}$. When will $\tilde{\lambda}$ be equal to λ? We will prove that a sufficient condition for this is that SME-scheme eligibility does not change firm's likelihood of performing R&D, which is something we test (and find empirical support for) in the data.

Let p_s and p_L be the probabilities a firm will perform R&D if it is eligible for the SME scheme (p_s), and if it is not (p_L), and $\rho \equiv p_S/p_L$. Note that by RD Design, we can assume that p_S (and p_L) is the same for firms just below and above the threshold. In the subsample of R&D performing firms, we then have:

$$\widetilde{\lambda_E} = \Pr(SME = 1|E, Z, R > 0) = \frac{\lambda_E p_s}{\lambda_E p_s + (1 - \lambda_E) p_L}.$$

Expanding and rearranging $\widetilde{\lambda_1} - \widetilde{\lambda_0}$ gives:

$$\widetilde{\lambda_1} - \widetilde{\lambda_0} = (\lambda_1 - \lambda_0) \frac{p_S p_L}{[\lambda_1 p_S + (1 - \lambda_1) p_L][\lambda_0 p_S + (1 - \lambda_0) p_L]}$$

$$\Rightarrow \tilde{\lambda} = \lambda \frac{\rho}{(\lambda_1 \rho + 1 - \lambda_1)(\lambda_0 + 1 - \lambda_0)} = \lambda \left\{ 1 + \frac{(\rho - 1)[(1 - \lambda_1)(1 - \lambda_0) - \lambda_1 \lambda_0 \rho]}{[1 + \lambda_1(\rho - 1)][1 + \lambda_0(\rho - 1)]} \right\}.$$

When SME-scheme eligibility does not change firm's likelihood of performing R&D, it is the case that $\rho = 1$ (i.e., $p_S = p_L$) and thus $\tilde{\lambda} = \lambda$. Column (1) of Table A9 shows that the policy does not appear to increase firm's participation in R&D performance, suggesting that $p_S \approx p_L$ or $\rho \approx 1$ holds in our setting. This implies that $\tilde{\lambda} \approx \lambda$ in a first-order approximation (as $\frac{(\rho-1)[(1-\lambda_1)(1-\lambda_0) - \lambda_1 \lambda_0 \rho]}{[1+\lambda_1(\rho-1)][1+\lambda_0(\rho-1)]} \approx 0$).

Some additional comments. First, formally the regression in column (1) of Table A9 estimates:

$$\begin{aligned} \Delta_p &= \Pr(R > 0|E = 1, Z) - \Pr(R > 0|E = 0, Z) \\ &= [\lambda_1 p_S + (1 - \lambda_1) p_L] - [\lambda_0 p_S - (1 - \lambda_0) p_L] \\ &= (\lambda_1 - \lambda_0)(p_S - p_L). \end{aligned}$$

$\Delta_p = 0$ implies that $p_S - p_L = 0$ under the reasonable assumption that $\lambda_1 - \lambda_0 > 0$. In addition, Table A10 provides further evidence that the policy effect on R&D is entirely driven by pre-policy R&D performing firms, whose decisions to engage in R&D performance in the pre-policy period did not depend on their post-policy SME status.

Second, note that although $p_S = p_L$ is a sufficient condition, it is not a necessary condition. $\tilde{\lambda} = \lambda$ also if (i) $\lambda = 0$, (ii) $\lambda_1 = 1$ and $\lambda_0 = 0$ (or vice versa), or (iii) $\rho = \frac{(1-\lambda_1)(1-\lambda_0)}{\lambda_1 \lambda_0}$.

Finally, consider the sign of the second-order bias when ρ is not exactly 1. If $\rho > 1$, the sign of the bias depends on $(1-\lambda_1)(1-\lambda_0) - \lambda_1\lambda_0\rho$, which can be either negative or positive. When $\lambda_1 + \lambda_o \geq 1$ (i.e., sufficiently large share of SME firms in the full baseline sample), $(1-\lambda_1)(1-\lambda_0) \leq \lambda_1\lambda_0 < \lambda_1\lambda_0\rho$, implying that the bias is negative. When $\lambda_1 + \lambda_o < 1$, the bias could still be either negative or positive.

E.3 Tax-adjusted user cost of R&D

Deriving tax-adjusted user cost of R&D. We calculate the tax-adjusted user cost ρ_f based on the design of the R&D Tax Relief Scheme:

$$\rho_f = \frac{(1-A_f)}{(1-\tau)}(r+\delta),$$

where (i) subscript $f \in \{SME, LCO\}$ denotes whether the firm is a smaller (*SME*) or larger company (*LCO*), (ii) A is the value of R&D tax relief, (iii) τ is the effective corporate tax rate, (iv) r is the real interest rate, and (v) δ is the depreciation rate.

We calculate *A* separately for the deduction regime and the payable credit regime using the policy parameters, then derive the average value of A using the probability that a baseline sample firm falls into each regime. In the deduction case, $A_f^{deduction} = \tau(1+e_f)$ where e_f is the enhancement rate. In the payable credit case, $A_f^{credit} = c_f(1+e_f)$ where c_f is the payable tax credit rate. (Note that in the payable tax credit case, $\tau = 0$ as eligible firms have no taxable profits and thus no corporate tax liabilities.)

Finally, we use the share of baseline firms with corporate tax liabilities over 2006-07 as a proxy for the probability that a baseline firm falls into the deduction regime. The full formula for tax-adjusted user cost of R&D is then as follows:

$$\rho_f = \left\{\Pr(Has\ tax\ liability) \times \frac{[1-\tau(1+e_f)]}{(1-\tau)} + \Pr(No\ tax\ liability) \times [1-c_f(1+e_f)]\right\} \times\ (r+\ \delta).$$

Note that as the design of the R&D Tax Relief Scheme changes, ρ_f also varies over time with τ, e_f, and c_f. On the other hand, r and δ do not matter to the difference (calculated as arc percentage difference or log difference) between ρ_{SME} and ρ_{LCO} (assuming firms face similar real interest and depreciation rates), as they cancel out.

For simplicity, we do not consider the possibility that a loss-making large company may still benefit from R&D tax relief by carrying the "enhanced" loss forward to future years to reduce its taxable income, as this reduction is only meaningful if the company makes enough profits in this next period. This simplification may overestimate large companies' tax-adjusted user cost of R&D and thereby underestimate the R&D tax-price elasticity (by overestimating the difference in tax-adjusted user costs of R&D between SMEs and large companies). We also do not consider combination claims (cases in which an SME combines tax deduction with the payable tax credit) as there are almost none of them in our baseline sample.

Evolution of tax-adjusted user cost of R&D. The evolution of tax adjusted user costs of R&D for SMEs and large companies over time is summarized in Table A2. For large companies (for which the payable credit rate c_{LCO} is always zero), there are slight decreases in the corporate tax rate over 2006-12 (from 30% to 28% to 26%) coupled with slight increases in the enhancement rate e_{LCO} (from 25% to 30%)

over the same period. This resulted in a relatively stable tax-adjusted user cost ρ_{LCO} of 0.190 throughout this period. It is therefore reasonable to use the baseline sample's average R&D over 2006-08 as a proxy for how much an average firm in the baseline sample would spend on R&D if it remained a large company over 2009-11, after the policy change.

For SMEs, large increases in enhancement rate e_{SME} (from 50% to 75% to 100%) more than offset the slight decrease in corporate tax rate and payable credit rate c_{SME} (from 16% to 14% to 12.5%), leading to a steady reduction in SMEs' tax-adjusted user cost of R&D ρ_{SME} from 0.154 in 2006 to 0.141 in 2011. This widens the difference in tax-adjusted user costs of R&D between SMEs and large companies over time, from an average percentage difference of -0.218 over 2006-08 to an average percentage difference of -0.269 over 2009-11.

Bounding the difference in tax-adjusted costs of R&D. As a robustness check, we consider using the small firm profit rate (from 19% to 21% to 20% over 2006-11) instead of the main rate for corporate tax rate. As the tax deduction is less generous with a lower corporate tax rate, the resulting tax-adjusted user cost of R&D in the tax deduction case is higher for both SMEs and large companies and their gap is smaller in magnitude (average percentage difference of -0.185 over 2006-08 and -0.228 over 2009-11). In other robustness checks, we compute this average percentage difference between the two schemes based only on the tax deduction case (-0.248 over 2009-11) or the payable tax credit case (-0.279 over 2009-11). Rows (11) to (13) of Table A16 reports the tax-price elasticities of R&D and patents corresponding to these robustness checks.

E.4 Tax-price elasticities of R&D and patents

Some comments on our elasticity estimation. We define elasticity as the percentage difference in R&D (patents) with respect to the percentage difference in the tax-adjusted user cost of R&D. First, given the large policy-induced R&D (patents) increase in our setting, calculating the percentage difference relative to one end point vs. the other end point yields very different results as the difference between the two points is large. We thus focus on the arc elasticity measure, which calculates the percentage difference relative to the midpoint instead of either end points. We also consider alternative elasticity definition using log difference instead of percentage difference (row (5) of Table A16) as discussed below.

Second, as described in subsection 5.2, we derive the elasticity estimate as $\frac{E(\Delta R_i)}{E(\Delta \rho_i)}$ and $\frac{E(\Delta PAT_i)}{E(\Delta \rho_i)}$, instead of $E\left(\frac{\Delta R_i}{\Delta \rho_i}\right)$ and $E\left(\frac{\Delta PAT_i}{\Delta \rho_i}\right)$ as is standard in the literature. This is because we do not observe SME_i and thereby the implied ρ_i for non-R&D-performing firms. In the sample, it is expected that financially constraint firms have larger elasticities, and are also more likely to experience larger reduction in tax-adjusted user costs of R&D. This positive correlation implies that $\left|\frac{E(\Delta R_i)}{E(\Delta \rho_i)}\right| > \left|E\left(\frac{\Delta R_i}{\Delta \rho_i}\right)\right|$ and $\left|\frac{E(\Delta PAT_i)}{E(\Delta \rho_i)}\right| > \left|E\left(\frac{\Delta PAT_i}{\Delta \rho_i}\right)\right|$.

Finally, to derive the empirical distributions and confidence intervals of our elasticity estimators, we perform a bootstrap procedure with 1,000 replications. In each replication, we draw observations with replacement from the baseline sample and calculate the elasticities based on the resulting regression estimates and sample means. The standard errors and confidence intervals are then calculated from the distribution of these 1,000 bootstrap elasticity estimates. As the first-stage estimate of the effect of firm's below-assets-threshold indicator on its post-policy SME status is based on a smaller sample of 361 R&D performing firms, we separately draw 361 observations from this subsample and 5,527 (= 5,888 - 361) observations from the remaining subsample. Drawing from the full sample without separating the subsamples yields quantitatively similar distributions.

Tax-price elasticities of R&D. Combining $\hat{\beta}^{RDD}$ = 63.4 for R&D outcome (column (1) in Panel B of Table 3) with $\hat{\lambda}$ = 0.353 (column (5) of Table A8) gives an R&D treatment effect (of the more generous SME scheme) of 179.5 (= 63.4/0.353) (see Figure A8 for the estimate's bootstrapped confidence interval). This treatment effect and the pre-policy mean R&D of 74.0 imply an R&D percentage difference of $\frac{R_{SME} - R_{LCO}}{(R_{SME} + R_{LCO})/2} = \frac{179.5}{(179.5+74.0+74.0)/2} = 1.10$. This then yields an R&D elasticity with respect to R&D tax-adjusted user cost of 4.1 (= 1.10/0.27), with a bootstrapped 90% confidence interval from 1.4 to 5.4 (see Figure A9). Similarly, using $\hat{\beta}^{RDD}$ estimated from the subsample of R&D performers used to estimate $\hat{\lambda}$ yields an elasticity of R&D with respect to R&D user cost of 3.5. (See Table A16 for further details.)

Appendix F: Macro aspects of the R&D Tax Relief Scheme

A full welfare analysis of the R&D Tax Relief Scheme requires both an analysis of the benefits in terms of (say) the increased GDP generated by the R&D induced by the policy (including spillovers) and the deadweight cost of taxation. We would also need to take a position on other general equilibrium effects such as the increase in the wages of R&D workers due to increased demand (Goolsbee, 1998). As an interim step towards this we follow the convention in the literature which is to calculate a "value for money" ratio $\mu \equiv \frac{\Delta_R}{\Delta_{EC}}$ where Δ_R is the amount of R&D induced by the policy and Δ_{EC} is the total amount of additional taxpayer money needed to pay for the scheme (which we call "Exchequer Cost", EC).

We consider three policy-relevant experiments. First, we look at the 2008 extension of the SME Scheme. Second, we do a "value for money" calculation in our data period 2006-11. Finally, we do a simulation of what the path of UK business R&D to GDP would have been with and without the R&D Tax Relief Scheme.

F.1 2008 extension of the SME Scheme

With respect to the 2008 extension of the SME Scheme to cover "larger" SMEs, Δ_R measures the increase in R&D induced by more generous tax relief under the SME Scheme by a firm benefitting from the scheme thanks to the new thresholds. That is, $\Delta_R = R_{new} - R_{old}$ where R_{new} and R_{old} are the firm's R&D's under the new and old policies respectively. Similarly, $\Delta_{EC} = EC_{new} - EC_{old}$ where EC_{new} and EC_{old} are the firm's corresponding Exchequer costs due to the policy change.

Rearranging the R&D tax-price elasticity formula gives:

$$\eta = \frac{\dfrac{R_{new} - R_{old}}{(R_{new} + R_{old})/2}}{\dfrac{\rho_{new} - \rho_{old}}{(\rho_{new} + \rho_{old})/2}} = \frac{\Delta_R / \bar{R}}{\Delta_\rho / \bar{\rho}} \Rightarrow \frac{\Delta_R}{\bar{R}} = \eta \times \frac{\Delta_\rho}{\bar{\rho}}, \tag{F1}$$

where ρ is the tax-adjusted user cost of R&D, $\Delta_X \equiv X_{new} - X_{old}$, and $\overline{X} \equiv (X_{new} + X_{old})/2$. For simplicity, we consider the tax deduction case and the SME payable tax credit case separately.

SME tax deduction case. In this case,

$$\rho^{deduction} = \frac{\big(1 - \tau(1 + e)\big)}{1 - \tau}(r + \delta), \tag{F2}$$

$$EC^{deduction} = R \times e \times \tau, \tag{F3}$$

where τ is the effective corporate tax rate, e is the enhancement rate, r is the real interest rate, and δ is the depreciation rate. As the above firm moves from being a large company pre-2008 to being an SME post-2008, its enhancement rate increases from 25% to 75%. At the same time, corporate tax rate decreases from 30% to 28%. Combining $e_{old} = 0.25, e_{new} = 0.75, \tau_{old} = 0.30, \tau_{new} = 0.28$ with estimated R&D tax-price elasticity of $\eta = -4.0$ gives $\frac{\Delta_\rho}{\bar{\rho}} = -0.23$ and $\frac{\Delta_R}{\bar{R}} = 0.92$, which implies $\frac{R_{new}}{R_{old}} = 2.70$.

On the cost side, we have:

$$EC_{old} = R_{old} \times e_{old} \times \tau_{old} = R_{old} \times 0.075,$$

$$EC_{new} = R_{new} \times e_{new} \times \tau_{new} = R_{new} \times 0.21.$$

Putting all the elements together gives:

$$\mu^{deduction} \equiv \frac{\Delta_R}{\Delta_{EC}} = \frac{R_{new} - R_{old}}{EC_{new} - EC_{old}} = \frac{(R_{old} \times 2.70) - R_{old}}{(R_{old} \times 2.70 \times 0.21) - (R_{old} \times 0.075)} = \frac{1.70}{0.49} = 3.46.$$

That is, the value for money ratio in the SME tax deduction case is 3.46. In other words, £1 of taxpayer money generates £3.46 in additional R&D.

Finally, note that Δ_{EC} could be rewritten as:

$$\Delta_{EC} = EC_{new} - EC_{old} = R_{new} \times 0.21 - R_{old} \times 0.075 = \Delta_R \times 0.21 + R_{old} \times (0.21 - 0.075),$$

where the first element represents the Exchequer costs associated with new R&D and the second term reflects additional Exchequer costs paid on existing R&D due to more generous tax relief. In this case, the majority of the additional costs are because of the new R&D generated, i.e., $\Delta_R \times 0.21 = R_{old} \times 0.36$ makes up close to 73% of Δ_{EC} ($\Delta_{EC} = R_{old} \times 0.49$).

SME payable tax credit case. In this case,

$$\rho^{credit} = \big(1 - c(1 + e)\big)(r + \delta), \tag{F4}$$

$$EC^{credit} = R \times c \times (1 + e), \tag{F5}$$

where c – the payable credit rate – is always zero for large companies and 14% for SMEs post-2008. Combining $c_{old} = 0, c_{new} = 0.14, e_{old} = 0.25, e_{new} = 0.75$, and $\eta = -4.0$ gives $\frac{\Delta_\rho}{\bar{\rho}} = -0.28$ and $\frac{\Delta_R}{\bar{R}} = 1.11$, which implies $\frac{R_{new}}{R_{old}} = 3.51$.

On the cost side, we have:

$$EC_{old} = 0,$$

$$EC_{new} = R_{new} \times c_{new} \times (1 + e_{new}) = R_{new} \times 0.25.$$

Putting all the elements together gives:

$$\mu^{payable} \equiv \frac{\Delta_R}{\Delta_{EC}} = \frac{R_{new} - R_{old}}{EC_{new} - EC_{old}} = \frac{R_{old} \times 3.51 - R_{old}}{R_{old} \times 3.51 \times 0.25 - 0} = \frac{2.51}{0.86} = 2.92.$$

The value for money ratio in the payable tax credit case is 2.92. In this case, the amount of additional R&D's Exchequer costs due to newly-generated R&D $\Delta_R \times 0.25 = R_{old} \times 0.62$ constitutes close to 72% of Δ_{EC} ($\Delta_{EC} = R_{old} \times 0.82$).

F.2 R&D Tax Relief Scheme over 2006-11

To evaluate the overall R&D Tax Relief Scheme over 2006-11, we calculate:

$$\mu \equiv \frac{\Delta_R}{\Delta_{EC}} = \frac{R_{tax\,relief} - R_{no\,tax\,relief}}{EC_{tax\,relief} - EC_{no\,tax\,relief}} = \frac{R_{taxrelief} - R_{no\,tax\,relief}}{EC} \tag{F4}$$

separately for each of three sub-schemes, SME tax deduction scheme (Panel B of Table A17), SME payable tax credit scheme row (Panel C), and large company tax deduction scheme (Panel D), in each year, using the same approach as described in detail above. We generalize our estimated tax-price elasticity of 4.0 to the whole population of SMEs, but use a lower-bound tax-price elasticity of 1.4 for the population of large companies as these firms are less likely to be credit constrained and therefore less responsive to tax incentives. In addition, we use the small profits rate (19%-21%) instead of the regular corporate tax rate (26%-30%) for the population of SMEs as most of them are much smaller than the "larger" SMEs in our baseline sample and therefore most likely qualify for the small profits rate.

As reported in Table A17, the SME tax deduction's value for money ratio decreases from 4.2 in 2006 to 3.6 in 2011 as SME tax deduction becomes significantly more generous over time. On the other hand, SME payable tax credits and large company tax deduction's value for money ratios are stable at around 2.9 and 1.9 respectively as these schemes do not change much over this period. The fact that all the value for money ratios are well above unity indicates that the R&D Tax Relief Scheme is effective in inducing additional R&D at relatively low cost to the Exchequer.

Finally, we estimate the amount of additional R&D induced by the R&D Tax Relief Scheme as $\Delta_R = \mu \times EC$ using the calculated value for money ratios μ's and Exchequer costs national statistics (HMRC 2015). We do this for each of the three schemes in each year in Panels B, C and D, and then aggregate them together in Panel E.

An illustration using the SME tax deduction case. Consider the SME tax deduction scheme in Panel B for 2009 (column (4)). The tax-adjusted user cost of R&D under this sub-scheme in 2009, calculated using the policy parameters, is $\frac{1-0.21\times(1+0.75)}{1-0.21}(0.05+0.15) = 0.16$. The counterfactual user cost in world without R&D tax relief is $0.05 + 0.15 = 0.20$ ($e = 0$). The percentage difference between these user costs is then $\frac{\Delta_\rho}{\overline{\rho}} = \frac{0.16-0.20}{(0.16+0.20)/2} = -0.22$. The tax-price elasticity of R&D of SMEs as estimated in subsection 5.2 is $\eta^{SME} = -4.0$.

The elasticity formula (F1) and Exchequer cost formula (F3) give:

$$\eta^{SME} = \frac{\Delta_R/\overline{R}}{\Delta_\rho/\overline{\rho}} \Rightarrow \Delta_R = \overline{R} \times \eta^{SME} \times \frac{\Delta_\rho}{\overline{\rho}},$$

$$\Delta_{EC} = EC_{tax\,relief} - 0 = R_{tax\,relief} \times e \times \tau = \left(\overline{R} + \frac{\Delta_R}{2}\right) \times e \times \tau = \overline{R} \times \left(1 + 0.5 \times \frac{\Delta_R}{\overline{R}}\right) \times e \times \tau,$$

$$\Rightarrow \mu^{SME\ deduction} = \frac{\Delta_R}{\Delta_{EC}} = \frac{\eta^{SME} \times \frac{\Delta_\rho}{\bar{\rho}}}{\left(1 + 0.5 \times \frac{\Delta_R}{\bar{R}}\right) \times e \times \tau} = \frac{4.0 \times 0.22}{(1 + 0.5 \times 4.0 \times 0.22) \times 0.75 \times 0.21} = 3.90.$$

We report this value for money ratio in row (2) in Panel B.[33] From HMRC data we know that £130m was paid out in the SME deduction in this year. Hence, we can calculate that the total amount of additional R&D induced $\Delta_R = \mu^{SME\ deduction} \times EC = 3.90 \times 130 = 507$ (£m), as shown in row (4) in Panel B.

As discussed in subsection 5.3, our aggregate estimates in Panel E suggest that the overall impact of the R&D Tax Relief Scheme is large. Over 2006-11, the policy, which costs less than £6 billion in lost tax revenue, induced over £13 billion in additional R&D. *On an annualized basis, spending £0.96 billion produced £2.25 billion of additional R&D.*

These calculations show our estimates of what the counterfactual path of R&D would have been in the absence of the R&D Tax Relief Scheme. Row (5) in Panel E gives the yearly breakdown. For example, the final column shows that on average 2006-11 we estimate that qualifying R&D would be 23% lower in the absence of the tax scheme.

F.3 Counterfactual R&D without the Tax Relief Scheme 2000-11

It is important to note that throughout our analysis we have been focusing on *qualifying* R&D, i.e., that part of business R&D that is eligible for tax relief. Aggregate qualifying R&D is lower than the figures for Business Enterprise R&D (BERD) reported in Figure 7. For example, in 2011 aggregate BERD was £17bn and aggregate qualifying R&D was £12bn. There are various reasons for this difference, including the fact that BERD includes R&D spending on capital investment whereas qualified R&D does not (only current expenses are liable). It is also the case that HMRC defines R&D more narrowly for tax purposes that BERD which is based on the Frascati definition.

We present counterfactual BERD to GDP ratios in Figure 7. To calculate the counterfactual (the dotted line "UK without tax relief" in Figure 7) we simply deduct the additional qualified R&D that we estimate were created by the R&D tax relief system (row (2) in of Panel E of Table A17) from the aggregate BERD numbers from OECD MSTI dataset (https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB). Since BERD is greater than qualifying R&D, the 23% fall in qualifying R&D (row (5) in Panel E) translates into a 14% fall in BERD (row (6) in Panel E).

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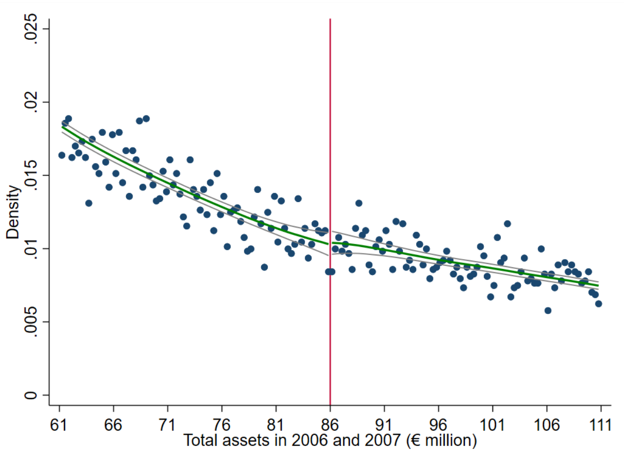
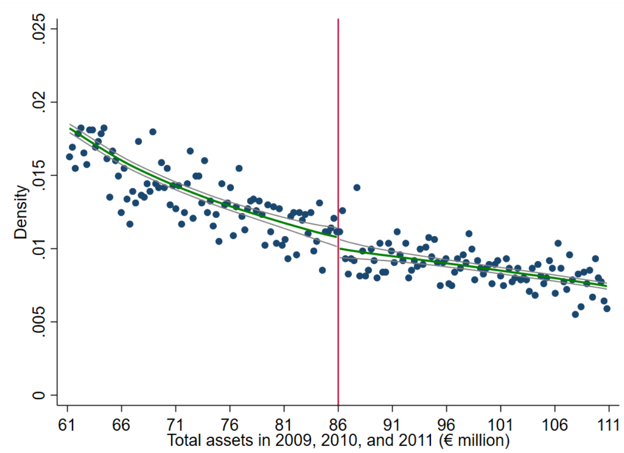
[33] To be consistent with how tax-payer costs are reported in HMRC data, we calculate these value-for-money ratios without accounting for pre-enhancement lost tax revenue from policy-induced R&D. If we also include this amount into tax-payer costs, the respective value-for-money ratios of the three schemes are 2.2, 2.9, and 1.2, and the aggregate value-for-money ratio of the whole R&D Tax Relief Scheme over 2006-11 is 1.6.

Figure A1: McCrary Tests for No Manipulation at the SME Assets Threshold



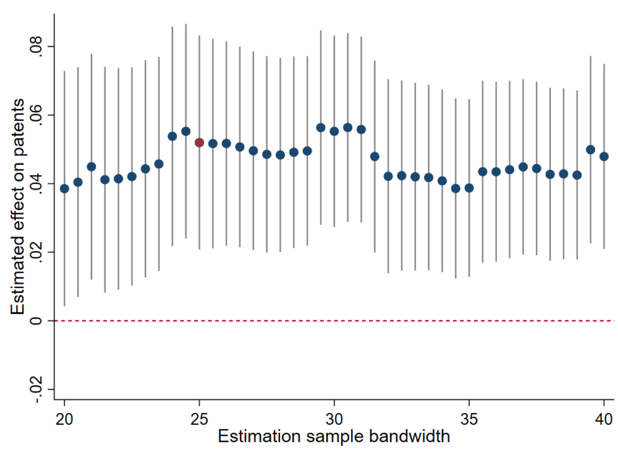
A. Before policy change



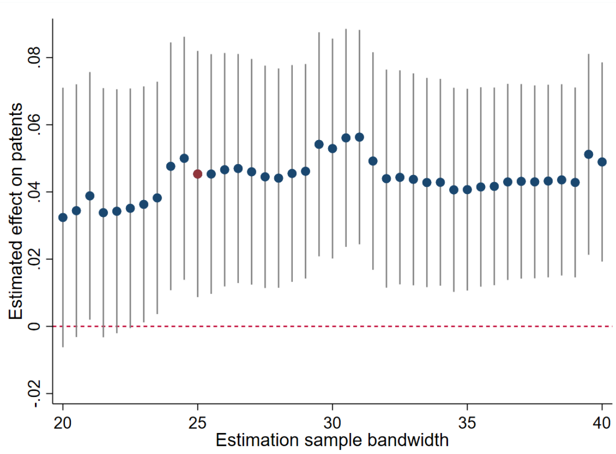
B. After policy change

Notes: This figure reports the McCrary tests for discontinuity in distribution density of total assets at the 2008 new SME assets threshold of €86m before, pooling together totat assets in 2006 and 2007 (Panel A), and after the policy change, pooling together total assets in 2009, 2010, and 2011 (Panel B). Estimation sample includes firms with total assets between €46m and €126m in each of the year. **Panel A:** The discontinuity estimate (log difference in density height at the SME threshold) (standard error) before the policy change is 0.013 (0.056). **Panel B:** The discontinuity estimate (log difference in density height at the SME threshold) (standard error) after the policy change is -0.072 (0.045).

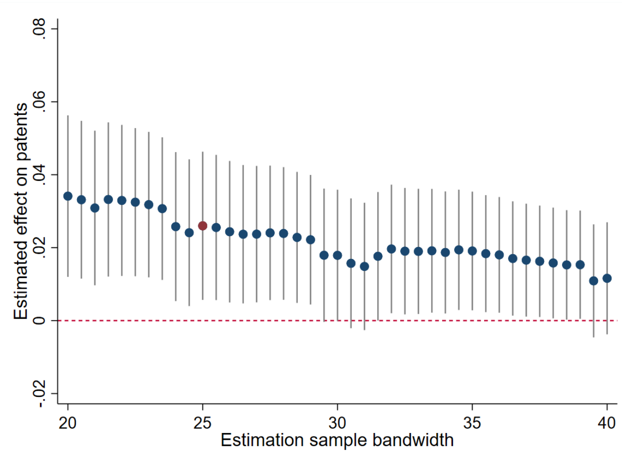
Figure A2: Policy Effect on Patents by Sample Bandwidth (Unweighted)



A. RD Design



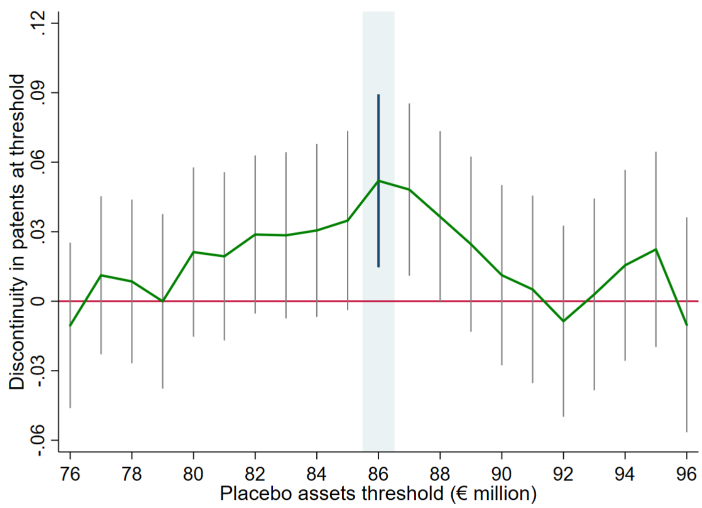
B. Diff-in-Disc Design



C. Diff-in-Diff Design

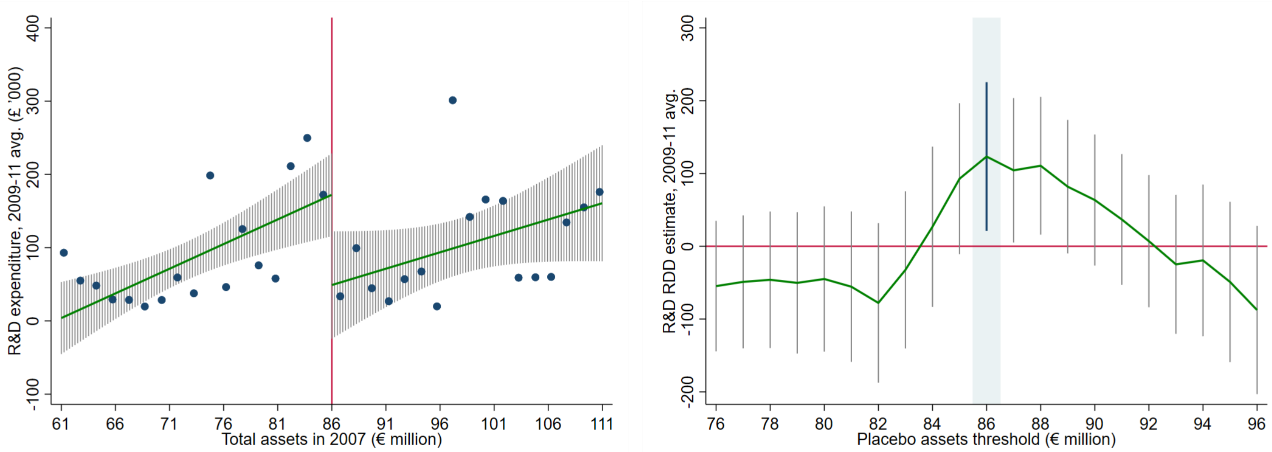
Notes: This figure plots the estimated policy effect on patents in various samples of firms around the SME assets threshold of €86m (the X-axis variable), ranging from 4,501 firms within a €20m bandwidth (i.e., firms with 2007 total assets between €66m and €106m) to 10,165 firms within a €40m of bandwidth (i.e., firms with 2007 total assets between €46m and €126m). **Panel A** plots the RD coefficients estimated using equation (1) over 2006-13. **Panel B** plots the Diff-in-Disc coefficients estimated using equation (3) over 2006-13. **Panel C** plots the Diff-in-Diff coefficients estimated using equation (2) over 2006-13. In both panels, for all estimates, all observations are weighted equally. The red dots correspond to the baseline sample (i.e., firms within a €25m bandwidth of the threshold), as reported in columns (2), (4), and (6) in Panel A of Table 3. Standard errors are clustered by firm. The grey lines indicate 90% confidence intervals of the estimates.

Figure A3: Discontinuities in Patents at Placebo SME Thresholds



Notes: This figure plots the discontinuities in firm's average patents over 2009-13 at different placebo assets thresholds. The coefficient at each threshold is estimated using the RD Design in equation (1). The running variable is total assets in 2007. Baseline sample includes firms with total assets in 2007 within €25m of the corresponding placebo threshold. Controls include (i) first order polynomials of running variable separately for each side of the placebo threshold, and (ii) 2006-08 (pre-policy) average of patent count. Standard errors are adjusted for heteroskedasticity. The grey lines indicate the 95% confidence intervals of the discontinuity estimates.

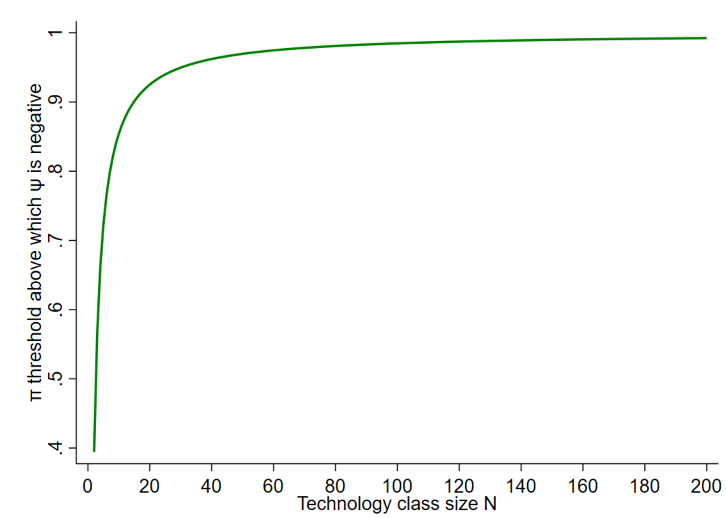
Figure A4: Discontinuities in R&D at Real and Placebo SME Thresholds



A. Real threshold B. Placebo thresholds

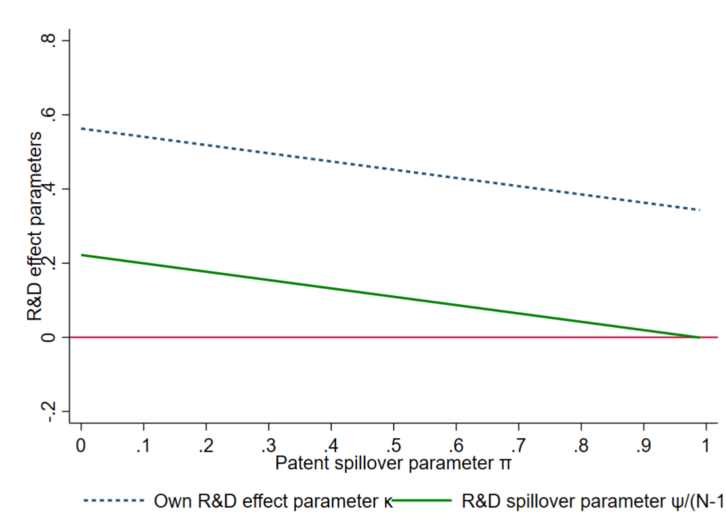
Notes: **Panel A** plots the discontinuity in firm's average post-policy R&D expenditure over 2009-11 at the SME assets threshold of €86m. The discontinuity estimate (standard error) is 123.3 (52.1), statistically significant at 5% level, as reported in column (8) in Panel C of Table A3. Each point represents a bin of 184 firms on average, over an assets range of €1.5m. The shaded areas indicate 95% confidence intervals of the fitted linear model shown on the plot. **Panel B** plots the discontinuities in firm's average post-policy R&D expenditure over 2009-11 at different placebo assets thresholds. The coefficient at each threshold is estimated using the RD Design analogous to equation (1). The running variable is total assets in 2007. Baseline sample includes firms with total assets in 2007 within €25m of the corresponding placebo threshold. Controls include first order polynomials of running variable separately for each side of the placebo threshold. Standard errors are adjusted for heteroskedasticity. The grey lines indicate the 95% confidence intervals of the discontinuity estimates.

Figure A5: Sign of R&D Spillover Given Patent Spillover and Technology Class Size



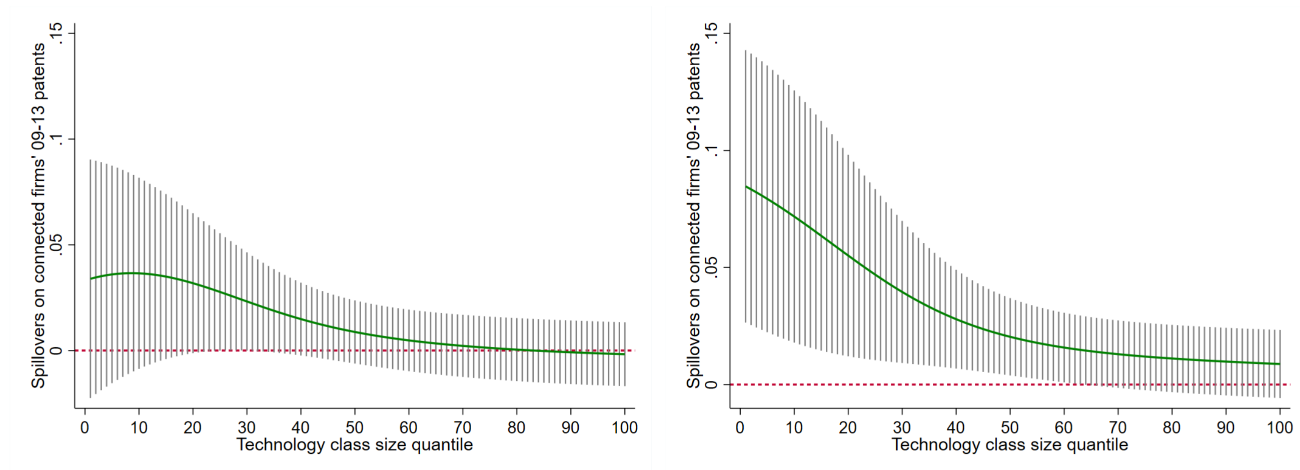
Notes: Recall equation (D1) which specifies the system of technology spillovers among firms. The green curve plots the $\bar{\pi}$ (direct patent spillover parameter) threshold above which ψ (direct R&D spillover parameter) is negative at each different value N (technology class size). $\bar{\pi}$ is calculated using equations (D3) and (D4), using $\hat{\gamma} = 0.563$ (estimate of net own R&D effect, reported in column (2) in Panel B of Table 3) and $\hat{\xi} = 0.222$ (estimate of net R&D spillover effect, reported in column (6) of Table 5). The area under the green curve represents the space in which ψ would be positive and vice versa. For the system to be stable, π must not exceed 1. (See Appendix D.1 for further details.)

Figure A6: Own R&D Effect and R&D Spillover Given Patent Spillover



Notes: Recall equation (D1) which specifies the system of technology spillovers among firms. This figure plots κ (direct own R&D effect parameter) and $\psi(N-1)$ (direct R&D spillover parameter) as a function of π (direct patent spillover parameter) for $N = 109$ ("average" value of technology class size N in small technology class sample). The calculations are based on equations (D2) and (D4), using $\hat{\gamma} = 0.563$ (estimate of net own R&D effect, reported in column (2) in Panel B of Table 3) and $\hat{\xi} = 0.222$ (estimate of net R&D spillover effect, reported in column (6) of Table 5). (See Appendix D.1 for further details.)

Figure A7: Spillovers on Connected Firms by Technology Class Size

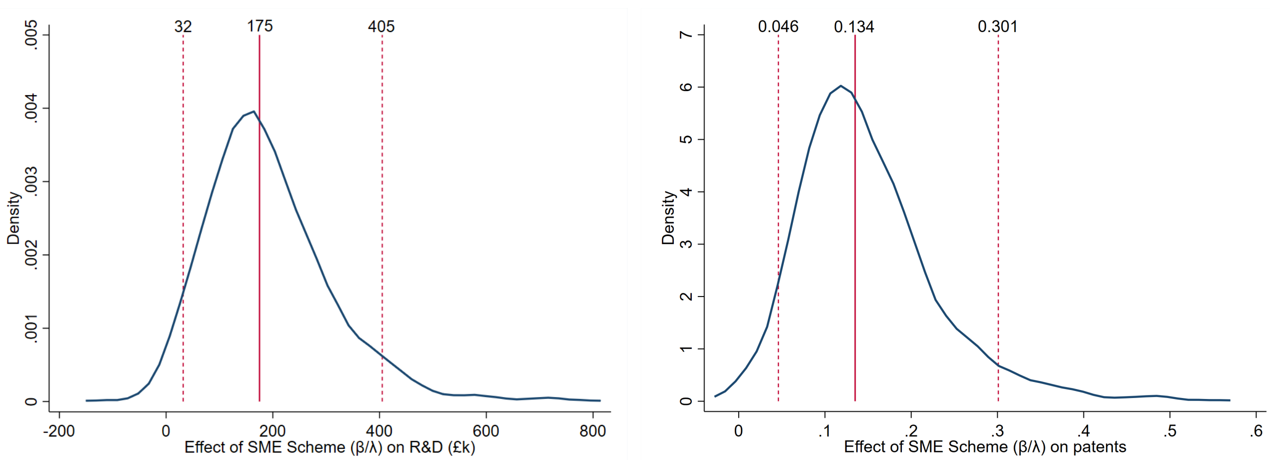


A. No technological proximity restriction

B. Technological proximity above 0.95

Notes: This figure plots the estimated spillover effect on technologically connected firms' patents as a function of the technology class size percentile (the X-axis variable) using alternative technological connectedness definitions. The semi-parametric estimation is based on a generalized version of equation (6) as specified in equation (D5), using a Gaussian kernel of the variable on the X-axis and a bandwidth of 25% of the range (see Appendix D.4 for details). **Panel A** considers all firm pairs patenting primarily in the same three-digit IPC technology class to be technologically connected. **Panel B** further requires that the Jaffe (1986) technological proximity between the firms is above 0.95 (75^{th} percentile). In both panels, standard errors are clustered by primary technology class. The grey lines indicate 90% confidence intervals of the spillover estimates.

Figure A8: Bootstrapped Distributions of SME Scheme's Treatment Effects (β/λ)

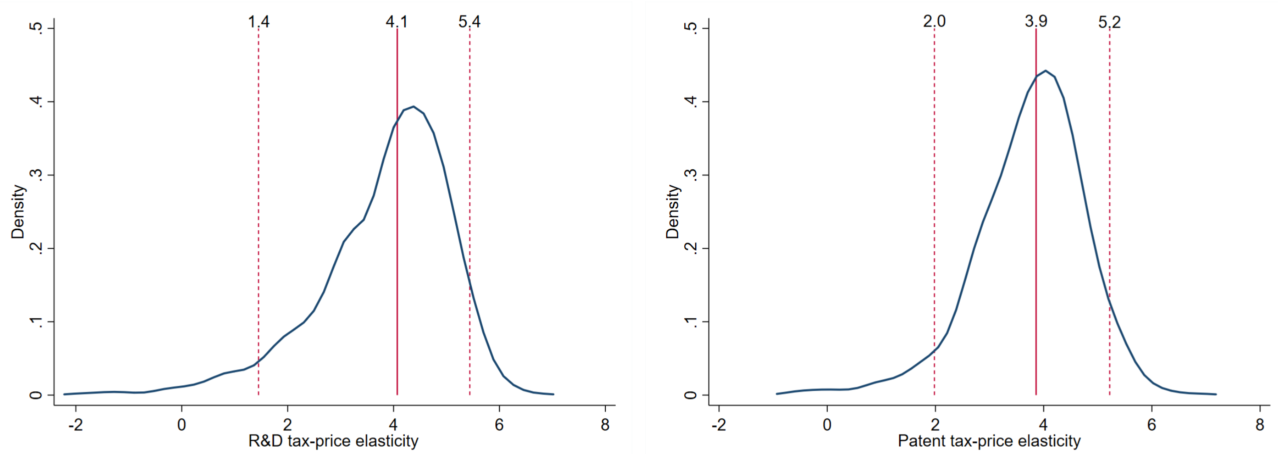


A. R&D

B. Patents

Notes: This figure plots the bootstrapped distributions of the treatment effects of the SME Scheme (β/λ) on R&D (**Panel A**) and patents (**Panel B**) from 1,000 replications (see Appendix E.4 for details). In each panel, the solid vertical line corresponds to the 50^{th} percentile of the distribution, and the dashed vertical lines correspond to the 5^{th} and 95^{th} percentiles.

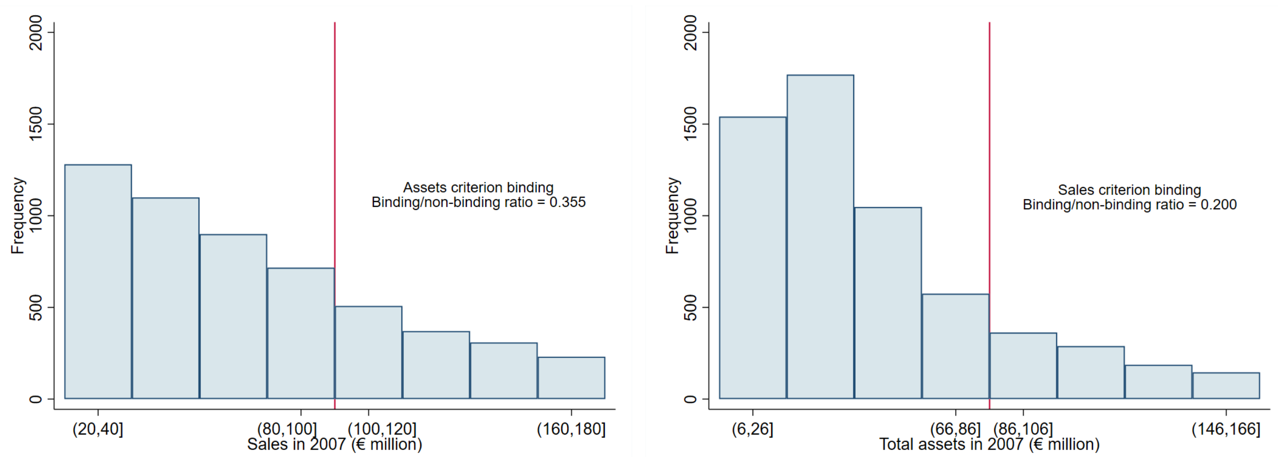
Figure A9: Bootstrapped Distributions of R&D and Patent Elasticities



A. R&D B. Patents

Notes: This figure plots the bootstrapped distributions of R&D (**Panel A**) and patent (**Panel B**) tax-price elasticities from 1,000 replications (see Appendix E.4 for details). In each panel, the solid vertical line corresponds to the 50$^{\text{th}}$ percentile of the distribution, and the dashed vertical lines correspond to the 5$^{\text{th}}$ and 95$^{\text{th}}$ percentiles.

Figure A10: Number of Firms with Binding and Non-Binding Assets and Sales Criteria



A. Assets criterion B. Sales criterion

Notes: **Panel A**: Sample includes firms with 2007 total assets in [€36m, €136m] and 2007 sales in (€20m, €180m]. Among them, the assets criterion is not binding for 4,223 firms with 2007 sales in (€20m, €100m], and binding for 1,450 firms with 2007 sales in (€100m, €180m]. The corresponding binding/non-binding ratio is 1,450/4,223 = 0.343. **Panel B**: Sample includes firms with 2007 sales in [€50m, €150m] and 2007 total assets in (€6m, €166m]. Among them, the sales criterion is not binding for 5,156 firms with 2007 total assets in (€6m, €86m], and binding for 1,059 firms with 2007 total assets in (€86m, €166m]. The corresponding binding/non-binding ratio is 1,059/5,156 = 0.205.

Table A1: Design of UK R&D Tax Relief Scheme Over Time

Effective from		SME ceilings: Employment	SME ceilings: Total assets	SME ceilings: Turnover	Enhancement: SME	Enhancement: Large company	Payable credit: SME	Payable credit: Large company	Effective for
2000	April	249	€27m	€40m	50%	0%	16%	0%	Expenditure incurred on or after April 1, 2020
2002	April	-	-	-	-	25%	-	-	Expenditure incurred on or after April 1, 2022
2005	January	-	€43m	€50m	-	-	-	-	Accounting period ended on or after January 1, 2005
2008	**April* August***	**499**	**€86m**	**€100m**	**75%**	**30%**	**14%****	**-**	LCOs: expenditure incurred on or after April 1, 2008 SMEs: expenditure incurred on or after August 1, 2008
2011	April	-	-	-	100%	-	12.5%**	-	Expenditure incurred on or after April 1, 2011
2012	April	-	-	-	125%	-	-	-	Expenditure incurred on or after April 1, 2012

Notes: To be considered an SME, a company must not exceed the employment ceiling and either the total assets ceiling or the sales ceiling. The measurements and account aggregation rules for employment, total assets, and sales are set according to 1996/280/EC (up to 2004) and 2003/361/EC (from 2005), yet the ceiling increase in 2008 applied only to the R&D Tax Relief Scheme. A company loses (acquires) its SME status if it fails (passes) the ceiling tests over two consecutive accounting periods (two-year rule). An SME working as subcontractor for a large company can only claim under the Large Company Scheme. From April 2000 to March 2012, there was a minimum requirement of £10,000 in qualifying R&D expenditure for both SMEs and large companies.

* Enhancement rate increase for large companies became effective on April 1, 2008. Changes in SME ceilings and enhancement and payable credit rates under the SME scheme became effective on August 1, 2008.

** The reductions in payable credit rate is to ensure that effective state aid intensity does not exceed the limit of 25% imposed by the European Commission.

Table A2: Tax-Adjusted User Cost of R&D Capital Over Time

Tax relief scheme:	(1) SME: Deduction	(2) SME: Payable credit	(3) SME: Average	(4) Large company: Deduction	(5) Large company: Payable credit	(6) Large company: Average	(7) **Arc % difference user cost**	(8) **Log difference user cost**
2006	0.157	0.152	0.154	0.179	0.200	0.190	-0.209	-0.210
2007	0.157	0.152	0.154	0.179	0.200	0.190	-0.209	-0.210
2008	0.147	0.151	0.149	0.177	0.200	0.190	-0.237	-0.238
2009	0.142	0.151	0.147	0.177	0.200	0.190	-0.254	-0.255
2010	0.142	0.151	0.147	0.177	0.200	0.190	-0.254	-0.255
2011	0.130	0.150	0.141	0.179	0.200	0.191	-0.300	-0.302
2006-08	**0.154**	**0.152**	**0.153**	**0.178**	**0.200**	**0.190**	**-0.218**	**-0.219**
2009-11	**0.138**	**0.151**	**0.145**	**0.177**	**0.200**	**0.190**	**-0.269**	**-0.271**

Notes: Tax-adjusted user cost of R&D capital is calculated using formulae as described in Appendix E.3. Corporate tax rate is 30% over 2006-07, 28% over 2008-2010, and 26% in 2011. Enhancement rate is 50% for SMEs and 25% for large companies pver 2006-08, 75% for SMEs and 30% for large companies over 2008-10, 100% for SMEs and 30% for large companies in 2011. Payable credit rate is 16% over 2006-08, 14% in 2008-10, and 12.5% in 2011. Share of the payable credit case is 55%. Real interest rate is 5%. Depreciation rate is 15%. Note that real interest and depreciation rates do not matter to the difference in tax-adjusted user cost of R&D capital between SMEs and large companies, as they cancel out.

Table A3: Evolution of R&D Tax Relief Effects on Patents and R&D

Panel A. Year-by-year effects on patents, 2006-15

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable:	**Patent count**									
	Before (pre-policy)			After (post-policy)						
Year:	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Below-threshold indicator	-0.011	0.028	0.045	0.083**	0.071**	0.074**	0.048*	0.057*	0.055**	0.043*
	(0.035)	(0.035)	(0.034)	(0.033)	(0.032)	(0.035)	(0.025)	(0.031)	(0.024)	(0.024)
Number of firms	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744

Panel B. Pre- and post-policy effects on patents

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable:	**Patent count**									
	Before	3 years After			5 years After			7 years After		
Period:	2006-08 average	2009-11 average	3yr Aft. - 3yr Bef.	09-11 avg. (w. LDV)	2009-13 average	5yr Aft. - 3yr Bef.	09-13 avg. (w. LDV)	2009-15 average	7yr Aft. - 3yr Bef.	09-15 avg. (w. LDV)
Below-threshold indicator	0.021	0.076**	0.055**	0.060***	0.066**	0.045**	0.052***	0.061**	0.040*	0.048***
	(0.032)	(0.031)	(0.023)	(0.022)	(0.027)	(0.022)	(0.019)	(0.024)	(0.023)	(0.018)
Number of firms	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744

Panel C. Evolution of effect on R&D, 2006-11

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable:	**R&D expenditure**									
	Before (pre-policy)			After (post-policy)			Before	3yr After	3yr Diff.	w. LDV
Year/period:	2006	2007	2008	2009	2010	2011	2006-08 average	2009-11 average	3yr Aft. - 3yr Bef.	2009-11 average
Below-threshold indicator	43.4	81.9	63.1	97.3*	133.6**	138.9**	62.8	123.3**	60.4*	63.4**
	(50.6)	(59.2)	(44.9)	(51.4)	(53.5)	(55.1)	(48.9)	(52.1)	(31.5)	(32.1)
Number of firms	5,888	5,888	5,888	5,888	5,888	5,888	5,888	5,888	5,888	5,888

Notes: Year-by-year pre- and post-policy discontinuities in patents (**Panels A and B**) and R&D (**Panel C**) are estimated using the RD Design analogous to equation (1). The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include first order polynomial of the running variable separately for each side of the threshold. Columns (3), (6), and (9) in Panel B and column (9) in Panel C use the difference between post- and pre-policy annual average patents or R&D as the outcome variable (i.e., equivalent to equation (3)'s Diff-in-Disc Design, see Appendix C.1 for details). Columns (4), (7), and (10) in Panel B and column (10) in Panel C additionally control for firm's 2006-08 (pre-policy) average patents or R&D (i.e., equation (1)'s RD Design). Robust standard errors are in brackets. Mean patent applications is 0.066 over 2006-08 and 0.054 over 2009-13. Mean R&D expenditure is £73,977 over 2006-08 and £88,825 over 2009-11, both in 2007 prices.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A4: Robustness Tests for R&D Tax Relief Effect on Patents

Panel A. In-lab sample, alternative kernel weights, and extended sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	**Patent count**								
Robustness test:	In-lab sample			Alternative kernel weight				Extended sample	
Specification:	RD	Diff-in-Disc	CCT	RD				Diff-in-Disc	Diff-in-Diff
Period:	09-13 avg.	06-13	09-13 avg.	09-13 avg.	09-13 avg.	09-13 avg.	09-13 avg.	06-13	06-13
Below-threshold indicator	0.049**		0.074***	0.045**	0.045**	0.039**	0.047***		
	(0.020)		(0.029)	(0.020)	(0.019)	(0.016)	(0.017)		
Below-threshold × Post-2008		0.042*						0.027***	0.014**
		(0.022)						(0.010)	(0.007)
Dependent variable mean, 2006-08 average	*0.064*	*0.064*		*0.065*	*0.066*	*0.059*	*0.062*	*0.095*	*0.095*
Sample/subsample	In lab	In lab	In lab						
Bandwidth (€m)			31			35	35	43/∞	43/∞
Kernel weight				Tri	Epa	Uni	Epa	Uni	Uni
Observations	5,888	47,104	7,872	5,744	5,744	8,577	8,577	187,624	187,624
Number of firms	5,888	5,888	7,872	5,744	5,744	8,577	8,577	23,453	23,453

Panel B. Alternative data trimming rules, polynomial controls and fixed effects, and estimation models

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dependent variable:	**Patent count (2009-13 average)**								
Robustness test:	Employ-ment ≤ 499	Alternative winsorization			Alt. polynomial controls		Industry FEs	Poisson	Neg. Bin.
Below-threshold indicator	0.095**	0.050**	0.043***	0.055***	0.037	0.051	0.042*	1.487***	0.707*
	(0.042)	(0.020)	(0.017)	(0.018)	(0.028)	(0.040)	(0.021)	(0.528)	(0.364)
Dependent variable mean, 2006-08 average	*0.101*	*0.073*	*0.058*	*0.055*	*0.066*	*0.066*	*0.070*	*0.066*	*0.066*
Sample/subsample	Emp ≤ 499								
Winsorized window		1.0%	5.0%	No outliers					
Polynomial controls					Second	Third			
Fixed effects							4-dig SIC		
Number of firms	2,176	5,744	5,744	5,741	5,744	5,744	5,314	5,744	5,744

Panel C. Alternative LDV controls and pre-/post-policy periods

	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
Dependent variable:					**Patent count**				
Robustness test:	Alternative LDV control		2008 as post-policy						
Specification:	RD		RD	Diff-in-Disc			Diff-in-Diff		
Period:	09-13 avg.	09-13 avg.	08-13 avg.	06-13	02-15	06-13	06-13	02-15	06-13
Below-threshold indicator	0.050**	0.048***	0.056***						
	(0.012)	(0.017)	(0.020)						
Below-threshold × Post-2008				0.054**	0.046*	0.055***	0.027**	0.026**	0.054**
				(0.024)	(0.027)	(0.020)	(0.012)	(0.012)	(0.023)
Year of LDV control	2007	06, 07 & 08	06-07 avg.						
2008 as post-policy year			X	X	X	X	X	X	X
Augmentation						Dynamic			With break
Observations	5,744	5,744	5,744	45,952	80,416	45,952	45,952	80,416	45,952
Number of firms	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744

Notes: Baseline specification is equation (1)'s RD Design. The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include (i) first order polynomial of the running variable separately for each side of the threshold, and (ii) 2006-08 (pre-policy) average patents. Standard errors are clustered by firm.

Panel A: Columns (1) to (3) replicate Table 3's main results using in-lab baseline sample. Column (1) employs equation (1)'s RD Design; column (2) equation (3)'s Diff-in-Disc Design; and column (3) Calonico, Catteneo, and Titunik's (2014) robust bias-corrected optimal bandwidth RD Design. Columns (4) and (5) employ triangular and Epanechnikov kernel weights using the baseline sample. Columns (6) and (7) employ uniform and Epanechnikov kernel weights using the wider €35m-bandwidth sample. Columns (8) and (9) consider all firms with 2007 assets above the old SME threshold of €43m. Column (8) implements equation (3)'s Diff-in-Disc Design and column (9) equation (2)'s Diff-in-Diff Design.

Panel B: Column (10) considers only firms with 2007 employment below 500. Columns (11) and (12) winsorize annual patents at 1% and 5% respectively. Column (13) excludes firms with pre- or post-policy annual average patents above 20. Columns (14) and (15) control for second or third order polynomial of the running variable separately for each side of the threshold. The coefficients on the second and third order assets terms are not statistically significant or jointly statistically significant. Column (16) add industry (four-digit SIC) fixed effects. Columns (17) and (18) employ Poisson and Negative Binomial specifications instead of OLS, to allow for a proportional effect on patents.

Panel C: Column (19) only controls for firm's patents in 2007 and column (20) firm's patents in 2006, 2007, and 2008 separately. Columns (21) to (27) treat 2008 as a post-policy year. Column (21) implements equation (1)'s RD Design; columns (22) to (23) equation (3)'s Diff-in-Disc Design, similar to columns (4) to (6) in Panel A of Table 3; columns (24) to (27) equation (2)'s Diff-in-Diff Design, similar to columns (7) to (9) in Panel A of Table 3.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A5: Robustness Tests for R&D Tax Relief Effect on R&D

Panel A. Alternative kernel weights, polynomial controls, and sample bandwidths

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	**R&D expenditure (2009-11 average, £k)**								
Robustness test:	Alternative kernel weight		Alt. polynomial controls		Alt. sample bandwidth				CCT
Below-threshold indicator	94.3**	91.6**	113.3**	82.9	117.7**	91.6**	114.5**	106.8**	190.0***
	(40.6)	(39.3)	(54.4)	(65.6)	(50.0)	(40.2)	(48.7)	(45.8)	(74.8)
Kernel weight	Tri	Epa							
Polynomial controls			Second	Third			Second	Second	
Bandwidth (€m)					15	20	30	35	20
Number of firms	5,888	5,888	5,888	5,888	3,384	4,615	7,255	8,818	4,859

Panel B. Additional fixed effects, alternative LDV control, data trimming rules, and estimation model

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dependent variable:	**R&D expenditure (2009-11 average, £k)**								
Robustness test:	Additional fixed effects			Alt. LDV control	Alt. winsorization			Employ-ment $\leq$ 499	Poisson
Below-threshold indicator	72.0*	76.9**	71.8**	60.8*	85.7**	53.8**	41.1**	153.2***	1.31***
	(41.1)	(37.1)	(34.1)	(33.9)	(40.8)	(28.5)	(20.0)	(76.3)	(0.49)
Fixed effects	Industry	Location	Ind $\times$ Loc						
Year of LDV control				2007					
Winsorized window					1%	5%	No outliers		
Sample/subsample								Emp $\leq$ 499	
Number of firms	4,504	5,868	4,498	5,888	5,888	5,888	5,872	2,246	5,888

Notes: Baseline specification is equation (1)'s RD Design. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). The running variable is total assets in 2007 with a threshold of €86m. Controls include (i) first order polynomial of the running variable separately for each side of the threshold, and (ii) 2006-08 (pre-policy) average patents. Robust standard errors are in brackets. Mean R&D expenditure is £73,977 over 2006-08 and £88,825 over 2009-11, both in 2007 prices.

Panel A: Columns (1) and (2) employ triangular and Epanechnikov kernel weights using the baseline sample. Columns (2) and (3) control for second or third order polynomial of the running variable separately for each side of the threshold. The coefficients on the second and third order assets terms are not statistically significant or jointly statistically significant. Columns (5) and (6) use samples with smaller bandwidths around the threshold. Columns (7) and (8) use sample with larger bandwidths around the threshold, controlling for second order polynomial of the running variable separately on each side of the threshold to improve fit (the coefficients on the second order assets terms are jointly significant). Column (9) implements Calonico, Catteneo, and Titunik's (2014) robust bias-corrected optimal bandwidth RD Design.

Panel B: Columns (10) to (12) add industry (four-digit SIC), location (two-digit postcode), and industry $\times$ location (two-digit SC $\times$ one-digit postcode) fixed effects. Column (13) controls for firm's patents in 2007. Columns (14) and (15) winsorize annual patents at 1% and 5% respectively and column (16) excludes outliers in R&D expenditure. Column (17) considers only firms with 2007 employment below 500. Columns (18) employs Poisson specification instead of OLS, to allow for a proportional effect on R&D.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A6: IV Estimation of Innovation Production Function

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	**Patent count (2009-13 average)**							
Sample:	Firms with 2007 assets ∈ [€61m-€111m]				Firms with 2007 assets ∈ [€51m-€121m]			
Specification:	Without LDV control		With LDV control		Without LDV control		With LDV control	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
R&D expenditure, 09-11 avg.	0.206***	0.563**	0.032	0.434*	0.184***	0.655*	0.030	0.501
	(0.070)	(0.282)	(0.030)	(0.243)	(0.058)	(0.363)	(0.027)	(0.312)
Anderson-Rubin test p-value		0.008		0.012		0.0xx		0.011
Number of firms	5,888	5,888	5,888	5,888	8,818	8,828	8,818	8,818

Notes: IV Design in even-numbered columns is based on equation (4). Instrument variable is the binary indicator of whether total assets in 2007 (the running variable) is at or below €86m (the threshold). Controls include (i) first order polynomial of the running variable separately for each side of the threshold. Column (4) and (8) additionally control for firm's 2006-08 (pre-policy) average patents. Odd-numbered columns report the corresponding OLS estimates. Columns (1) to (4) employ uniform weights for the €25m-bandwidth baseline sample. Columns (5) and (6) employ triangular weights for the wider €35m-bandwidth sample. Robust standard errors are in brackets. P-values of Anderson-Rubin weak-instrument-robust inference tests indicate that the IV estimates are statistically different from zero even in the possible case of weak IV. The units for R&D expenditure as the explanatory variable are £ million in 2007 prices.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A7: Robustness Tests for Spillovers on Technologically Connected Firms

Panel A. Alternative clustering schemes, firm j controls, technological connectedness definition, and estimation models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	**Firm j's patent count (2009-13 average)**								
Robustness test:	Alternative clustering			Alt. controls		Alt. definition		Poisson	Neg. Bin.
Technology class size:	Small	Small	Small	Small	Small	All	All	All	All
Firm i's below-threshold indicator	0.085*	0.085*	0.085*	0.093**	0.081**	0.112**	0.179**	0.963*	1.352**
	(0.044)	(0.046)	(0.045)	(0.036)	(0.031)	(0.055)	(0.086)	(0.514)	(0.628)
Firm i's below-threshold × Tech. class size						-0.118*	-0.179*	-1.004*	-1.393**
						(0.063)	(0.091)	(0.532)	(0.651)
Dependent variable mean, 2006-08 avg.	*0.286*	*0.286*	*0.286*	*0.286*	*0.286*	*0.358*	*0.243*	*0.349*	*0.349*
Clustering scheme	Firm i	Firm j	Two-way						
Firm j's 2007 asset controls				None	E_j^{2007}				
Jaffe technological proximity cutoff						None	0.95		
Number of firms i-j pairs	6,703	6,703	6,703	6,703	6,703	285,692	66,644	156,908	156,908
Number of connected firm j's	2,977	2,977	2,977	2,977	2,977	19,549	9,554	15,685	15,685
Number of treated firm j's	146	146	146	146	146	536	363	517	517
Number of 3-digit IPC classes	55	55	55	55	55	85	72	83	83

Panel B. Alternative post-policy periods, LDV controls, and in-lab sample

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dependent variable:			**Firm j's patent count**				**Firm j's patents**	**Firm i's R&D exp.**	
Robustness test:		Alternative period			Alt. LDV control			In-lab sample	
Period:	09-11 avg.	09-13 avg.	09-15 avg.	02-15	09-13 avg.	09-13 avg.	09-13 avg.	09-11 avg.	09-11 avg.
Technology class size:	Small	Small	Small	Small	Small	Small	Small	Small	All
Firm i's below-threshold indicator	0.068**	0.085**	0.078**		0.111***	0.181**	0.196**	0.884***	0.933***
	(0.033)	(0.033)	(0.031)		(0.035)	(0.083)	(0.093)	(0.157)	(0.013)
Firm i's below-threshold × Post-2008				0.065*					
				(0.035)					
Dependent variable mean, 2006-08 avg.	*0.286*	*0.286*	*0.286*	*0.286*	*0.286*	*0.286*	*0.286*	*0.248*	*0.499*
Specification			Diff-in-Disc						
Year of LDV control					2007	None	None	None	None
Number of observations	6,703	6,703	6,703	93,842	6,703	6,703	2,093	2,093	203,832
Number of firms i-j pairs	6,703	6,703	6,703	6,703	6,703	6,703	2,093	2,093	203,832
Number of connected firm j's	2,977	2,977	2,977	2,977	2,977	2,977	1,190	1,190	17,632
Number of treated firm j's	146	146	146	146	146	146	67	67	547
Number of 3-digit IPC classes	55	55	55	55	55	55	36	36	91

Notes: Baseline specification is equation (6)'s spillover RD Design. Each observation is a pair of a treated firm i and a technologically connected firm j. The running variable is treated firm i's total assets in 2007 with a threshold of €86m. Controls in the spillover RD Design include (i) first order polynomials of the running variable separately for each side of the threshold, (ii) second order polynomial of connected firm j's total assets in 2007, and (iii) firm j's 2006-08 (pre-policy) average patent count. Technology class size is the number of firms whose primary technology class is the said class, converted to percentile and normalized to be between 0 and 1. Small (large) technology class subsample includes firms whose primary technology classes have below (above) 200 firms. Standard errors in brackets are clustered by primary technology class.

Panel A: Columns (1) to (3) cluster standard errors by treated firm i, connected firm j, and two-way by firm i and firm j. Column (4) excludes controls for connected firm j's 2007 assets. Column (5) controls for whether firm j's 2007 assets is at or below €86m and a second-order polynomial of this additional running variable separately on each side of the threshold. Columns (6) and (7) vary the Jaffe (1986) technological proximity cutoff used to define technological connectedness. Column (6) effectively drops this restriction while column (7) tightens it from 0.75 (median) to 0.95 (75^{th} percentile). Columns (8) and (9) employ Poisson and Negative Binomial specifications instead of OLS, to allow for a proportional effect on connected firm j's patents.

Panel B: Columns (10) to (12) consider different post-policy periods, including up to 3 years, 5 years, and 7 years after the policy change. Column (13) employ equation (7)'s spillover Diff-in-Disc Design over the extended 2002-15 period. Column (14) only controls for connected firm j's patents in 2007 and column (15) excludes control for firm j's pre-policy patents. Columns (16) and (17) report the reduced-form and first stage regressions that correspond to the spillover RD IV regression in column (6) of Table 5, using in-lab sample of technologically connected firm pairs in small technology classes. Column (18) replicates column (17) on the full in-lab sample of technologically connected firm pairs. Note that columns (16) to (18) do not include control for firm j's pre-policy patents. The units for R&D expenditure as the dependent variable in columns (17) and (18) are £ thousand in 2007 prices.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A8: Being Below the Assets Threshold as a Predictor for SME Eligibility

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	**Indicator: Has R&D claims under SME Scheme**								
Sample bandwidth:	Firms with 2007 assets ∈ [€61m-€111m]						2007 assets ∈ [€51m-€121m]		
Period:	2009	2010	2011	2008-09	2008-11	2009-11	2008-09	2008-11	2009-11
Below-threshold indicator	0.326***	0.301***	0.184*	0.464***	0.353***	0.248***	0.427***	0.345***	0.271***
	(0.085)	(0.089)	(0.100)	(0.087)	(0.090)	(0.093)	(0.079)	(0.082)	(0.085)
Number of firms	215	218	248	265	361	333	407	555	520

Notes: Sharpness of the below-assets-threshold indicator as predictor for firm's post-policy SME status is estimated using the RD Design in equation (8). The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m) unless noted otherwise. Controls include first order polynomials of the running variable separately for each side of the threshold. The sample for a certain year (period) effectively includes firms in the baseline sample with R&D tax relief claims in that year (period). A firm's SME status over a period is the maximum of its SME status in each of the year within the period. Robust standard errors are in brackets.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A9: R&D Tax Relief Effect on Doing Any R&D or Filing Any Patents

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	**Indicator: R&D exp. > 0**	**Indicator: Patent count > 0**							
Year:	2009-11	2009	2010	2011	2012	2013	2014	2015	2009-13
Below-threshold indicator	0.003	0.006	0.005	0.012*	0.011**	0.015***	0.012**	0.009	0.011
	(0.009)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)	(0.008)
Dependent variable mean	*0.056*	*0.017*	*0.017*	*0.017*	*0.014*	*0.015*	*0.013*	*0.012*	*0.032*
Number of firms	5,888	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744

Notes: RD Design is based on equation (1). Dependent variables are indicators of whether the firm has R&D expenditure (column (1)) or files patents (columns (2) to (9)) during the corresponding year or period. The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include (i) first order polynomials of the running variable separately for each side of the threshold, and (ii) lagged dependent variable over 2006-08 (pre-policy period). Robust standard errors are in brackets. Mean lagged dependent variable for R&D is 0.044. Mean lagged dependent variable for patents is 0.030.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A10: Heterogeneous Effects of R&D Tax Relief by Firm's Past Innovation Activities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Firm characteristic (D):	Has past R&D		Has past patents		In high patenting industry				Has past capital investments			
Dependent variable:	**R&D exp., 09-11 avg.**		**Patent fam., 09-13 avg.**		**R&D exp., 09-11 avg.**		**Patent fam., 09-13 avg.**		**R&D exp., 09-11 avg.**		**Patent fam., 09-13 avg.**	
Sample:	D = 1	D = 0	D = 1	D = 0	D = 1	D = 0	D = 1	D = 0	D = 1	D = 0	D = 1	D = 0
Below-threshold indicator	1,708*	6.3	1.50**	0.002	167.4*	107.8	0.160**	0.017	305.5***	-36.7	0.148***	-0.000
	(885)	(9.6)	(0.68)	(0.005)	(95.2)	(68.3)	(0.065)	(0.011)	(106.4)	(30.0)	(0.055)	(0.013)
Dependent variable mean, 2006-08 average	*1,682*	*0.0*	*2.18*	*0.000*	*124.7*	*25.0*	*0.118*	*0.020*	*159.6*	*4.4*	*0.123*	*0.016*
Difference	1,702*		1.50**		59.5		0.142**		342.2***		0.148***	
	(879)		(0.67)		(117.2)		(0.066)		(110.6)		(0.056)	
Number of firms	259	5,629	172	5,716	2,272	2,232	2,272	2,232	2,640	3,248	2,640	3,248

Notes: RD estimates are based on a version of equation (1) without controlling for pre-policy patents. The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include first order polynomials of the running variable separately for each side of the threshold. $D = 1$ samples include firms having past R& (column (1)) or past patents (column (3)), in high patenting industries (columns (5) and (7)), or having past capital investments (columns (9) and (11)). $D = 0$ samples are the complements of the those in the preceding $D = 1$ columns. Past period is the pre-policy period of 2006-08. In columns (5) to (8), industry patenting intensity is calculated as the share of firms in the four-digit SIC industry having filed any patent before 2007. High (low) patenting subsample includes firms in industries above (below) median in patenting intensity. Examples of high-patenting industries include electric domestic appliances, basic pharmaceutical products, medical and surgical equipment, organic and inorganic basic chemicals, optical and photographic equipment, etc. In columns (9) to (12), past capital investments is calculated as average machinery and plant investments over 2005-07 reported in CT600 (as coverage of capital expenditure in FAME is limited). Robust standard errors are in brackets.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A11: Heterogeneous Effect of R&D Tax Relief by Industry's External Finance Dependence

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	**Patent count (2009-13 avg. or annual over 2006-13)**					
Industry measure:	Rajan-Zingales		Cash flow/K		Current assets/K	
Specification:	RD	Diff-in-Disc	RD	Diff-in-Disc	RD	Diff-in-Disc
Below-threshold × D: High dependence	0.097***		0.093***		0.089**	
	(0.038)		(0.031)		(0.035)	
Below-threshold × D: Low dependence	0.017		0.019		0.025	
	(0.018)		(0.026)		(0.022)	
Below-threshold × Post-2008 × D: High dependence		0.092*		0.082*		0.060
		(0.047)		(0.035)		(0.037)
Below-threshold × Post-2008 × D: Low dependence		0.008		0.017		0.039
		(0.016)		(0.032)		(0.032)
Difference	0.081*	0.084*	0.074*	0.065	0.063	0.021
	(0.041)	(0.050)	(0.040)	(0.048)	(0.040)	(0.049)
Observations	5,283	42,264	5,285	42,280	5,285	42,280
Number of firms	5,283	5,283	5,285	5,285	5,285	5,285

Notes: RD Design is based on equation (1). Diff-in-Disc Design is based on equation (3). The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls in the RD Design include (i) first order polynomials of the running variable separately for each side of the threshold, and (ii) 2006-08 (pre-policy) average of patent count. Controls in the Diff-in-Disc Design include (i) first order polynomials of the running variable separately for each side of the threshold and pre- and post-policy period, and (ii) firm and year fixed effects. Rajan-Zingales (1998) index for external finance dependence (i.e., $\frac{Capex-Cash\ flow}{Capex}$), Cash flow/K, and Current assets/K are calculated at the three-digit SIC industry level using UK firm data over 2000-05. High (low) dependence sample includes firms in industries with above (below) median Rajan-Zingales index (columns (1) and (2)), below (above) median Cash flow/K measure (columns (3) and (4)), or below (above) median Current assets/K measure. Standard errors are clustered by firm.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A12: Effects of R&D Tax Relief on Non-Qualifying Expense Categories

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sample:	Full baseline sample					R&D performing firms				
Dependent variable:	**Admin exp.**	**Admin exp., excl. R&D**	**Total exp., excl. R&D**	**Capex imputed from PPE**	**Qual. M&P exp.**	**Admin exp.**	**Admin exp., excl. R&D**	**Total exp., excl. R&D**	**Capex imputed from PPE**	**Qual. M&P exp.**
Below-threshold indicator	480	280	-1,301	20	32	1,553	-344	-5,254	-311	254
	(1,179)	(1,171)	(3,558)	(230)	(40)	(4,197)	(4,138)	(11,947)	(510)	(226)
Dependent variable mean, 2006-08 average	*14,806*	*14,715*	*42,875*	*3,464*	*505*	*23,490*	*22,340*	*71,470*	*2,459*	*1,743*
Number of firms	4,441	4,441	4,569	3,061	5,575	323	323	326	318	329

Notes: RD estimates are based on a version of equation (1) without controlling for pre-policy patents. The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include first order polynomials of the running variable separately for each side of the threshold. Columns (1) to (5) employ the full baseline sample. Columns (6) to (10) consider the subsample of R&D performing firms during 2009-11 (post-policy period) in the baseline sample. Columns (1) and (6) look at total administrative expenses reported in FAME; columns (2) and (7) total administrative expenses minuses qualifying R&D expenditure; columns (3) and (8) total expenses reported in FAME minuses qualifying R&D expenditure; column (4) and (9) capital expenditure imputed from net change in balance sheet's property, plant, and equipment reported in FAME; and column (5) and (10) qualifying machinery and plant investments reported in CT600 (for capital allowance tax relief purpose). The dependent variables are averaged over the years for which data are not missing. Robust standard errors are in brackets. The units for all dependent variables are £ thousand in 2007 prices.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A13: Effects of R&D Tax Relief on Other Measures of Firm Performance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Before (pre-policy)			After (post-policy)					3yr Before	5yr After	5yr Diff.
Year:	2006	2007	2008	2009	2010	2011	2012	2013	2006-08 average	2009-11 average	5yr After - 3yr Before
Panel A. Dependent variable: Ln(Sales)											
Below-threshold indicator	-0.187	0.029	-0.102	0.212	0.404**	0.307	0.198	0.188	-0.023	0.170	0.193
	(0.170)	(0.167)	(0.162)	(0.180)	(0.187)	(0.192)	(0.204)	(0.217)	(0.157)	(0.181)	(0.123)
Number of firms	3,292	3,439	3,394	3,312	3,296	3,260	3,207	3,153	3,451	3,451	3,451
Panel B. Dependent variable: Ln(Employment)											
Below-threshold indicator	-0.012	0.102	0.079	0.104	0.258*	0.283*	0.289*	0.364**	0.022	0.240*	0.219**
	(0.126)	(0.123)	(0.131)	(0.140)	(0.148)	(0.153)	(0.156)	(0.160)	(0.125)	(0.143)	(0.095)
Number of firms	2,468	2,548	2,430	2,443	2,553	2,470	2,370	2,281	2,403	2,403	2,403
Panel C. Dependent variable: Ln(Capital)											
Below-threshold indicator	-0.013	-0.032	-0.007	-0.016	-0.004	0.015	0.070	0.125	-0.065	0.010	0.075
	(0.120)	(0.109)	(0.113)	(0.122)	(0.131)	(0.135)	(0.142)	(0.146)	(0.108)	(0.125)	(0.084)
Number of firms	3,724	3,959	3,793	3,609	3,457	3,322	3,205	3,074	3,665	3,665	3,665
Panel D. Dependent variable: Total factor productivity											
Below-threshold indicator	-0.069	0.037	0.020	0.178	0.265	0.127	0.146	0.184	0.070	0.210	0.140
	(0.171)	(0.162)	(0.152)	(0.166)	(0.173)	(0.178)	(0.191)	(0.201)	(0.157)	(0.163)	(0.113)
Number of firms	1,590	1,629	1,575	1,527	1,508	1,487	1,418	1,367	1,605	1,605	1,605

Notes: RD estimates are based on a version of equation (1) without controlling for pre-policy patents. The running variable is total assets in 2007 with a threshold of €86m. Baseline sample includes firms with total assets in 2007 within €25m of the threshold (i.e., between €61m and €111m). Controls include first order polynomials of the running variable separately for each side of the threshold and two-digit SIC industry fixed effects. (All results are qualitatively similar without these fixed effects.) **Panel A** uses sales from CT600. **Panel B** uses employment (from FAME). **Panel C** uses fixed assets (from FAME). **Panel D** uses total factor productivity from Olley-Pakes production function estimation at two-digit SIC industry level (see Appendix B.5 for details). Columns (9) and (10) condition on the "balanced" sample where we observe the outcome variable in at least one year of the pre-policy sample and one year of the post-policy sample (i.e., it is a subsample of the observations in columns (1) to (8)). Robust standard errors are in brackets.
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A14: Estimating Impacts of R&D Tax Relief Using other SME Criteria

Panel A. Using employment, assets, and sales criteria

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	**Patent count (2009-13 average)**							
Sample based on :	Employment		Emp. | Assets, Sales		Assets | Sales		Sales | Assets	
BTI: Employment	0.055*	0.054*	0.064**	0.065**				
	(0.029)	(0.029)	(0.030)	(0.030)				
BTI: Assets		0.052*		0.095***	0.080	0.088*		
		(0.031)		(0.032)	(0.060)	(0.051)		
BTI: Sales		-0.006		-0.011			0.029	0.011
		(0.025)		(0.040)			(0.034)	(0.032)
Dependent var. mean, 2006-08 avg.	*0.142*	*0.142*	*0.106*	*0.106*	*0.180*	*0.141*	*0.084*	*0.120*
Joint F-statistics (p-value)		0.18		0.01				
Sample criterion	Emp.	Emp.	Emp.	Emp.	Assets	Assets	Sales	Sales
Sample bandwidth	250	250	250	250	€25m	€35m	€40m	€50m
Additional condition			A. $\leq$ €86m | S. $\leq$ €100m		Sales > €100m		Assets > €86m	
Number of firms	5,764	5,764	4,824	4,824	1,059	1,521	1,557	1,971

Panel B. Combining employment, assets, and sales criteria

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	**Patent count (2009-13 average)**							
Sample based on :	Emp. AND Assets		Emp. AND Assets AND Sales				Emp. OR Assets OR Sales	
BTI: Employment	0.146**		0.247**		0.249**		0.021	
	(0.061)		(0.101)		(0.103)		(0.017)	
BTI: Assets	0.102		0.190				0.035**	
	(0.067)		(0.119)				(0.015)	
BTI: Emp. AND Assets		0.188***		0.328***				0.033**
		(0.066)		(0.117)				(0.014)
BTI: Sales			0.088	0.099			0.004	0.005
			(0.114)	(0.115)			(0.013)	(0.013)
BTI: Assets OR Sales					0.231			
					(0.176)			
BTI: Emp. AND (Assets OR Sales)						0.284**		
						(0.125)		
Dependent var. mean, 2006-08 avg.	*0.188*	*0.188*	*0.234*	*0.234*	*0.234*	*0.234*	*0.095*	*0.095*
Joint F-statistics (p-value)	0.02		0.06	0.02	0.04		0.08	0.06
Number of firms	1,395	1,395	793	793	793	793	11,487	11,487

Notes: RD Design is based on variations of equation (1). Controls include (i) first order polynomials of the running variable(s) separately for each side of the threshold, and (ii) 2006-08 (pre-policy) average of patent count. **Panel A:** The main explanatory variable is whether the firm's running variable is below the corresponding SME threshold. The running variable in columns (1) and (3) is employment in 2007 with a threshold of 499; in columns (5) and (6) total assets in 2007 with a threshold of €86m; in columns (7) and (8) sales in 2007 with a threshold of €100m. Columns (2) and (4) include all three. **Panel B:** In columns (3), (4), and (8), "BTI: Employment AND Assets" is a binary indicator of whether the firm's 2007 employment and 2007 assets are below the respective SME threshold. Its running variable polynomial control is the full interaction between 2007 employment and 2007 assets, both separately on each side of the threshold. In column (5), "BTI: Assets OR Sales" is a binary indicator of whether the firm's 2007 assets or 2007 sales is below the respective SME threshold. Its running variable polynomial control is the full interaction between 2007 assets and 2007 sales, both separately on each side of the threshold. In column (6), "BTI: Employment AND (Assets OR Sales)" is a binary indicator of whether (i) the firm's 2007 employment is below or at 499, and (ii) the firm's 2007 assets or 2007 sales is below the respective SME threshold. Its running variable polynomial control is the full interaction between 2007 employment, 2007 assets, and 2007 sales, all separately on each side of the threshold. Reported joint F-statistics are for all below-threshold indicators included in the regression. Robust standard errors are in brackets.

*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A15: Spillovers on Technologically Connected Firms Using Alternative Approach

	(1)	(2)	(3)	(4)	(5)	(6)
Specification:	First stage		Reduced form		IV	
Dependent variable:	**spilltechR**, **09-11 avg.**	**R&D exp., 09-11 avg.**	**Patent fam., 09-13 avg.**	**R&D exp., 09-11 avg.**	**Patent fam., 09-13 avg.**	**Patent fam., 09-13 avg.**
spilltechE (sum tech. proximity × indicator)	11.18***	0.053	0.174***			
	(2.20)	(0.089)	(0.074)			
Below-threshold indicator	0.40	0.156***	0.070**	0.154**	0.063*	
	(1.28)	(0.060)	(0.029)	(0.060)	(0.037)	
spilltechR (sum tech. proximity × R&D exp.)				0.005	0.016*	0.014
				(0.008)	(0.008)	(0.011)
R&D expenditure, 2009-11 average						0.412
						(1.959)
Dependent variable mean, 2006-08 average	*25.02*	*0.070*	*0.061*	*0.070*	*0.061*	*0.061*
Number of firms	8,818	8,818	8,818	8,818	8,818	8,818

Notes: Alternative approach to estimate spillovers is specified in equation (D6). Each observation is a spillover-receiving firm j with total assets in 2007 between €51m and €121m. Controls include (i) second order polynomials of firm j's total assets in 2007, separately for each side of the assets threshold of €86m; (ii) $F_j(Z^{2007}) = \Sigma_{i,i\neq j}\omega_{ij}f(z_i^{2007})$ where $f(z_i^{2007})$'s are second order polynomials of spillover-generating firm i's total assets in 2007, also separately for each side of the assets threshold; and (iii) $techconnect_j = \Sigma_{i,i\neq j}\omega_{ij}$, which measures firm j's level of connectivity in technology space. In column (6), the instrument variable for *spilloverR* is *spilloverE* and the instrument for own R&D expenditure is own below-assets-threshold indicator. Standard errors in brackets are corrected using 1,000 bootstrap replications over firms. (See Appendix D.6 for further details.)
*** denotes statistical significance at 1% level, ** 5% level, * 10% level.

Table A16: Tax-Price Elasticities of R&D and Patents Using Different Approaches

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	SME status	**R&D expenditure**				**Patent count**				**R&D user cost**	**Elasticity**	
	Fuzziness estimate	Discontinuity estimate	Adjusted discontinuity estimate	Pre-policy baseline mean	R&D difference	Discontinuity estimate	Adjusted discontinuity estimate	Pre-policy baseline mean	Patent difference	Tax-adjusted user cost difference	R&D (wrt. R&D cost)	Patent (wrt. R&D cost)
(1) **Baseline**	**0.353**	**63.4**	**179.5**	**74.0**	**1.096**	**0.052**	**0.147**	**0.066**	**1.055**	**0.269**	**4.076**	**3.921**
(2) In-lab patent estimate	0.353	63.4	179.5	74.0	1.096	0.049	0.140	0.064	1.046	0.269	4.076	3.889
(3) Diff-in-Disc estimate	0.353	60.4	171.1	74.0	1.073	0.045	0.127	0.066	0.983	0.269	3.989	3.653
(4) Diff-in-Diff estimate	0.353	11.1	31.4	74.0	0.350	0.026	0.074	0.066	0.716	0.269	1.303	2.663
(5) Log difference elasticity	0.353	63.4	179.5	74.0	1.231	0.052	0.147	0.066	1.173	0.271	4.544	4.329
(6) SME status over 2009-11	0.248	63.4	255.6	74.0	1.267	0.052	0.210	0.066	1.227	0.269	4.709	4.563
(7) SME status over 2008-09	0.464	63.4	136.6	74.0	0.960	0.052	0.112	0.066	0.918	0.269	3.569	3.414
(8) Pre-policy mean over 2006-07	0.353	63.4	179.5	77.6	1.073	0.045	0.127	0.067	0.975	0.269	3.987	3.625
(9) R&D performing firms	0.353	729	2,065	1,148	0.947	0.416	1.178	0.680	0.928	0.269	3.521	3.452
(10) 2007 assets ∈ [€51m-€121m]	0.345	58.8	170.4	69.8	1.099	0.047	0.136	0.059	1.072	0.269	4.087	3.984
(11) Small profits tax rate	0.353	63.4	179.5	74.0	1.096	0.052	0.147	0.066	1.055	0.228	4.808	4.626
(12) Tax deduction only	0.353	63.4	179.5	74.0	1.096	0.052	0.147	0.066	1.055	0.248	4.420	4.253
(13) Payable tax credit only	0.353	63.4	179.5	74.0	1.096	0.052	0.147	0.066	1.055	0.279	3.929	3.781

Notes: Baseline elasticity calculations summarized in row (1) are explained in detail in subsection 5.2. Row (2) replicates row (1) using estimates from the in-lab sample. Rows (3) and (4) use Diff-in-Disc and Diff-in-Diff estimates instead of RD estimates to derive the policy's effects. Row (5) reports log elasticities instead of arc elasticities. Rows (6) and (7) use alternative estimates for how "sharp" the below-assets-threshold indicator is as an instrument for SME status, based on SME status over 2009-11 or 2008-09. Row (8) uses average R&D and patents over 2006-07 as the pre-policy baseline means. Row (9) uses estimates from subsample of R&D performing firms. Row (10) uses larger baseline sample of firms with 2007 total assets between €51m and €121m. Row (11) applies the small profits corporate tax rate in calculations of tax-adjusted user costs. Rows (12) and (13) consider only tax deduction or payable tax credit in deriving the difference in tax-adjusted user costs between the two schemes. (See Appendices E.3 and E.4 for further details.)

Table A17: Value for Money Analysis of R&D Tax Relief Scheme

Year	(1) 2006	(2) 2007	(3) 2008	(4) 2009	(5) 2010	(6) 2011	(7) 2006-11 average
Panel A. Policy parameters							
(1) SME enhancement rate e_{SME}	50%	50%	67%	75%	75%	100%	
(2) SME payable credit rate c_{SME}	16%	16%	15%	14%	14%	14%	
(3) SME effective corporate tax rate τ_{SME}	19%	19%	21%	21%	21%	20%	
(4) LCO enhancement rate e_{LCO}	25%	25%	30%	30%	30%	30%	
(5) LCO effective corporate tax rate τ_{LCO}	30%	30%	28%	28%	28%	26%	
Panel B. SME tax deduction scheme							
(1) Tax-adjusted user cost of R&D ρ	0.177	0.177	0.165	0.160	0.160	0.150	
(2) Value for money ratio μ	4.20	4.20	4.00	3.90	3.90	3.64	3.88
(3) Exchequer costs Δ_{EC} (£m)	50	60	80	130	160	210	115
(4) Additional R&D Δ_R (£m)	210	252	320	507	624	764	446
Panel C. SME payable tax credit scheme							
(1) Tax-adjusted user cost of R&D ρ	0.152	0.152	0.151	0.151	0.151	0.150	
(2) Value for money ratio μ	2.94	2.94	2.93	2.93	2.93	2.91	2.93
(3) Exchequer costs Δ_{EC} (£m)	150	180	190	190	190	220	187
(4) Additional R&D Δ_R (£m)	441	529	556	556	556	640	546
Panel D. Large company deduction scheme							
(1) Tax-adjusted user cost of R&D ρ	0.179	0.179	0.177	0.177	0.177	0.179	
(2) Value for money ratio μ	1.96	1.96	1.90	1.90	1.90	1.85	1.91
(3) Exchequer costs Δ_{EC} (£m)	480	550	730	670	750	780	660
(4) Additional R&D Δ_R (£m)	940	1,077	1,387	1,273	1,425	1,445	1,258
Panel E. Aggregates							
(1) Total Exchequer costs Δ_{EC} (£m)	680	790	1,000	990	1,100	1,210	962
(2) Total additional R&D Δ_R (£m)	1,591	1,858	2,263	2,336	2,604	2,849	2,250
(3) Value for money ratio $\mu = \Delta_R/\Delta_{EC}$	2.34	2.35	2.26	2.36	2.37	2.35	2.34
(4) Total qualifying R&D (£m)	7,670	8,880	10,800	9,730	10,870	11,840	9,965
(5) Fall in qualifying R&D without policy	21%	21%	21%	24%	24%	24%	23%
(6) Fall in BERD without policy	11%	12%	14%	15%	16%	16%	14%

Notes: Tax-adjusted user cost of R&D and value for money ratio are calculated using the formulae as described in Appendix F using the above policy parameters. In addition, real interest rate is 5% and depreciation rate is 15%. Tax-adjusted user cost of R&D without any tax relief is calculated to be 0.200. Tax-price elasticity of R&D among SMEs is -4.0 as estimated in subsection 5.2. Tax-price elasticity of R&D among large companies is -1.4 (i.e., the lower-bound elasticity estimate). Exchequer costs (Panels B to D) and total qualifying R&D (Panel E) comes from HMRC national statistics. In Panels B to D, additional R&D is calculated as value for money ratios times Exchequer costs (i.e., $\Delta_R = \mu \times \Delta_{EC}$). In Panel E, total Exchequer costs and total additional R&D are the sums of the corresponding amounts in Panels B to D; value for money ratio is total Exchequer costs over total additional R&D; fall in qualifying R&D (BERD) without policy is total additional R&D over total qualifying R&D (BERD).

Table B1: CT600 and FAME Descriptive Statistics

Panel A. Full CT600 dataset

		(1) **2006**	(2) **2007**	(3) **2008**	(4) **2009**	(5) **2010**	(6) **2011**	(7) **2006-11**
Number of firms	*Firm*	1,406,696	1,487,173	1,484,311	1,504,927	1,564,871	1,646,641	2,495,944
Number of firms claiming R&D relief	*Firm*	6,431	7,429	8,334	9,144	10,150	12,003	20,730
SME Scheme								
Number of firms claiming	*Firm*	5,153	5,855	6,570	7,354	8,238	9,921	20,205
Average qualifying R&D expenditure	*£K*	257.8	268.9	266.7	244.9	263.8	258.5	1,569.7
Average estimated Exchequer costs	*£K*	39.4	42.2	41.0	44.1	43.1	43.5	169.6
Large Company Scheme								
Number of firms claiming	*Firm*	1,290	1,592	1,776	1,795	1,923	2,092	4,048
Average qualifying R&D expenditure	*£K*	4,926.9	4,616.8	5,121.0	4,435.3	4,508.2	4,357.4	12,580.7
Average estimated Exchequer costs	*£K*	371.1	346.6	412.1	376.4	382.3	357.9	1,030.9
SME subcontractors								
Number of firms claiming	*Firm*	399	443	522	610	720	715	2,100
Average qualifying R&D expenditure	*£K*	630.1	465.6	406.3	504.6	658.9	928.2	1,007.5
Average estimated Exchequer costs	*£K*	47.4	48.0	43.0	42.6	46.8	56.8	315.6
Patenting								
Number of firms having patents	*Firm*	3,093	3,085	2,965	2,806	2,682	2,662	9,420
Average number of patent families	*Patent*	2.68	2.77	2.72	2.63	2.66	2.64	4.93

Panel B. Full FAME dataset

	Unit	(1) **2006**	(2) **2007**	(3) **2008**	(4) **2009**	(5) **2010**	(6) **2011**	(7) **2006-11**
Number of firms	*Firm*	1,780,531	1,858,209	1,870,089	1,898,721	1,973,722	2,073,930	3,140,060
Variable coverage								
Number of firms with total assets	*Firm*	1,732,169	1,807,743	1,818,448	1,843,896	1,914,848	2,015,058	3,012,397
Total assets coverage	*%*	97.3%	97.3%	97.2%	97.1%	97.0%	97.2%	95.9%
Number of firms with sales	*Firm*	352,680	319,726	275,938	274,768	263,394	227,463	626,025
Sales coverage	*%*	19.8%	17.2%	14.8%	14.5%	13.3%	11.0%	19.9%
Number of firms with employment	*Firm*	95,615	93,855	91,375	94,332	98,426	97,814	164,849
Employment coverage	*%*	5.4%	5.1%	4.9%	5.0%	5.0%	4.7%	5.2%

Panel C. CT600 and FAME matching

		(1) **2006**	(2) **2007**	(3) **2008**	(4) **2009**	(5) **2010**	(6) **2011**	(7) **2006-11**
Number of CT600 firms that appear in FAME over 2006-11	*Firm*	1,353,844	1,427,132	1,442,619	1,468,000	1,529,012	1,598,012	2,358,948
As share of CT600 firms	*Firm*	96.2%	96.0%	97.2%	97.5%	97.7%	97.0%	94.5%
Out of which								
Number of firms claiming tax relief	*Firm*	6,411	7,409	8,298	9,105	10,108	11,937	20,627
As share of CT600 R&D firms	*%*	99.7%	99.7%	99.6%	99.6%	99.6%	99.5%	99.5%
Number of firms having patents	*Firm*	352,680	319,726	275,938	274,768	263,394	227,463	626,025
As share of CT600 patenting firms	*%*	99.5%	99.4%	99.5%	99.4%	99.4%	98.9%	99.5%

Notes: Average qualifying R&D expenditure and estimated Exchequer costs are computed for firms with R&D tax relief claims in the corresponding year or period. Average patents are computed for firms with corresponding patent applications in corresponding year or period.