Do tax incentives for research increase firm innovation?

A RDD (Regression Discontinuity Design) for R&D

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Outline

• Motivation & institutional background

• Data & Empirical Strategy

• Baseline Results: R&D and patenting

• Tax-price elasticities & policy implications

• Extensions – heterogeneity; other performance outcomes; spillovers
Motivation

• UK’s productivity low by international standards
  – Despite some improvement pre-crisis, UK’s productivity level still lagged behind its peers
  – And things have deteriorated post-2008
UK has lower productivity than its peers

GDP per hour worked, G7 countries (UK=100), 2014

Notes: Current price GDP per hour worked PPP adjusted. “Average” is G7 countries excluding the UK
Motivation

• What to do? Growth theory suggests *innovation* key to productivity growth, and that government can influence via R&D subsidies
UK levels of R&D intensity unimpressive

General Expenditure on R&D (GERD) over GDP ratio, 2010

Source: OECD (2013)
Business R&D/GDP 1981-2014. UK falling since 1980s, but stabilized after early 2000s (when R&D tax credit introduced)

Source: OEC MSTI downloaded Feb 1st 2015
General motivation

• Lots of evidence on impact of tax incentives on **R&D spend**: (Becker, 2015; OECD, 2012 surveys: +ve effect). **But:**
  – Difficult to establish causality
  – Little evidence of impacts on **R&D outputs** (innovation). Important because relabelling issue, etc.

• **This paper:**
  – Evaluate impact of current UK R&D Tax Relief Scheme (in 2013 HMRC estimate cost £1.4bn) on firm R&D & patenting.
  – Exploit discontinuity in generosity of R&D relief at new (lower) eligibility thresholds for SMEs in 2008.
  – SME Eligibility determined by pre-2008 financials so can implement a fuzzy Regression Discontinuity Design (RDD)
Summary

• Use population tax administrative data & firm accounts.
• 2008 Policy change induced treated firms in 2009-11 to
  – Increase R&D by \( \sim £75k \) p.a. (\( \sim \) double baseline R&D)
  – File \( \sim 0.04 \) additional patents p.a. (\( \sim 60\% \) up on baseline)
• Implied elasticity of R&D to tax-adjusted user cost = \(-2.6\)
  – Bigger elasticity than conventional wisdom (elasticity of 1 to 2 typical), but our treatment group is SMEs where credit constraints more are likely (Arrow, 1962)
• R&D tax policy as a whole: (i) £1.7 extra R&D for £1 of taxpayer money; (ii) Aggregate R&D \( \sim 16\% \) higher
• We also find evidence for spillovers, suggesting policy passes cost-benefit test
Some related literature


- **Impact of R&D subsidies**: Bronzini & Iachini (2014); Einiö (2014); Jacob & Lefgren (2010); Wallsten (2000); Takalo et al., (2013); Howell (2015)

- **Returns to R&D**: Bloom, Schankerman & Van Reenen (2013); Hall et al. (2005, 2013); Griffith et al. (2004); Doraszelski & Jaumandreu (2013)

- **Tax & investment**: Hassett & Hubbard (2002); Hall & Jorgenson (1967)

- **General determinants of innovation**: Hall & Rosenberg survey (2010); *Trade*: Grossman & Helpman (1991); Bloom et al. (2015); *Competition*: Blundell et al. (1999); Aghion et al. (2005)
UK R&D Tax Relief Scheme

• Current R&D always treated as expense (rather than capitalized as intangible asset)
• Additional relief introduced in 2000 then gradually expanded
• Reduces chargeable profits by proportion of a firm’s qualified R&D (“enhancement”)
• Includes Small & Medium Sized Enterprises (SME) & Large Company (LCO) component
  – SME gets larger additional deduction & can get payable tax credits (direct government cash) when no corporation tax liability
  – SME eligibility based on assets, turnover & employment
UK R&D Tax Relief Scheme – major changes

- In 2008, UK doubled size limits for SME eligibility, only for the R&D Tax Relief scheme (no other policies at new thresholds)
  - **2007**: Jobs < 250 & (Assets ≤ €43m OR Turnover ≤ €50m)
  - **2008**: Jobs < 500 & (Assets ≤ €86m OR Turnover ≤ €100m)
  - Must meet SME criteria for 2 consecutive years to qualify
- After 2008 enhanced deduction of 75% of R&D for SMEs vs. 30% for large companies
- Discontinuity using 2007 data. For data reasons focus on assets (97% report in FAME), but also consider jobs (5%) & sales (15%)
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Data

- **CT600** panel Corporation tax returns March 2000 to March 2012 plus RDTC database (HMRC Datalab)
  - qualified R&D expenditure, exchequer costs, etc. 9.1m obs over 2.5m firms between 2006-11
- **BVD FAME**: Financials of all incorporated UK firms - assets, industry, location, 3.1m firms between 2006-11
- **PATSTAT**: All patents applications to 80 offices (USPTO, JPO). Patent “family”, citations, technology class, etc.
- **Match CT600 & FAME/PATSTAT** on firm identifier (CRN). 95% match (100% of R&D performing & patenting firms).
- **Baseline Sample**: 5,888 firms with 2007 total assets in +/-1 €25m around €86m threshold (range of €61m to €111m). 3,561 firms below threshold & 2,327 firms above
Regression Discontinuity Design for R&D

R&D equation for firm $i$ in year $t$

$$rd_{i,t} = \alpha_{1,t} + \beta_{FS,t}E_{i,07} + f_{1,t}(z_{i,07}) + \varepsilon_{1i,t}$$

- $E_{i,07} = I(z_{i,07} \leq \bar{z})$: dummy = 1 if firm $i$’s total assets ($z$) in 2007 is below €86m & zero otherwise
  - Total assets in 2007 as the running variable
  - Essentially, comparing companies below and above threshold

- Focus on 2009-11 as post-policy change period (as 2008 a transition year). Estimate separately for each year 2006 through 2011 (also present averages pre- & post-2008)
Regression Discontinuity Design for patents

“Reduced form” patent equation:

\[ \text{pat}_{i,t} = \alpha_{2,t} + \beta_{RF,t} E_{i,07} + f_{2,t}(z_{i,07}) + \varepsilon_{2i,t} \]

- \( \text{pat}_{i,t} \): number of patents filed in year \( t \)
- \( E_{i,07} \) as before

“Structural” patents equation:

IV regression:

\[ \text{pat}_{i,t} = \alpha_{3,t} + \gamma_{3,t} r\text{d}_{i,t} + f_{3,t}(z_{i,07}) + \varepsilon_{3i,t} \]

using \( E_{i,07} \) as an instrument for \( r\text{d}_{i,t} \)
Fig 1: No manipulation at threshold (McCrary Test)

Note: Discontinuity estimate -0.026 (0.088). We see some bunching from 2009 onward, consistent with firms responding to incentives, cf. Garicano et al. (2014).
### Table 3: Pre-treatment covariate balance

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Log turnover</th>
<th>Log fixed assets</th>
<th>Log employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>-0.08</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.12)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>SME threshold</td>
<td>€86m</td>
<td>€86m</td>
<td>€86m</td>
</tr>
<tr>
<td>Sample bandwidth</td>
<td>€61m-</td>
<td>€61m-</td>
<td>€61m-</td>
</tr>
<tr>
<td></td>
<td>€111m</td>
<td>€111m</td>
<td>€111m</td>
</tr>
<tr>
<td>Observations</td>
<td>3,650</td>
<td>3,848</td>
<td>4,771</td>
</tr>
</tbody>
</table>

**Notes:** RDD results: running variable is total assets in 2007; threshold is €86m; sample includes firms with total assets in 2007 in [€61m, €111m] range. RDD controls for first order polynomials of running variable separately for each side of the threshold. Robust standard errors are in brackets.
R&D before & after 2008 policy change (Baseline sample)

Annual R&D expenditure per firm (£ ’000)

Before

<table>
<thead>
<tr>
<th>Year</th>
<th>Firms with total assets below threshold</th>
<th>Firms with total assets above threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-08</td>
<td>58</td>
<td>36</td>
</tr>
<tr>
<td>2009-11</td>
<td>94</td>
<td>22</td>
</tr>
</tbody>
</table>

Before & after 2008 policy change (Baseline sample)

- Firms with total assets below threshold
- Firms with total assets above threshold
R&D before & after 2008 policy change (Baseline sample)

Annual R&D expenditure per firm (£ ’000)

Before

- Firms with total assets below threshold: 58
- Firms with total assets above threshold: 94

After

- Firms with total assets below threshold: 72
- Firms with total assets above threshold: 94

2006-08

2009-11

Firms with total assets below threshold
Firms with total assets above threshold
Outline

• Motivation & institutional background

• Data & Empirical Strategy

• **Baseline Results: R&D and patenting**
  
  • Tax-price elasticities & policy implications
  
  • Extensions – heterogeneity; other performance outcomes; spillovers
Figure 2: Discontinuity in R&D 2009-11 average

Notes: 5,888 observations. Assets from FAME based on SME assets threshold (€86m) definition. R&D is from CT600. Sample of firms with €25m above & below the threshold.
### Table 2: Discontinuity in R&D spending

<table>
<thead>
<tr>
<th>Year</th>
<th>Before (pre-policy)</th>
<th>After (post-policy)</th>
<th>Before</th>
<th>After</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61.5</td>
<td>96.1</td>
<td>32.0</td>
<td>120.7**</td>
<td>157.8***</td>
</tr>
</tbody>
</table>

#### Notes:
5,888 observations. ***significant at 1%, ** 5%, *10% level. RDD coefficients with robust standard errors in brackets. Running variable: 2007 assets; threshold is €86m; sample includes firms with 2007 between €61m and €111m. Controls are 1st order polynomials of running variable separately for each side of the threshold. Mean R&D expenditure was £72.3k between 2006-08 and £80.5 2009-11. 2007 prices.
Figure 3: Discontinuity on patenting 2009-11 average

Notes: 5,888 observations. Assets from FAME based on SME assets threshold (€86m) definition. R&D is from CT600. Sample of firms with €25m above & below the threshold. Outcome is average number of patents filed between 2009 and 2011.
Table 4: Discontinuity in patenting

<table>
<thead>
<tr>
<th>Year</th>
<th>Before (pre-policy)</th>
<th>After (post-policy)</th>
<th>Before Average</th>
<th>After Average</th>
<th>Diff Before - After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>0.026 (0.028)</td>
<td>0.043 (0.030)</td>
<td>0.045 (0.032)</td>
<td>0.081*** (0.029)</td>
<td>0.066** (0.027)</td>
</tr>
<tr>
<td>All patent count</td>
<td>0.038 (0.027)</td>
<td>0.073*** (0.026)</td>
<td>0.035* (0.020)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 5,888 observations. RDD coefficients with robust standard errors in brackets. Running variable: 2007 assets; threshold is €86m; sample includes firms with 2007 between €61m and €111m. Controls are 1st order polynomials of running variable separately for each side of the threshold. Mean patent count was 0.060 2006-08 and 0.052 between 2009-11.
Table 5: No evidence that additional patents are of lower quality

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Baseline</th>
<th>EPO patents</th>
<th>UK patents</th>
<th>Family size</th>
<th>Chemical/pharma patents</th>
<th>Non-chemical/pharma patents</th>
<th>EPO patent citations</th>
<th>UK patent citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>0.073***</td>
<td>0.037***</td>
<td>0.094***</td>
<td>0.214***</td>
<td>0.024*</td>
<td>0.050**</td>
<td>0.004**</td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td>(0.026)</td>
<td>(0.016)</td>
<td>(0.033)</td>
<td>(0.085)</td>
<td>(0.014)</td>
<td>(0.022)</td>
<td>(0.002)</td>
<td>(0.021)</td>
</tr>
<tr>
<td>Dependent variable mean over 2006-08</td>
<td>0.060</td>
<td>0.031</td>
<td>0.077</td>
<td>0.222</td>
<td>0.015</td>
<td>0.045</td>
<td>0.013</td>
<td>0.062</td>
</tr>
</tbody>
</table>

Notes: 5,888 observations. RDD coefficients with robust standard errors in brackets. Running variable: 2007 assets; threshold is €86m; sample includes firms with 2007 between €61m and €111m. Controls are 1st order polynomials of running variable separately for each side of the threshold.
Table 6: Effects of R&D on patents (using SME eligibility as IV)

<table>
<thead>
<tr>
<th>Method</th>
<th>OLS</th>
<th>IV</th>
<th>OLS</th>
<th>IV</th>
<th>OLS</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All patent count</td>
<td></td>
<td>EPO patent count</td>
<td></td>
<td>UK patent count</td>
<td></td>
</tr>
<tr>
<td>Dependent variable (average 2009-11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualifying R&amp;D expenditure (£ million), 2009-11 average</td>
<td>0.17**</td>
<td>0.53**</td>
<td>0.09**</td>
<td>0.27*</td>
<td>0.21**</td>
<td>0.68**</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.25)</td>
<td>(0.04)</td>
<td>(0.14)</td>
<td>(0.09)</td>
<td>(0.33)</td>
</tr>
<tr>
<td>Hausman test p-value</td>
<td>0.15</td>
<td>0.32</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** IV is dummy of whether total assets in 2007 below €86m. Sample includes firms with total assets in 2007 between €61m and €111m. Controls include first order polynomials of running variable (total assets in 2007) separately for each side of the threshold. Robust standard errors in brackets.

- Patent costs firm **£1.9m** (=1/0.53) in R&D; EPO patent **£3.7m**; UK patent **£1.5m**
  - Benchmark costs per patent $1m-$5m, e.g. Hall & Zedonis (2001); Arora et al. (2008); Gurmu & Pérez-Sebastián (2008), Dernis et al (2015)
Robustness checks (Tables A3-A5)

- Placebo at different thresholds
- Higher order polynomial controls (2\textsuperscript{nd} & 3\textsuperscript{rd} orders)
- Lagged dependent variable controls
- 4 digit Industry dummies, 2 digit postcodes, industry*location FEs
- Alternative bandwidths around the threshold instead of +/- €25m
- Larger weights for firms with total assets closer to the threshold (e.g. Epanechnikov & triangular kernel weights)
- Alternative winsorization thresholds (1% & 5% instead of 2.5%) or trimming outliers in R&D & patenting
- Poisson regressions
Figure A1: Placebo R&D effects from different cut-offs than actual eligibility threshold
Figure A2: Placebo Patent effects from different cut-offs than actual eligibility threshold
Robustness checks (Table A4)

- Placebo at different thresholds
- Higher order polynomial controls (2\textsuperscript{nd} & 3\textsuperscript{rd} orders)
- Lagged dependent variable controls
- 4 digit Industry dummies, 2 digit postcodes, industry*location FEs
- Alternative bandwidths instead of +/- €25m around threshold
- Larger weights for firms with total assets closer to the threshold (e.g. Epanechnikov & triangular kernel weights)
- Alternative winsorization thresholds (1\% & 5\% instead of 2.5\%) or trimming outliers in R&D & patenting
- Poisson regressions
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Implications for tax-price elasticity of R&D

Tax-price elasticity of R&D

\[ \eta \equiv \frac{\partial \ln(rd)}{\partial \ln \rho} = \frac{\ln(rd_{SME}/rd_{LCO})}{\ln(\rho_{SME}/\rho_{LCO})} \]

- \( \rho \) = Tax adjusted user cost of R&D. Different for SMEs vs. large companies (LCO)

- How much does R&D change when user cost shifts in a firm from the LCO to SME scheme?

- \( \ln(rd_{SME}) - \ln(rd_{LCO}) \): Derived from Table 2 first stage R&D equation \( = \ln(75 + 72) - \ln(72) = 0.71 \)

- \( \ln(\rho_{SME}) - \ln(\rho_{LCO}) \): Derived from designs of SME and Large Company (LCO) Schemes:
Implications for tax-price elasticity of R&D

Tax-adjusted User Cost of R&D capital (e.g. Eisner et al, 1986)

\[ \rho = \left( \frac{1 - A_f}{1 - \tau_f} \right) (r + \delta) \]

- \( A_f \) = value of R&D tax relief in scheme \( f \); \( \tau_f \) = corporate tax rate; \( r \) = real interest rate; \( \delta \) = depreciation rate.

  - **Deduction case**: \( A = \tau (1 + e) \); enhancement rate \( e \) higher under the SME Scheme

  - **Payable credit case**: \( A = c (1 + e) \) non-zero payable credit rate \( c \) applicable only under SME Scheme (\( \tau = 0 \) in this case)

- Putting these together gives \( \ln(\rho_{SME}) - \ln(\rho_{LCO}) = -0.271 \)
Implications for tax-price elasticity of R&D

• Tax-price elasticity of R&D ≈ -2.63 ( = 0.71/0.27)
  – Bigger elasticity than many other studies (1 to 2 typical)
  – But other studies effectively focus on large firms (e.g. Compustat or macro data dominated by large firms because R&D concentrated)
  – Our policy experiment on medium & smaller firms, for which credit constraints likely (e.g. Arrow, 1962)
### Table 7: Policy Effect on R&D greater for young firms, (more likely to be credit constrained)

<table>
<thead>
<tr>
<th>Year</th>
<th>After - Before</th>
<th>After - Before</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young (under 12 years)</td>
<td>Old (over 12 years)</td>
</tr>
<tr>
<td>Sub-sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below asset threshold</td>
<td>97.9**</td>
<td>56.3</td>
</tr>
<tr>
<td></td>
<td>(42.2)</td>
<td>(59.4)</td>
</tr>
<tr>
<td>Mean R&amp;D 2006-08</td>
<td>37.9</td>
<td>107.1</td>
</tr>
<tr>
<td>% Treatment Effect</td>
<td>2.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Firms</td>
<td>2,928</td>
<td>2,955</td>
</tr>
</tbody>
</table>

**Notes:** OLS RDD, robust SE. Running variable 2007 assets, threshold €86m. Firms with total assets €25m below & above the cut-off. Controls: running variable each side of the threshold are included. Median firm age is 12 years. “% Treatment effect” is the ratio of treatment effect to average 2006-08 R&D statistically different at the 10% (implied tax-elasticities 4.7 vs. 1.6). “Profits > 0” firm had corporate tax liabilities at some point 2005 to 2007.
Is UK R&D policy worthwhile?

- Full welfare assessment requires assumptions over deadweight cost of taxation, spillovers & other GE effects
- How many £ of R&D stimulated per £ of Exchequer Cost? “Value for money” ratio
- Simulate using:
  - Empirical estimates of treatment effects: elasticity of 2.6 for SMEs & (conservatively) 1.0 for LCOs
  - Changes in user cost using parameters of the tax system for the 3 schemes (LCO, deductible SME & payable tax credit SME)
- Since we know annual Exchequer Cost in data for each scheme can calculate counterfactual R&D levels given our empirical model (Table A13)
- Averaging 2006-2011, R&D scheme generated £1.64bn p.a. of R&D for cost of £0.96bn
  - £1.7 of R&D for every £ of taxpayer money
  - R&D 16% lower without tax policy on average 2006-11
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Extensions

- Intensive/Extensive Margin
- Other measures of Firm Performance – sales, employment, capital, TFP
- High/Low tech industries
- Other ways of defining SME threshold using sales & employment
- R&D Spillovers
Table A7: Effects are driven by intensive margin not more firms starting to do R&D or patents

<table>
<thead>
<tr>
<th>Dependent variable (2009-11 average)</th>
<th>R&amp;D expenditure (£ '000)</th>
<th>All patents counts</th>
<th>UK patent counts</th>
<th>EPO patent counts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Past R&amp;D &gt; 0</td>
<td>Past all pat. &gt; 0</td>
<td>Past UK pat. &gt; 0</td>
<td>Past EPO pat. &gt; 0</td>
</tr>
<tr>
<td></td>
<td>Past R&amp;D = 0</td>
<td>Past all pat. = 0</td>
<td>Past UK pat. = 0</td>
<td>Past EPO pat. = 0</td>
</tr>
<tr>
<td>Below asset threshold dummy (in 2007)</td>
<td>2,775** 0.0</td>
<td>1.80*** 0.00</td>
<td>2.52*** 0.00</td>
<td>1.58** 0.00</td>
</tr>
<tr>
<td></td>
<td>(1,134) (7.1)</td>
<td>(0.66) (0.00)</td>
<td>(0.91) (0.01)</td>
<td>(0.61) (0.00)</td>
</tr>
<tr>
<td>Mean over 2006-08</td>
<td>1,901 0.0</td>
<td>2.08 0.00</td>
<td>2.96 0.00</td>
<td>1.60 0.00</td>
</tr>
<tr>
<td>Difference between having vs. not having R&amp;D/patents</td>
<td>2,775</td>
<td>1.80***</td>
<td>2.52***</td>
<td>1.58**</td>
</tr>
<tr>
<td></td>
<td>(1,125)</td>
<td>(0.65)</td>
<td>(0.90)</td>
<td>(0.60)</td>
</tr>
<tr>
<td>Firms</td>
<td>224 5,664</td>
<td>170 5,718</td>
<td>153 5,735</td>
<td>116 5,772</td>
</tr>
</tbody>
</table>

Note: OLS estimates based on the 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 below and above the cut-off (i.e. between €61m and €111m). Controls for first order polynomials of running variable separately for each side of the threshold are included. Robust standard errors are in brackets.
<table>
<thead>
<tr>
<th>Year</th>
<th>Before (pre-policy)</th>
<th>After (post-policy)</th>
<th>Before 2006-2008 average</th>
<th>After 2009-2011 average</th>
<th>Diff After - Before</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td>Ln(sales)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>-0.187 (0.170)</td>
<td>0.029 (0.167)</td>
<td>-0.102 (0.162)</td>
<td>0.212 (0.180)</td>
<td>0.404** (0.187)</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td>Ln(capital)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>-0.017 (0.120)</td>
<td>-0.035 (0.109)</td>
<td>-0.010 (0.113)</td>
<td>-0.020 (0.122)</td>
<td>-0.008 (0.131)</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td>Ln(employment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>-0.012 (0.126)</td>
<td>0.102 (0.123)</td>
<td>0.084 (0.131)</td>
<td>0.107 (0.140)</td>
<td>0.263* (0.147)</td>
</tr>
<tr>
<td>Observations</td>
<td>2,468</td>
<td>2,550</td>
<td>2,431</td>
<td>2,445</td>
<td>2,551</td>
</tr>
<tr>
<td>Dependent variable</td>
<td></td>
<td></td>
<td>Total factor productivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below new SME asset threshold in 2007</td>
<td>-0.328 (0.255)</td>
<td>-0.106 (0.237)</td>
<td>-0.199 (0.235)</td>
<td>-0.0321 (0.245)</td>
<td>0.123 (0.258)</td>
</tr>
<tr>
<td>Observations</td>
<td>2,025</td>
<td>2,091</td>
<td>2,017</td>
<td>1,952</td>
<td>1,913</td>
</tr>
</tbody>
</table>

Note: RDD results: running variable is total assets in 2007; threshold is €86m; sample includes firms with total assets in 2007 in [€61m, €111m]. RDD controls for first order polynomials of running variable separately for each side of the threshold. Robust standard errors are in brackets.
Table A10 Using other SME criteria (sales, employment)

<table>
<thead>
<tr>
<th>SME Criteria</th>
<th>Assets</th>
<th>Assets</th>
<th>Sales</th>
<th>Sales</th>
<th>Employm</th>
<th>Employm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R&amp;D exp.</td>
<td>All patent count</td>
<td>R&amp;D exp.</td>
<td>All patent count</td>
<td>R&amp;D exp.</td>
<td>All patent count</td>
</tr>
<tr>
<td>Dependent variable (2009-2011 average)</td>
<td>(£ '000)</td>
<td>(£ '000)</td>
<td>(£ '000)</td>
<td>(£ '000)</td>
<td>(£ '000)</td>
<td>(£ '000)</td>
</tr>
<tr>
<td>Below SME threshold dummy (in 2007)</td>
<td>138.5**</td>
<td>0.073***</td>
<td>133.9**</td>
<td>0.035</td>
<td>77.2</td>
<td>0.120*</td>
</tr>
<tr>
<td></td>
<td>(55.3)</td>
<td>(0.026)</td>
<td>(66.5)</td>
<td>(0.050)</td>
<td>(114.3)</td>
<td>(0.062)</td>
</tr>
<tr>
<td>Sample</td>
<td>Total assets in [€61m, €111m]</td>
<td>Sales in [€50m, €150m]</td>
<td>Employment in [300, 700]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firms</td>
<td>5,888</td>
<td>5,888</td>
<td>7,101</td>
<td>7,101</td>
<td>4,526</td>
<td>4,526</td>
</tr>
</tbody>
</table>

Notes: OLS RDD, robust SE. Running variable are 2007 values of (i) assets (threshold €86m); (ii) sales (threshold €100m); (iii) employment (threshold 500). Running variable each side of the threshold are included.
Spillovers

- Key rationale for R&D subsidy is knowledge externality. Define:
  
  \[ SpilltechRD_{i,09-11} = \sum_{j \neq i} \omega_{ij} rd_{j,09-11} \]

- \( rd_{j,09-11} = \) average R&D 2009-11 by firm \( j \)

- \( \omega_{ij} \) is the “technological proximity” between every firm \( i \) & \( j \) in the population.

- Following Jaffe (1986) \( F_i \) is vector of % of firms \( i \)'s patents in each of the \( \sim 500 \) technology classes. Proximity is the uncentered angular correlation between vectors for any 2 firms:
  
  \[ \omega_{ij} = \frac{F_i F_j'}{(F_i F_i')^{1/2}(F_j F_j')^{1/2}}. \]
Spillovers

• Exploit exogenous increase in R&D induced by policy around SME threshold to look at impact on other firms’ innovation
• Identified because other firms differentially affected depending on their technological distance from the directly treated firms (i.e. indirect treatment effects)
• **SpilltechSME** is an IV for **SpilltechRD**:

\[
SpilltechSME_{i,09-11} = \sum_{j \neq i} \omega_{ij} E_{j,2007}
\]

• **Structural patent equation with spillovers is:**

\[
pat_{i,09-11} = \delta SpilltechRD_{i,09-11} + \theta rd_{i,09-11} + G(z_{j,07}) + f_4(z_{i,07}) + \varepsilon_{4i}
\]

\[
G(z_{j,07}) = \sum_{j \neq i} \omega_{ij} g(z_{j,07})
\]
## Table 9: Spillovers

<table>
<thead>
<tr>
<th>Specification:</th>
<th>First stage</th>
<th>Red. Form</th>
<th>IV</th>
<th>IV</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpilltechSME (Tech. Proximity * threshold)</td>
<td>35.9***</td>
<td>133.9</td>
<td>0.344**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(11.0)</td>
<td>(204.7)</td>
<td>(0.146)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E_{07}, Below threshold dummy</td>
<td>-0.5</td>
<td>180.7**</td>
<td>0.045</td>
<td>182.4**</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>(4.1)</td>
<td>(83.8)</td>
<td>(0.052)</td>
<td>(80.1)</td>
<td>(0.063)</td>
</tr>
<tr>
<td>SpilltechRD (R&amp;D of other firms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D expenditure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** 10,449 observations. Sample of firms with total assets in 2007 between €46m and €126m. SE clustered by firm in brackets. Controls include third order polynomials of 2007 assets, separately for each side of the asset threshold of €86m, and \( G(z_{j,2007}) = \sum_{j \neq i} w_{ij} g(z_{j,2007}) \). In last two columns the IV for spilltechRD is spilltechSME and IV for R&D is below-asset-threshold dummy. SpilltechRD and R&D expenditure multiplied by £1m.
Conclusion

• First evidence that R&D tax policy causes increases innovation

• Change in R&D Tax thresholds in a RDD: firms increased R&D & produced more innovations (patents)
  – Innovations were not lower value
  – Generated significant technology spillovers

• Magnitudes:
  – R&D up by ~£75k p.a. at implied tax-price elasticity of -2.6
  – Policy induced ~0.04 additional patents p.a. (60% increase)
  – £1 of taxpayer money stimulated £1.7 private R&D

• Suggests that R&D tax policies were effective in UK, especially if targeted on SMEs

• Next steps: longer-run outcomes; GE