Do tax incentives for research increase firm innovation? An RD Design for R&D

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The need to support innovation

- For advanced countries, long-run growth depends on innovation, but many market failures:
  - Public good nature of knowledge (technology spillovers)
  - Financial frictions (Arrow, 1962)
  - Empirical evidence shows social returns to R&D at least three times larger than private returns (e.g. Bloom, Shankerman & Van Reenen, 2013; Lucking et al., 2020; Jones & Summers (2022).

- One policy to tackle this market failure is to increase subsidies to R&D through the tax system

What's the problem with current evidence on R&D tax credits?

- Much evidence on impact of tax incentives on **R&D,** <u>But:</u>
  - Difficult to clearly establish causality
  - Little evidence of impacts on innovative **outputs.** Important because of "re-labelling" issue (e.g. Chen et al, 2021), etc.

What do we do?

- **This paper:** Use administrative tax data & firm accounts (near universe of private and publicly listed) in UK.
  - Evaluate impact of R&D Tax Relief Scheme on firm **R&D, patenting & jobs** (as well as sales, productivity, etc.)
  - Effects on the subsidized firm itself **and** technology **spillovers** to other firms
  - Exploit **discontinuity** in generosity of R&D tax relief at new (lower) asset eligibility thresholds for Small & Medium Enterprises (SME) in 2008.
  - SME eligibility determined by pre-2008 assets so we can implement a **Regression Discontinuity Design** (RDD)

- **An RDD for R&D!**

Summary of our findings

- For firms around the threshold, policy approximately:
  - Doubled R&D 2009-11
  - Increase (quality adjusted) patents by 68% (by 2015)
  - Patents-R&D elasticity about 0.5

Summary of our findings

- For firms around the threshold, policy approximately:
  - Doubled R&D 2009-11
  - Increase (quality adjusted) patents by 68% (by 2015)
  - Patents-R&D elasticity about 0.5
- These larger effects than elsewhere in literature
  - Treated firms are smaller than most of existing literature & more likely to be financially constrained (Arrow, 1962)
- RD Design shows positive **technology spillovers** (peer effects in small technology classes for close neighbors)
- Macro simulations suggest UK R&D would have been about 13% lower without tax credit scheme
- Implies tax is an effective innovation policy (but not only one!)

Some related literature

- **R&D tax incentives:** **OECD (2019)**, Becker et al (2015); *Cross country panel:* Corrado et al. (2015); Bloom, Griffith & Van Reenen (2002); *US states panel:* Wilson (2009); *US firms*: Eisner (1982), Hall (1993); **Rao (2016**); *Non-US firms:* Czarnitzki et al. (2011); Lokshin & Mohnen (2012); Agrawal et al. (2014); Chen, Liu, Suarez-Serrato & Xu (2017); **Guceri & Liu (2017)**

- **Impact of direct R&D subsidies:** Bronzini & Iachini (2014); Einiö (2014); Jacob & Lefgren (2010); Wallsten (2000); Takalo et al (2013); Moretti et al (2022); **Howell (2017**), Brown and Howell (2020)

- **Impact of R&D on productivity & innovation:** Griliches (1979); Hall et al. (2005, 2013); Blundell, Griffith & Windmeijer (2004); Doraszelski & Jaumandreu (2013),

- **Spillovers:** Griliches (1992); Jaffe et al (1993); Lucking et al (2020)

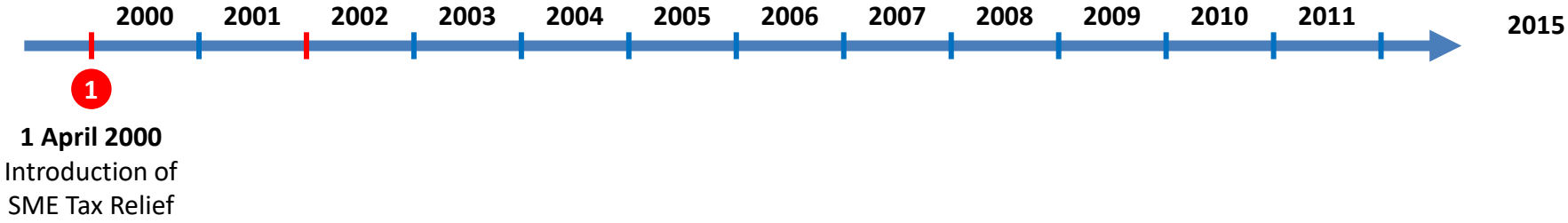
- **Tax more generally**: **Akcigit, Grigsby, Nicholas & Stantcheva (2021);** Akcigit, Baslandze and Stantcheva (2017); Moretti & Wilson (2017);

- **Models of R&D policies:** Akcigit, Hanley & Stantcheva (2018); Akcigit, Ates, & Impullitti (2018); Bell et al (2019a,b); Bloom, Williams & Van Reenen (2019)

Outline (take break before each section)

- **Institutional background**
- Data & Empirical Strategy
- Baseline Results: Patenting and R&D
- Spillovers
- Macro implications

UK R&D Tax Relief Scheme – major changes



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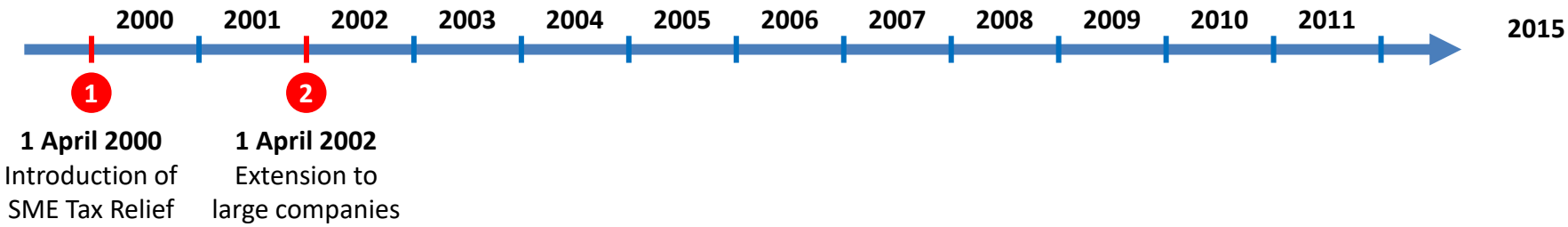

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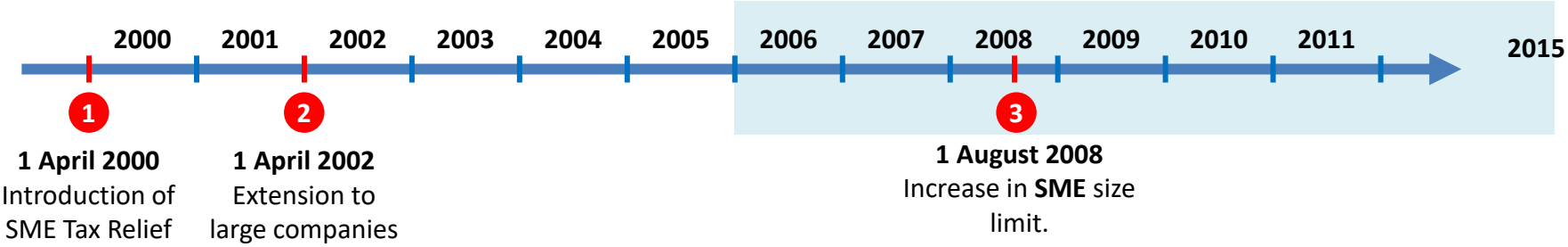

- In 2008, UK doubled size limits for SME eligibility, only for the R&D Tax Relief scheme (**no other policies at new thresholds**)
  - **2007**: Employment<250 & (**<u>Assets ≤ €43m</u>** or sales ≤ €50m)
  - **2008**: Employment<500 & (**<u>Assets ≤ €86m</u>** or sales ≤ €100m)
  - Must meet SME criteria for at 2 consecutive years to qualify
- Our discontinuity uses 2007 data.
- For data reasons focus on **assets threshold,** but also consider employment & sales (reported by fewer firms)

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Data

- **BVD FAME/ORBIS**: Financial accounts of all incorporated UK firms - assets, industry, location
- **PATSTAT**: All patents applications to 60 offices 1900-2015. Use patent “family”. Also consider quality (e.g. citations).
- **CT600** panel Corporation tax returns 2000-12 + RDTC (IRS Datalab). Qualified R&D expenditure & tax returns for 2.5m firms. 95% matched with FAME/PATSTAT (100% of R&D performing & patenting firms).
- **Baseline Sample:** 5,744 firms with 2007 total assets in +/- €25m around €86m threshold (range of €61m to €111m).
  - 3,485 firms below threshold & 2,259 above.

Estimate direct policy effect on patents

1. Regression Discontinuity Design

$$PAT_i^{Post} = \alpha + \beta^{RDD} E_i^{2007} + f\left(z_i^{2007}\right) + \mu PAT_i^{Pre} + \varepsilon_i$$

- $\mathrm{E}_i^{2007} = 1\left(z_i^{2007} \leq \bar{z}\right)$: dummy = 1 if firm i's total assets (z) in 2007 is below SME threshold of €86m & zero otherwise
  - Total assets in 2007 as the running variable
  - Essentially comparing firms just below & above threshold
- Focus on 2009-13 as post-policy period and 2006-08 as pre-policy period (as 2008 is transition year)
- **Also estimate:**
  - Analogous equation for **R&D spend** (2009-11 HMRC lab)
  - Knowledge production function with E_i^{2007} as IV for R&D exp
  - Compare to alt. Diff-In-Discontinuities & Diff-in-Diff designs

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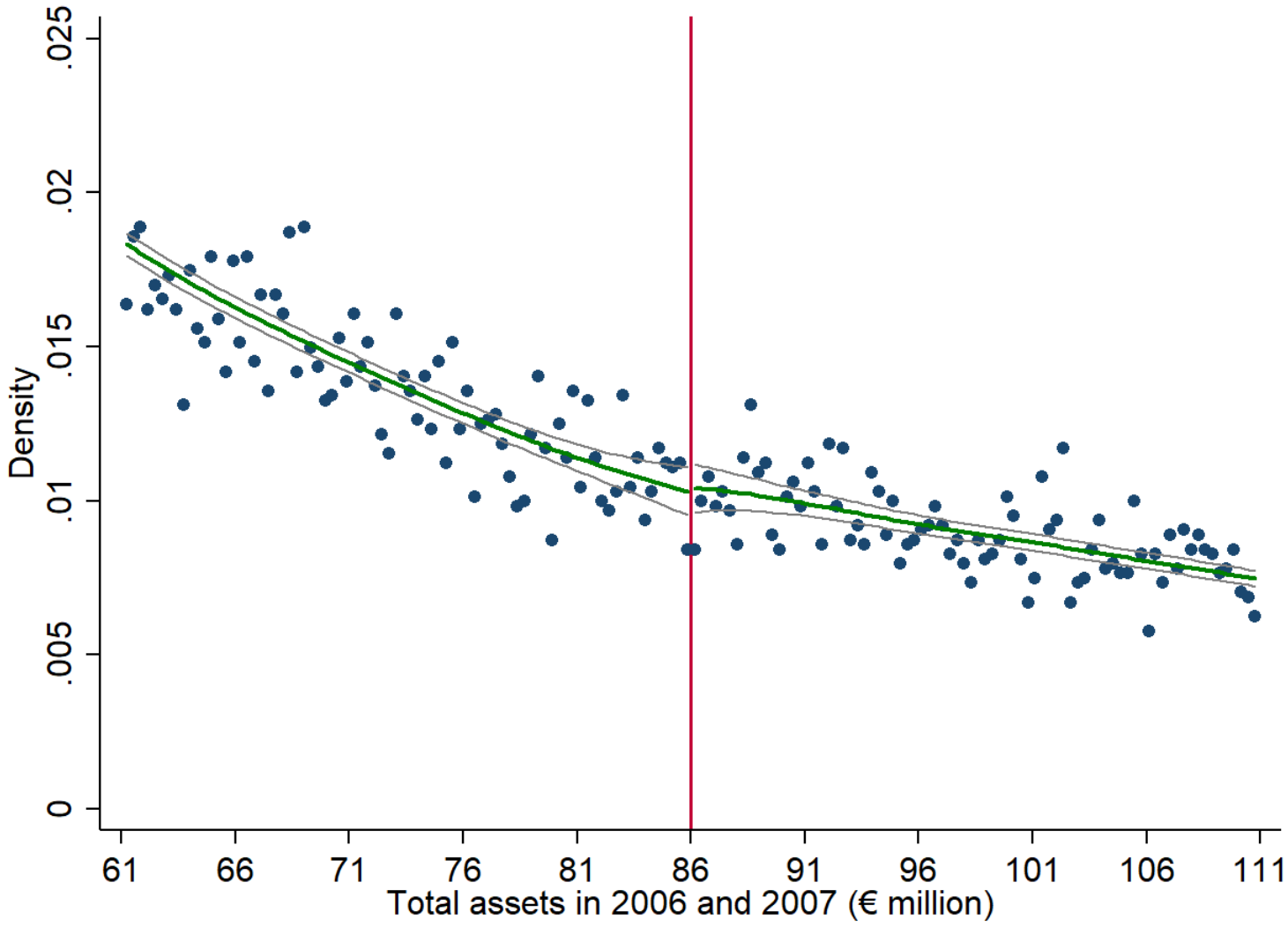
Diagnostics

- No bunching around threshold prior to policy change (Figure 1)

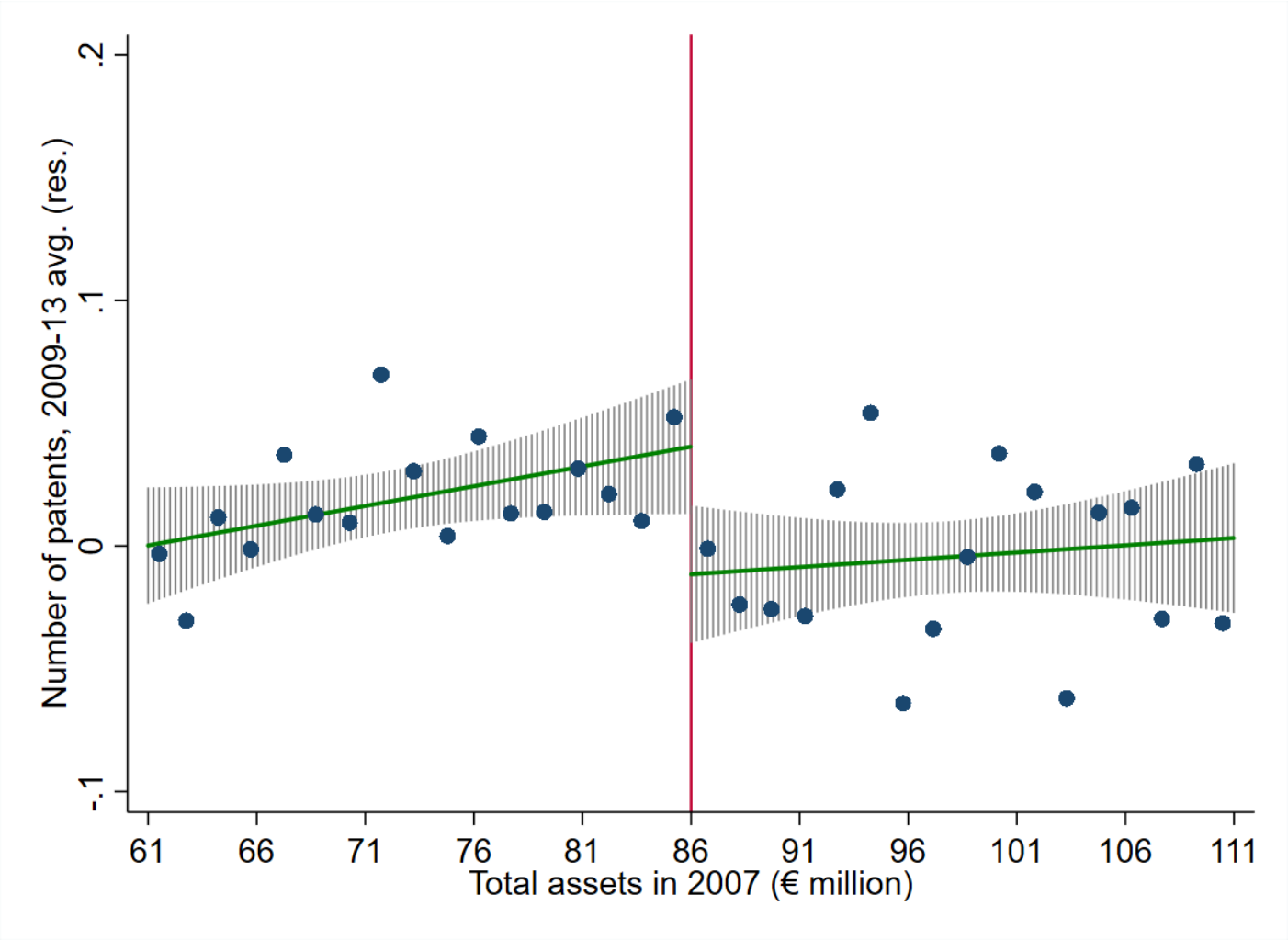
- Covariates Balanced (Table 2)

Fig 1: No manipulation at threshold (McCrary Test)



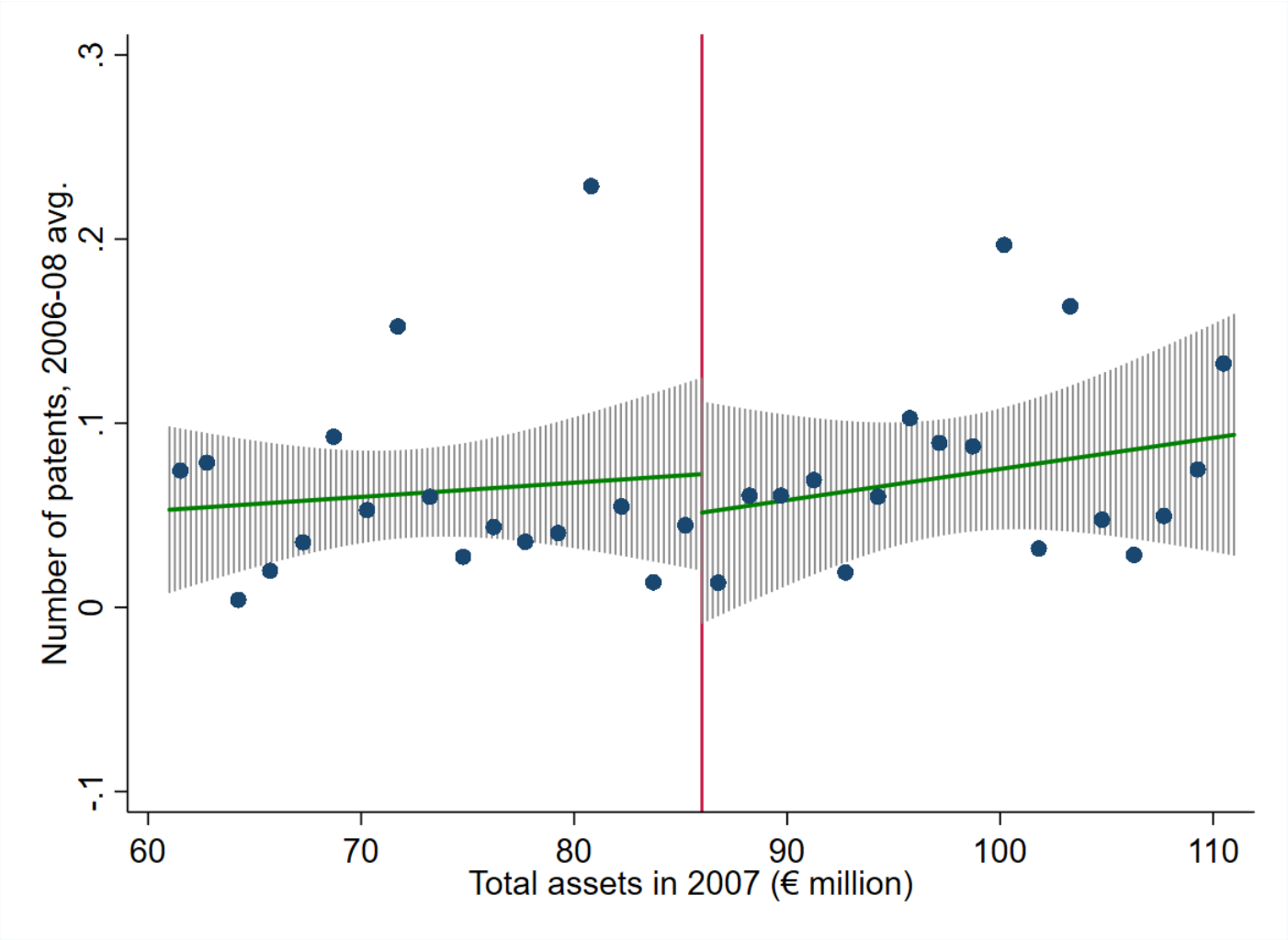
Notes: Discontinuity estimate -0.026 (0.088).

Figure 2A: Strong Patent Discontinuity post policy, 2009-13 average



Notes: 5,744 observations. Patents from PATSTAT with average pre-policy patents over 2006-08 partialled out using RD equation. Assets from FAME. Sample of firms with 2007 assets in [€61m, €111m], based on SME threshold of €86m. Average of 173 obs per €1.5m bin.

Figure 2B: No Patent Discontinuity pre-policy, 2006-08 average



Notes: 5,744 observations. Patents from PATSTAT. Assets from FAME. Sample of firms with 2007 assets in [€61m, €111m], based on SME threshold of €86m. Average of 173 obs per €1.5m bin.

Table 3: Tax policy effects on patents

Dependent variable	**Patent count**		
Specification	Regression Discontinuity		
Period	09-11 avg	09-13 avg	09-15 avg
Below-threshold indicator in 2007	0.060***	0.052***	0.048***
	(0.022)	(0.019)	(0.018)
Below-threshold x Post-2008			
Augmentation			
Observations	5,744	5,744	5,744
Number of firms	5,744	5,744	5,744

Notes: RD/Diff-in-Disc/Diff-in-Diff estimates with standard errors clustered by firm in brackets. Running variable (RV): 2007 assets; threshold: €86m; sample: firms with RV in [€61m, €111m]. Controls: (i) 1st order polynomials of RV separately for each side of threshold (RD/Diff-in-Disc); (ii) 2006-08 average of dependent variable (RD); (iii) firm & year FEs (Diff-in-Disc/Diff-in-Diff). *Dynamic:* additional lagged DV control. *With break:* additional firm size control separately for before and after. **Mean patent count was 0.066 between 2006-08 and 0.054 between 2009-15.**

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Dependent variable	**Patent count**						
Specification	Regression Discontinuity			Diff-in-Disc		Diff-in-Diff	
Period	09-11 avg	09-13 avg	09-15 avg	06-13	06-13	06-13	06-13
Below-threshold indicator in 2007	0.060***	0.052***	0.048***				
	(0.022)	(0.019)	(0.018)				
Below-threshold x Post-2008				0.045**	0.052***	0.027**	0.047**
				(0.022)	(0.019)	(0.013)	(0.022)
Augmentation					*Dynamic*		*W. break*
Observations	5,744	5,744	5,744	45,952	45,952	45,952	45,952
Number of firms	5,744	5,744	5,744	5,744	5,744	5,744	5,744

Notes: RD/Diff-in-Disc/Diff-in-Diff estimates with standard errors clustered by firm in brackets. Running variable (RV): 2007 assets; threshold: €86m; sample: firms with RV in [€61m, €111m]. Controls: (i) 1st order polynomials of RV separately for each side of threshold (RD/Diff-in-Disc); (ii) 2006-08 average of dependent variable (RD); (iii) firm & year FEs (Diff-in-Disc/Diff-in-Diff). *Dynamic:* additional lagged DV control. *With break:* additional firm size control separately for before and after. **Mean patent count was 0.066 between 2006-08 and 0.054 between 2009-15.**

Table 5: Additional patents do not appear to be of much lower quality

Dependent variable	**Quality-weighted patent count, 2009-13 average**						
Quality measure	Baseline	EPO, US, or Japan	Family size (# countries)	Granted patents	Scope top quartile	Originality top quartile	Citation top quartile
Below-threshold indicator (in 2007)	0.052***	0.037*	0.104*	0.023***	0.035**	0.039***	0.021**
	(0.019)	(0.022)	(0.054)	(0.009)	(0.012)	(0.014)	(0.010)
Dependent variable mean, 2006-08 avg	*0.066*	*0.060*	*0.199*	*0.041*	*0.042*	*0.044*	*0.046*
Normalized effect	0.79	0.62	0.52	0.55	0.84	0.88	0.44
Observations/Firms	5,744	5,744	5,744	5,744*	5,744*	5,744	5,744

Notes: RD estimates with robust standard errors in brackets. Running variable (RV): 2007 assets; threshold: €86m; sample: firms with RV in [€61m, €111m]. Controls: (i) 1st order polynomials of RV separately for each side of threshold; (ii) 2006-08 average of dependent variable. **Normalized effect** is coefficient divided by mean of dependent variable in pre-policy period 2006-08.

- Also looked at patents by different industries, e.g., pharma (very strong effect), ICT (weaker effect)

Policy also increases firm employment size (sales, capital, TFP, etc. in Table A13)

Dependent variable	Ln(Employment)										
Year	2006	2007	2008	2009	2010	2011	2012	2013	06-08 avg	09-11 avg	5yr After - Before
Below-threshold indicator (in 2007)	-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)
Observations/Firms	2,468	2,548	2,430	2,443	2,553	2,470	2,370	2,281	2,403	2,403	2,403

Notes: RD estimates with robust standard errors in brackets. Running variable (RV): 2007 assets; threshold: €86m; sample: firms with RV in [€61m, €111m]. Controls: (i) 1st order polynomials of RV separately for each side of threshold; (ii) 2006-08 average of dependent variable.

- Slow build up to growth in firm size after 5 years

Extensions

- **Effects stronger in environments where financial constraints more likely to be an issue**
  - **High vs. low (cash holdings)/capital in SIC 3 digit industry in pre-policy period (2000-05) using FAME population database, split at median**

Table 7: Policy effects greater for firms in sectors more likely to be financially constrained

Dependent variable	**Patent count**	
Specification	RD	
Period	09-13 avg	09-13 avg
Below-threshold indicator x D: Low Cash/K	0.113***	
	(0.036)	
Below-threshold indicator x D: High Cash/K	0.001	
	(0.018)	
Below threshold indicator x Cash/K measure		-0.027**
		(0.012)
Below-threshold x Post-2008 x D: Low Cash/K		
Below-threshold x Post-2008 x D: Low Cash/K		
Below-threshold x Post-2008 x Cash/K measure		
Observations	5,285	5,285
Number of firms	5,285	5,285

- Similar results among firms with 2007 assets in [€51m, €121m]
- Similar results using other measures: RZ, CF/K, CA/K (Table A11)

Robustness checks on patents (Tables A3/A4) and R&D and patent IV (Tables A5/A6)

- Alternative bandwidths for smaller/larger samples
- Placebo at different thresholds
- Could not find much evidence of relabelling (Table A12). Examine admin expenses like Chen et al (2017)
- Higher order polynomial controls (2nd & 3rd order) for RV
- SIC4 ind dummies, 2 digit zip-codes, ind*location FEs
- Larger weights for obs closer to threshold (e.g. Epanechnikov & triangular kernel)
- Winsorization/trimming (1%, 5% instead of 2.5%)
- Count data model (Poisson; Negative Binomial)
- Alternative LDV controls and pre-/post-policy periods

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- **Knowledge Spillovers**
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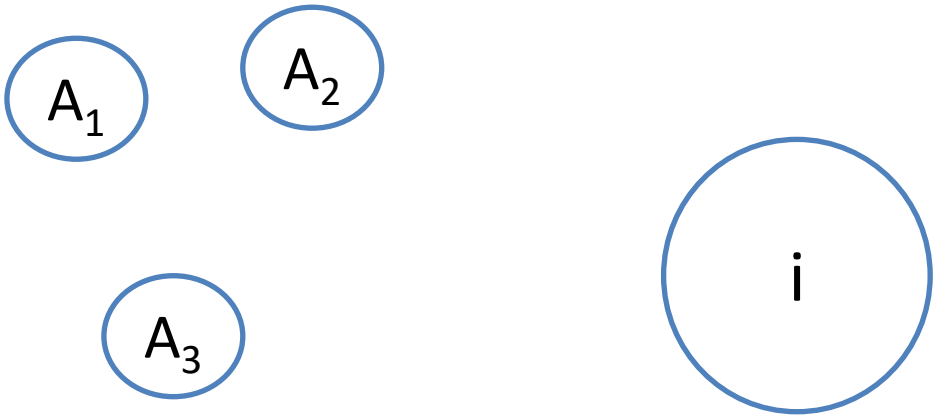
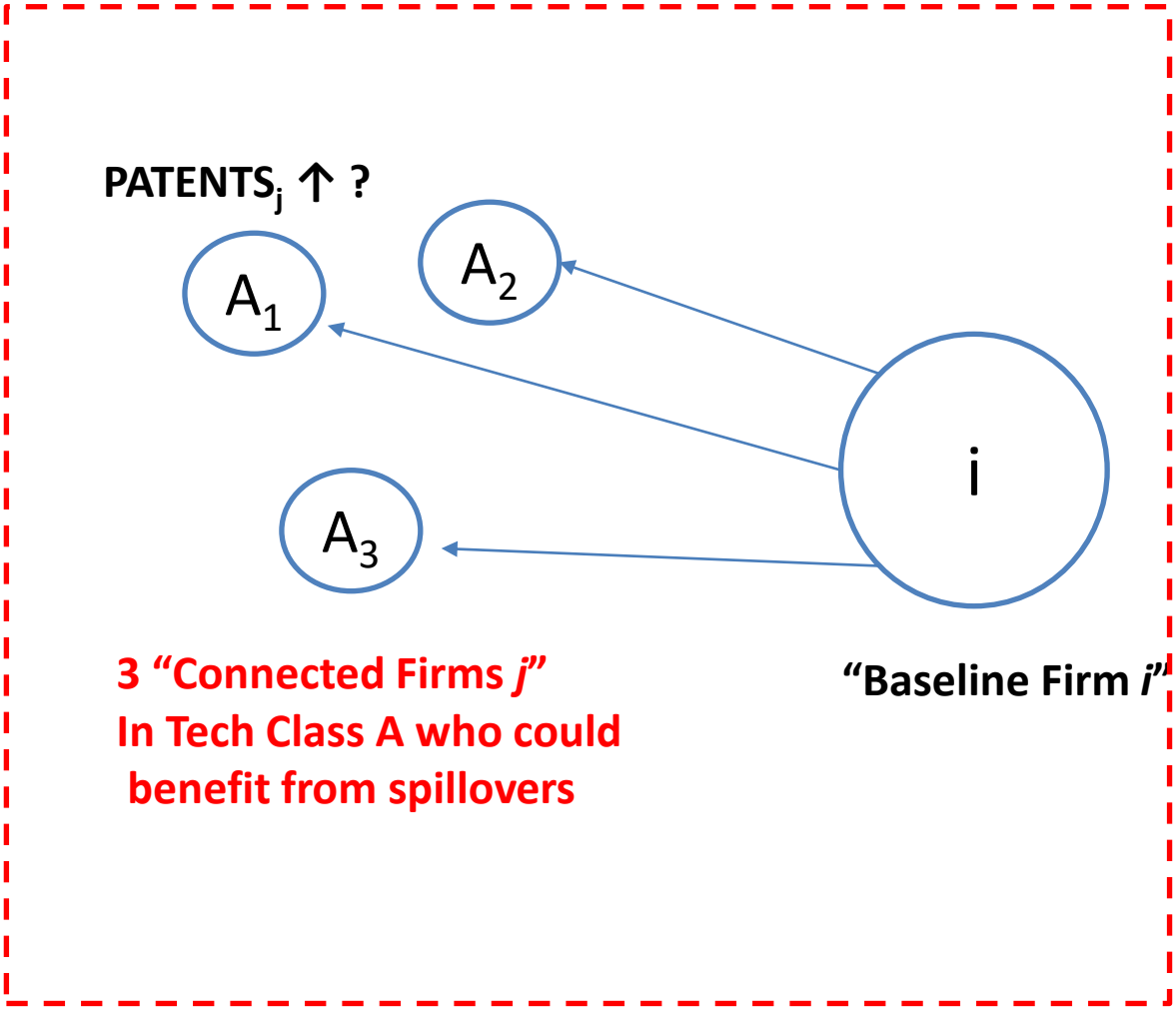
R&D tax credit boosts R&D in firm i



"Baseline Firm *i*"
(affected by R&D credit
$R\&D_i$ ↑; $PATENTS_i$ ↑)

Spillovers: R&D tax credit boosts R&D in firm i, which may also increase innovation in other firms



Technology Class A

Spillovers: RD equation

- Consider dyad of 2 firms $\{i, j\}$ If firm i is below new assets threshold, did innovation rise in "connected" firm j?
- Connection = Same 3-digit technology class (& above median Jaffe, 1989, proximity). Use firm population for this.

$$PAT_j^{Post} = \alpha + \boxed{\delta^{RDD} E_i^{2007} + f\left(z_i^{2007}\right)} + \boxed{g\left(z_j^{2007}\right) + \mu PAT_j^{Pre}} + \varepsilon_{ij}$$

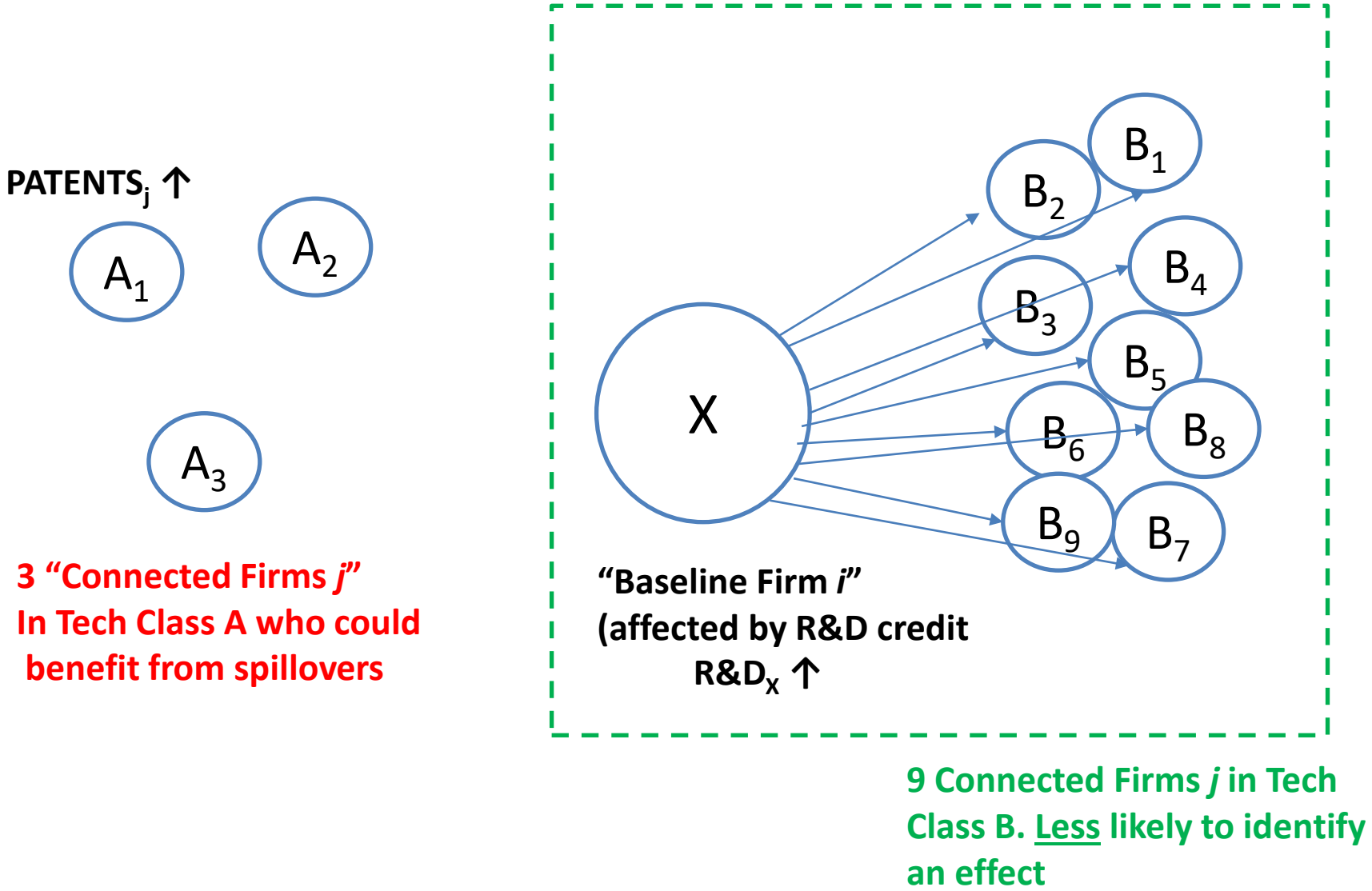
Spillover: Shifted exogenously by firm i's being near threshold

Own: firm j's size and pre-policy patents

Issues with Spillover analysis

- If large numbers of peer firms, magnitude of coefficient likely to be smaller & hard to identify.
  - For example, firm *i*'s R&D less likely to be shifting the technology frontier if there are many firms in same class

Spillovers: Firm X also in tech class B, but large number of peers in this space



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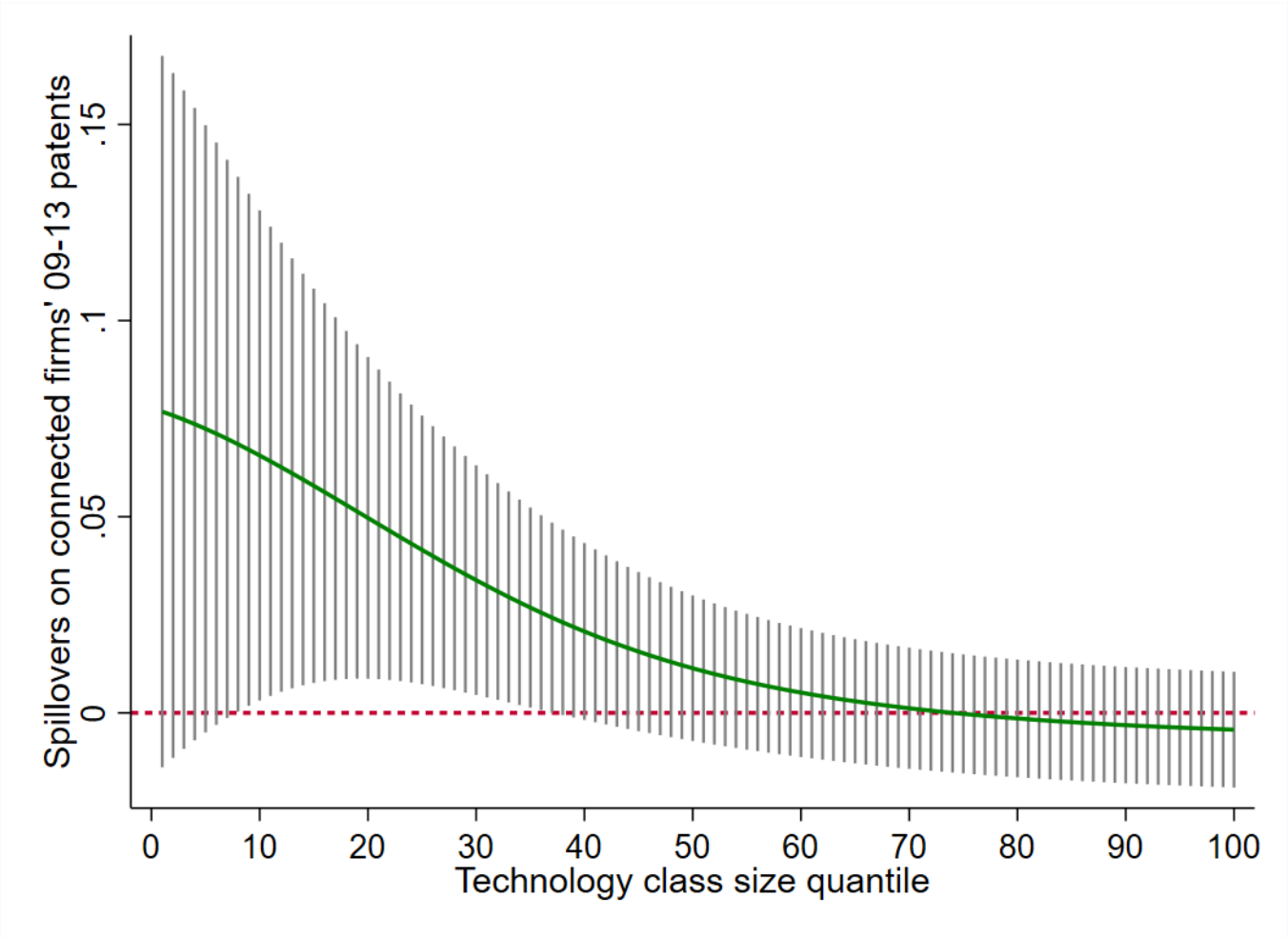
  - For example, firm *i*'s R&D less likely to be shifting the technology frontier if there are many firms in same class

- **So, we allow spillover treatment effect δ to vary with number of neighbors (size of technology class)**

Figure 5: Spillovers (δ^{RDD}) strongest in technology classes with a smaller number of firms



Notes: Spillover RD semi-parametric estimates as a function of # peers in technology class (percentiles on X-axis), using Gaussian kernel function of the X-axis variable and a bandwidth of 25%. For example, there are 200 firms in 40th percentile technology class. 90% confidence intervals based on standard errors clustered by main technology class.

Table 6: Spillovers

Dependent variable	**Firm *j*'s patent count (2009-13 avg or annual over 2006-13)**					
Specification	Regression Discontinuity				Diff-in-Disc	RD IV
Technology class size	All	All	Large	Small	Small	Small
Firm *i*'s below-threshold indicator in 2007	-0.001	0.228***	-0.004	0.085**		
	(0.009)	(0.083)	(0.009)	(0.033)		
Firm *i*'s below-threshold x technology class size		-0.243***				
		(0.088)				
Firm *i*'s below-threshold x Post-2008					0.082**	
					(0.037)	
Firm *i*'s R&D exp, 09-11 avg (£ millions)						0.222**
						(0.110)
Anderson-Rubin test						0.036
Dep var mean, 06-08 avg	*0.349*	*0.349*	*0.352*	*0.286*	*0.286*	*0.291*
Observations	156,908	156,908	150,205	6,703	53,624	2,093
Number of firms *i-j* pairs	156,908	156,908	150,205	6,703	6,703	2,093

Notes: Spillover RD/Diff-in-Disc estimates with standard errors clustered by main technology class in brackets. Running variable (RV): firm *i*'s 2007 assets; threshold: €86m; sample: treated-connected firm pairs with firm *i*'s RV in [€61m, €111m]. Controls: (i) 1st order polynomials of RV separately for each side of threshold (RD/Diff-in-Disc); (ii) 2006-08 avg of firm *j*'s patents and 2nd order polynomial of firm *j*'s 2007 assets (RD); (iii) firm *j* & year FEs (Diff-in-Disc). Small technology classes have below 200 firms. **Similar results among firms with 2007 assets in [€51m, €121m].**

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- **Macro implications**

Implications for tax-price elasticity of R&D

- Arc Elasticity of R&D wrt tax-adjusted user cost (ρ)
- $\eta_{\boldsymbol{\rho}}^{RD} \equiv \frac{\%\, Difference\ in\ RD}{\%\, Difference\ in\ \boldsymbol{\rho}} = \frac{(RD_{SME} - RD_{LCO})/\overline{RD}}{(\boldsymbol{\rho}_{SME} - \boldsymbol{\rho}_{LCO})/\overline{\boldsymbol{\rho}}}$;

$\overline{RD} = 0.5(RD_{SME} + RD_{LARGE})$; $\overline{\boldsymbol{\rho}} = 0.5(\boldsymbol{\rho}_{SME} + \boldsymbol{\rho}_{LARGE})$

- Use our RD design to get treatment effects of policy $(RD_{SME} - RD_{LARGE})$
- Calculate R&D user cost (*ρ*) using all parameters of tax system by year for 3 firm types:
  - Large Firm enhancement; SME enhancement; SME repayable tax credit

Implications for tax-price elasticity of R&D

- Need to scale reduced form coefficients ($\widehat{\beta^{RDD}}$ for both patents & R&D exp) by estimating participation/complier equation (Table A8)

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

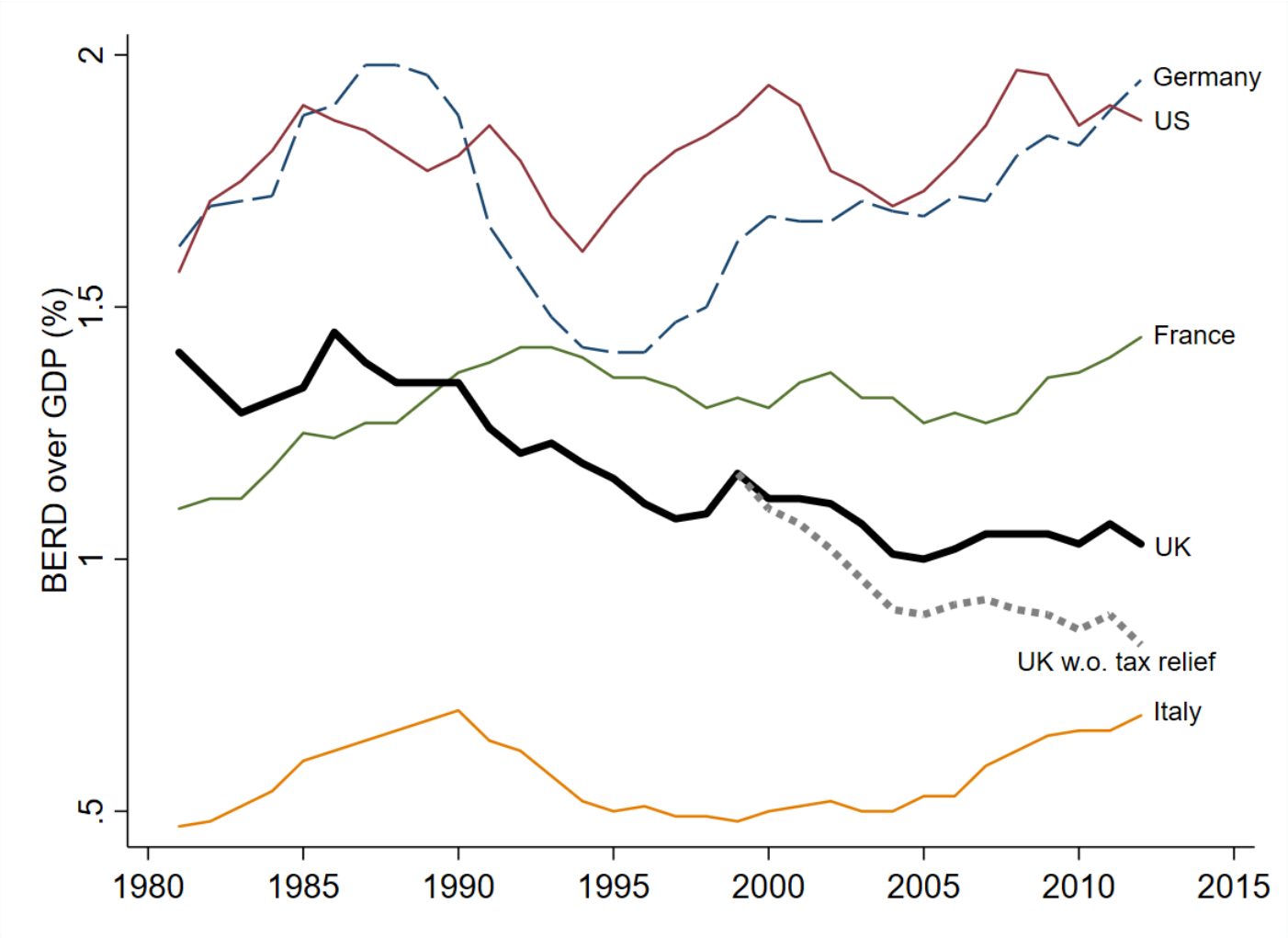
- At 5% significance level, we can rule out (absolute) patents to tax-adjusted user cost elasticities less than 2.0 & R&D to user cost elasticities less than 1.4 (Figure A9)

- These are larger than existing literature. But:
  - Our firms smaller & therefore more likely to be financially constrained
  - Cleaner identification

Macro Implications

- Calculate change in user cost for all firms by year and simulate effect of tax change. Use admin data on taxpayers' costs
- About $2 billion extra R&D per annum at $1 billion cost
- Simulate path of UK business R&D without R&D policy 2000-2012
  - UK R&D intensity would have continued fall & been about 14% lower in 2012 without policy

Figure 7: Simulated UK Business R&D/GDP ratio without R&D tax policy



Notes: The data is from OECD MSTI. The dotted line ("UK without tax relief") is the counterfactual R&D intensity in the UK that we estimate in the absence of the R&D Tax Relief Scheme.

Conclusion

- Change in R&D Tax thresholds in a RD Design: firms **increased R&D** & produced more **innovations (patents)**
  - Innovations were not significantly low value
  - Magnitudes substantial (~68% increase in patents)
  - Causal evidence for technology spillovers
- R&D tax policies can be effective esp. targeted on SMEs

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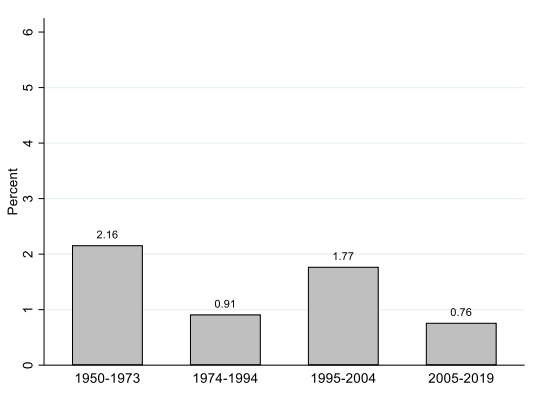
  - Causal evidence for technology spillovers
- R&D tax policies can be effective esp. targeted on SMEs
- **Next steps:** structural approaches (Aghion et al, 2022); more investigation of spillovers (e.g. international); other countries; longer-run outcomes.
  - Comparison with alternative innovation policies (Bloom, Van Reenen & Williams, 2019)
  - Concern of GE effects. Motivates study of other policies (Bell et al, 2019a,b; Moretti et al, 2022)

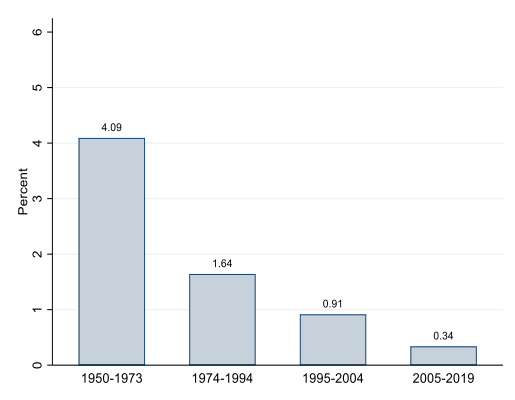
Thanks!

Total Factor Productivity (TFP) growth 1950-2019: Big slowdown since Global Financial Crisis

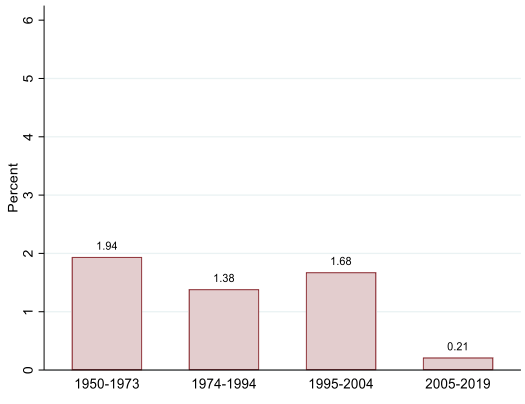
A. United States



B. Euro Area



C. United Kingdom



Source: Teichgraber & Van Reenen (2022) Updated data from Bergeaud, Cette, and Lecat (2016). Data publicly available at: http://www.longtermproductivity.com/. *Notes:* Average annual TFP growth in the US (panel A), Euro-area (panel B), and UK (panel C). Insufficient data for whole Euro-area so Germany, France, Italy, Spain, Netherlands, and Finland are used.

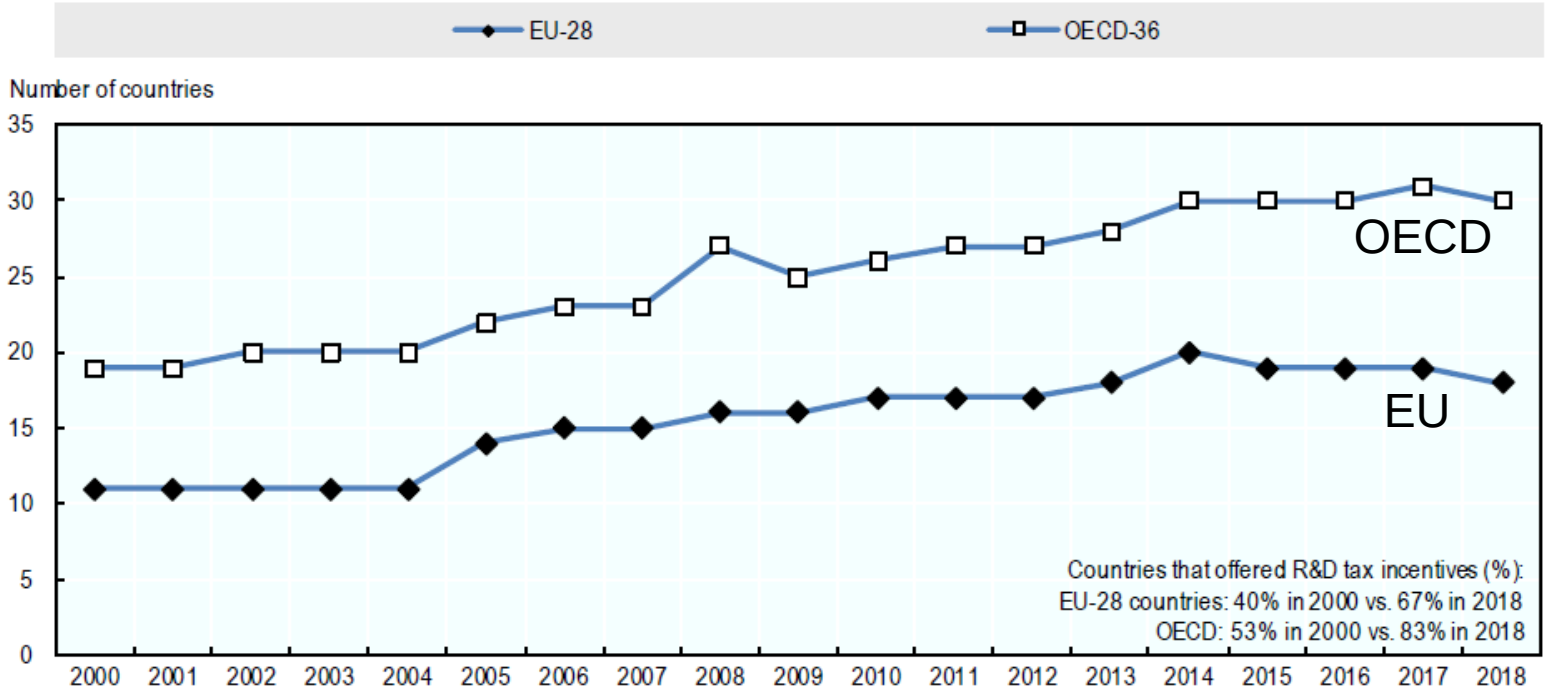
Motivation: Global concern with slow productivity growth (US data)

US Total Factor Productivity Growth slowdown

Note: Total Factor Productivity (TFP); Annual average growth over different periods;

Source: BLS; Fernald (2019)

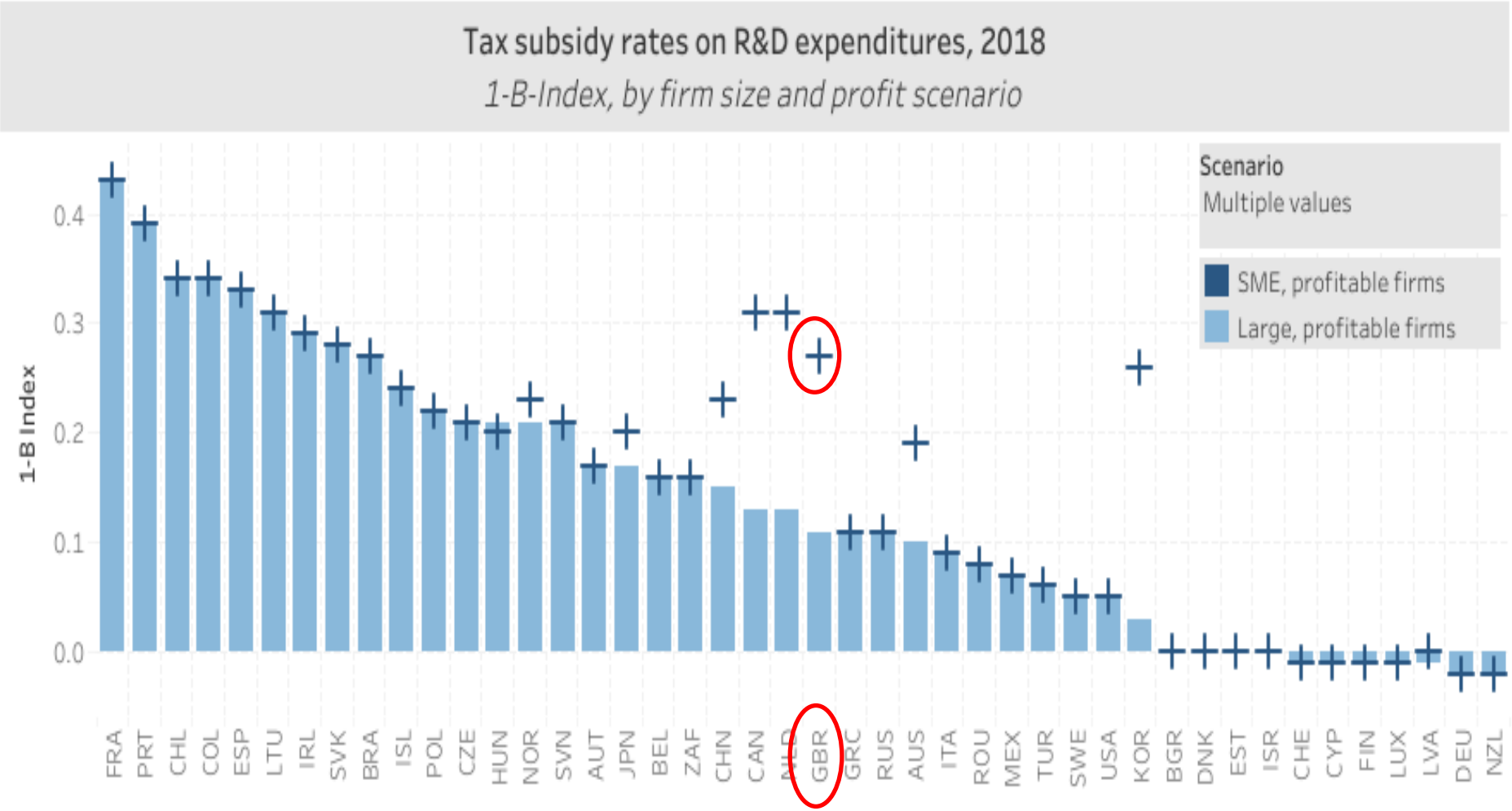
Increase in use of R&D tax incentives in OECD 83% of countries in 2018 compared to 40% in 2000



Note: EU-28 excludes Malta as no sufficiently detailed information is available on R&D tax relief provisions.
Source: OECD R&D Tax Incentives Database, http://oe.cd/rdtax, March 2019.

- In 2016 OECD countries granted $45bn R&D tax relief 46% of all gov support in form of tax relief (up from 36% in 2006)

US R&D tax credit one of least generous. UK Small & Medium sized Enterprise (SME) credit one of most generous



Source: OECD, R&D Tax Incentive Database, http://oe.cd/rdtax , March 2019. Data & notes: https://oe.cd/ds/rdtax

Table A1. Design of UK R&D Tax Relief Scheme,

Effective from		SME ceilings			Enhancement rate		Payable credit rate		Effective for
		Employ-ment	Total assets	Turn-over	SME	Large company	SME	Large company	
2000	April	249	€27m	€40m	50%	0%	16%	0%	Expenditure that incurred on or after April 1st 2000
2002	April	"	"	"	"	25%	"	"	Expenditure that incurred on or after April 1st 2002
2005	January	"	€43m	€50m	"	"	"	"	Accounting period that ended on or after January 1st 2005
2008	**April August**	**499**	**€86m**	**€100m**	**75%**	**30%**	**14%**	**"**	Large companies: expenditure that incurred on or after April 1st 2008 SMEs: expenditure that incurred on or after August 1st 2008
2011	April	"	"	"	100%	"	12.5%	"	Expenditure that incurred on or after April 1st 2011
2012	April	"	"	"	125%	"	"	"	Expenditure that incurred on or after April 1st 2012

Note: To be considered an SME, a company must fall below the employment ceiling and either the total asset ceiling or the sales ceiling ("ceiling tests"). The measurements and account aggregation rules for employment, total assets, and sales are set according to 1996/280/EC (up to December 31st 2004) and 2003/361/EC (from January 1st 2005). 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.

Simple Model of R&D and Patenting

CES Production Function of Output

$$Y = A\left[aG^{(\sigma-1)/\sigma} + (1-a)K^{(\sigma-1)/\sigma}\right]^{\sigma/(1-\sigma)}$$

G = R&D capital stock
RD = Flow of R&D
K = Non-R&D capital stock

Perpetual Inventory model for R&D capital stock

$$G_t = (1-\delta)G_{t-1} + RD_t$$

Simple Model of R&D and Patenting

First Order Condition for R&D capital

$$\ln G = -\sigma \ln \rho + \sigma \ln U + \ln K + \sigma \ln\left(\frac{a}{1-a}\right)$$

ρ = Tax-adjusted user cost of R&D capital
U = Tax-adjusted user cost of non-R&D capital

In steady state: $RD = \delta G$

Flow R&D equation

$$\ln RD = -\sigma \ln \rho + \ln K + \sigma \ln U + \ln \delta + \sigma \ln\left(\frac{a}{1-a}\right)$$

Knowledge Production Function (Patent equation)

$$\ln PAT = \alpha \ln RD + \mu$$

Estimate direct policy effect on patents

2. Difference-in-Differences Design

$$PAT_{it} = \beta^{DiD}\left(E_i^{2007} \times 1_{\{t>2008\}}\right) + \theta_i + \tau_t + \varepsilon_{it}$$

- $1_{\{t>2008\}}$: dummy = 1 if year t is in post-policy period
- Compare the **difference** in patenting by firms below & above the threshold *after* the policy change to analogous difference *before* the policy change

3. Difference-in-Discontinuities Design

$$PAT_{it} = \beta^{Disc}\left(E_i^{2007} \times 1_{\{t>2008\}}\right) + f_{1_{\{t>2008\}}}(z_i^{2007}) + \theta_i + \tau_t + \varepsilon_{it}$$

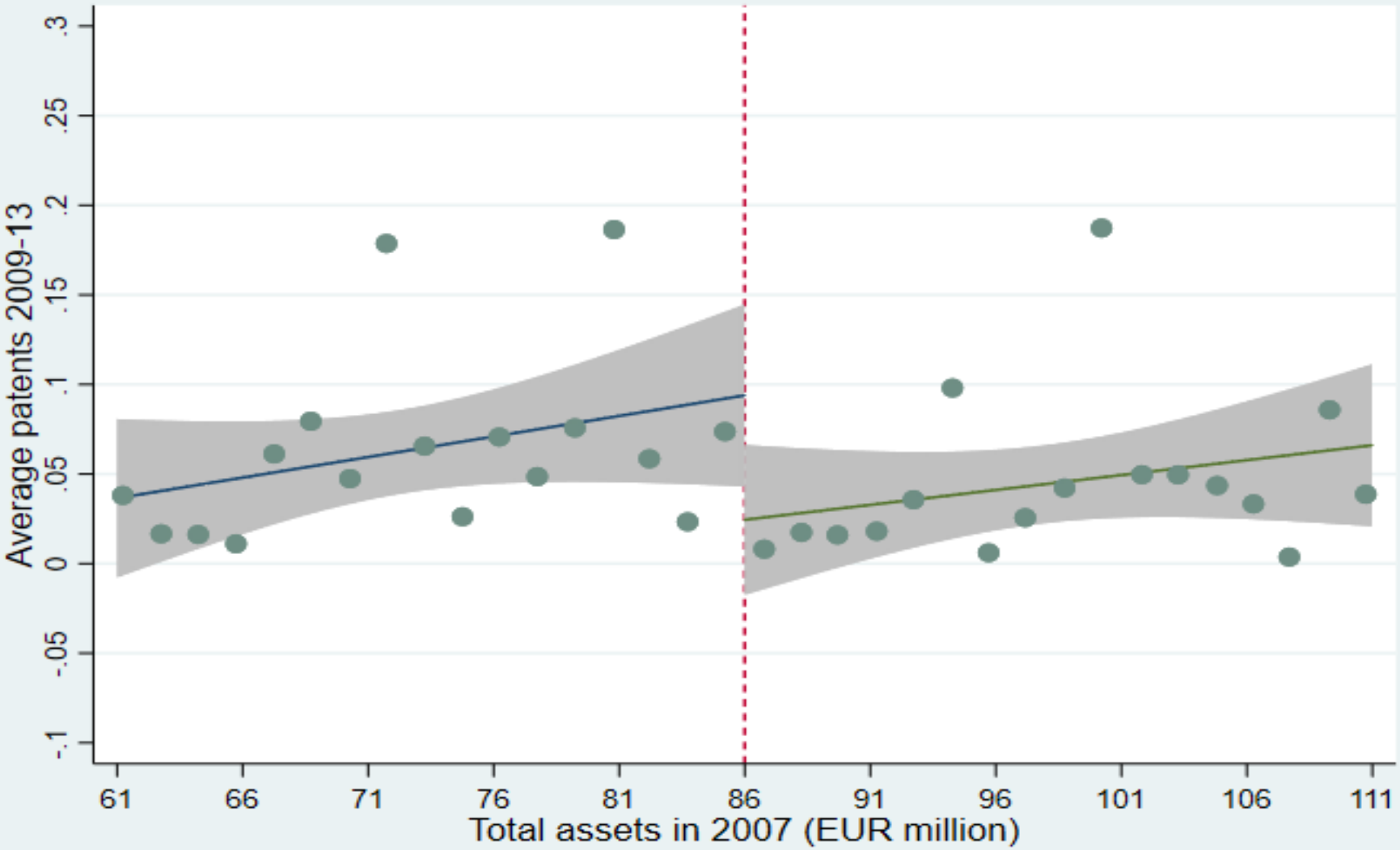
- Compare the **discontinuity** in patenting by firms below & above the threshold *after* the policy change to analogous discontinuity *before* the policy change

Table 2: Balance of predetermined covariates

Dependent variable	Ln(Sales)		Ln(Employment)		Ln(Capital)		R&D exp (£ '000s)	
Year	2006	2007	2006	2007	2006	2007	2006	2007
Below-threshold indicator in 2007	-0.124	0.086	0.118	0.151	0.020	-0.007	43.4	81.9
	(0.162)	(0.161)	(0.135)	(0.131)	(0.112)	(0.103)	(50.6)	(59.2)
SME threshold	€86m	€86m	€86m	€86m	€86m	€86m	€86m	€86m
Observations/Firms	4,155	4,348	2,973	3,091	4,763	5,079	5,888	5,888

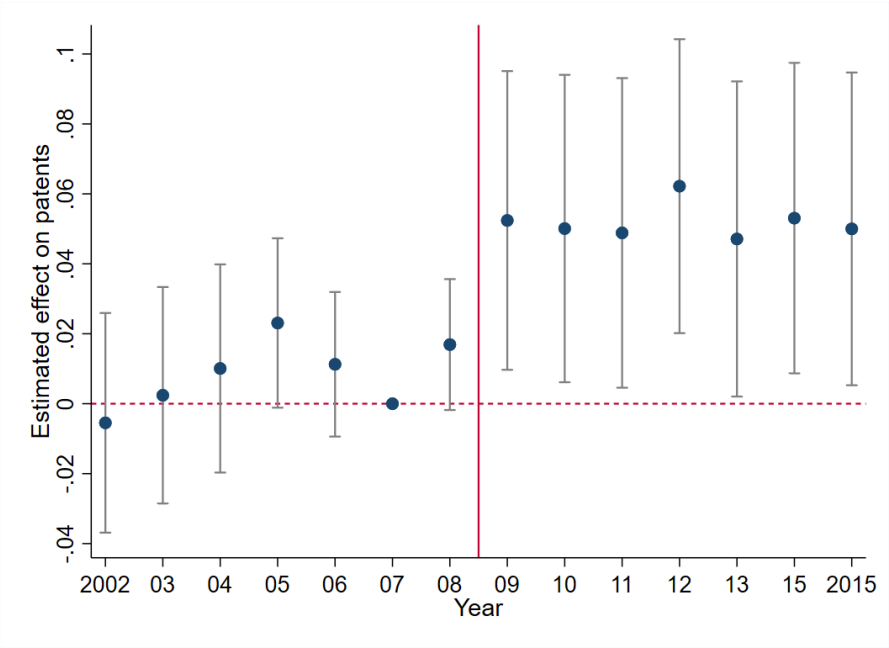
Notes: RD estimates with robust standard errors in brackets. Running variable (RV): 2007 assets; threshold: €86m; sample: firms with RV in [€61m, €111m]. Controls: 1st order polynomials of RV separately for each side of threshold.

Figure 3: Discontinuity on patenting 2009-13 average (narrow bins)

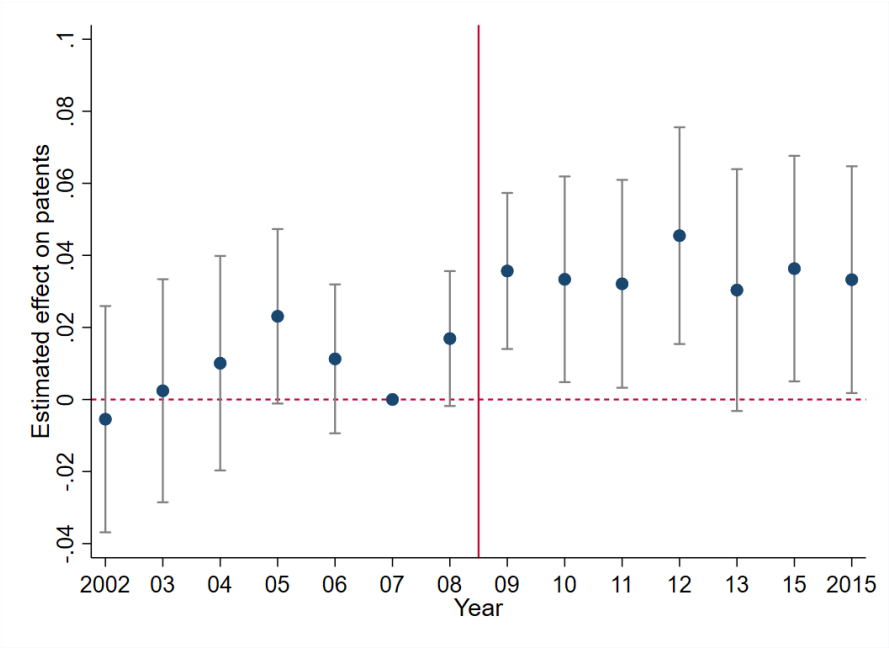


Estimates: Linear .069 (.026); N = 5888. Bin size EUR 1.5m.

Figure 3: Pre- vs. post-policy effects on patents



Panel A: Diff-in-Disc Design



Panel B: Diff-in-Diff Design

Notes: Diff-in-Disc/Diff-in-Diff estimates relative to 2007. Sample: firms with 2007 assets in [€61m, €111m]. 90% confidence intervals based on standard errors clustered by firm.

Table 4: Tax policy effects on R&D and robustness of effects on patents in larger sample

Sample bandwidth	2007 Assets in [€61m, €111m]			2007 Assets in [€51m, €121m]			
Dependent variable	**R&D exp (£ '000s)**	**Patent count**		**Patent count**			**R&D exp (£ '000s)**
Specification	RD	RD IV	RD IV w. LDV ctrl	RD	Diff-in-Disc	Diff-in-Diff	RD
Period	09-11 avg	09-13 avg	09-13 avg	09-13 avg	06-13	06-13	09-11 avg
Below-threshold indicator in 2007	63.4**			0.047***			58.8*
	(32.1)			(0.017)			(33.5)
Below-threshold x Post-2008					0.043**	0.026**	
					(0.019)	(0.011)	
R&D exp, 09-11 avg (£ millions)		0.563**	0.434*				
		(0.282)	(0.243)				
Anderson-Rubin test		0.008	0.012				
Observations	5,888	5,888	5,888	8,577	68,616	68,616	8,818
Number of firms	5,888	5,888	5,888	8,577	8,577	8,577	8,818

Notes: RD/RD IV/Diff-in-Disc/Diff-in-Diff estimates with standard errors clustered by firms in brackets. Running variable: 2007 assets; threshold: €86m. Controls are as described in Table 3's notes. **Mean R&D exp was £73,977 between 2006-08 and £88,825 between 2009-15.**

Extensions

- Intensive/Extensive Margin (Tables A9/A10)
  - R&D results coming from **intensive** margin. Firms already doing R&D do more of it
  - Patents results from both intensive and extensive
- Other measures of Firm Performance –jobs, TFP, sales, capital, (Table A13)

Implications for tax-price elasticity of R&D

Year	2009 & 2010		2011		Average 2009-11	
Tax relief scheme	SME	LCO	SME	LCO	SME	LCO
e: enhancement rate	75%	30%	100%	30%	-	-
c: payable credit rate	14%	0%	12.5%	0%	-	-
τ: effective tax rate	28%	28%	26%	26%	-	-
r: real interest rate	5%	5%	5%	5%	-	-
δ: depreciation rate	15%	15%	15%	15%	-	-
$\Pr(credit)$ (i.e. % zero-profit firms)	55%	55%	55%	55%	-	-
ρ: user cost of R&D	0.147	0.190	0.141	0.191	0.145	0.190
$\ln(\rho_{SME}) - \ln(\rho_{LCO})$					**-0.271**	

R&D treatment effect is 60.4 but scaled by participation coefficient of 0.353; 171= 60.4/ 0.353

Tax-price elasticity of R&D

$$\eta = \frac{\ln(rd_{SME}) - \ln(rd_{LCO})}{\ln(\rho_{SME}) - \ln(\rho_{LCO})} = \frac{171/((171+74+74)/2)}{-0.271} = \frac{1.072}{-0.271} = \mathbf{-3.99}$$

Table A8: Participation/Complier equation

Dependent variable: Firm has SME R&D claim 2008-11	
Below-asset-threshold indicator (in 2007)	0.353***
	(0.090)
Firms	361

Note: *** significant at 1% level, ** 5% , * 10%. OLS estimates based on the RD Design. Running variable is 2007 assets with a threshold of €86m. Baseline sample includes firms with assets within €25m below& above the cut-off. Controls for running. SEs clustered by firm in brackets. The sample for a certain year (period) effectively includes firms in the baseline sample with R&D tax relief claims in that year (period).

Descriptive Statistics

- For our sample period 2006-11
- 53,491 claims from 20,730 firms (81% under SME scheme)
- ~£1bn per annum in lost tax revenue pa (£1.4bn in 2011)
- Qualified R&D about 80% of firms' reported R&D
- CT600: 2.5m firms & 9.1m observations
- FAME: 3.1m firms & 11.5m observations
- PATSTAT: 9,420 firms with at least patent application (46,405 patent families). 90% of all UK PATSTAT patents

Table A14: Using other SME criteria (sales, employment)

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

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.

Table 2:
Pre-treatment covariate balance

Dependent variable	ln(sales)		Ln(Capital)		Ln(employ-ment)	
Year	2006	2007	2006	2007	2006	2007
Below new SME asset threshold in 2007	-0.124	0.086	0.020	-0.007	0.118	0.151
	(0.162)	(0.161)	(0.112)	(0.103)	(0.135)	(0.131)
SME threshold	€86m	€86m	€86m	€86m	€86m	€86m
Sample bandwidth	€61-€111m	€61-€111m	€61-€111m	€61-€111m	€61-€111m	€61-€111m
Firms	4,155	4,348	4,763	5,079	4,763	5,079

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.

No extensive margin effects for R&D, but some extensive margin effects on patents

Table A8. Discontinuities in the probabilities of doing any R&D or filing any patents

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	**Indicator: R&D exp. > 0**			**Indicator: All patent family count > 0**				
Year	2009	2010	2011	2009	2010	2011	2012	2013
Below-assets-threshold indicator (in 2007)	0.008	0.006	0.013	0.011*	0.008	0.014*	0.013**	0.018***
	(0.011)	(0.012)	(0.011)	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)
Dependent variable mean	*0.036*	*0.041*	*0.045*	*0.017*	*0.017*	*0.017*	*0.015*	*0.016*
Firms	5,888	5,888	5,888	5,888	5,888	5,888	5,888	5,888

Note: *** significant at 1% level, ** 5% level, * 10% level. 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. Dependent variables are indicators of whether a firm has R&D expenditure or files patents during the corresponding year.

Source: Calculations based on HMRC administrative datasets

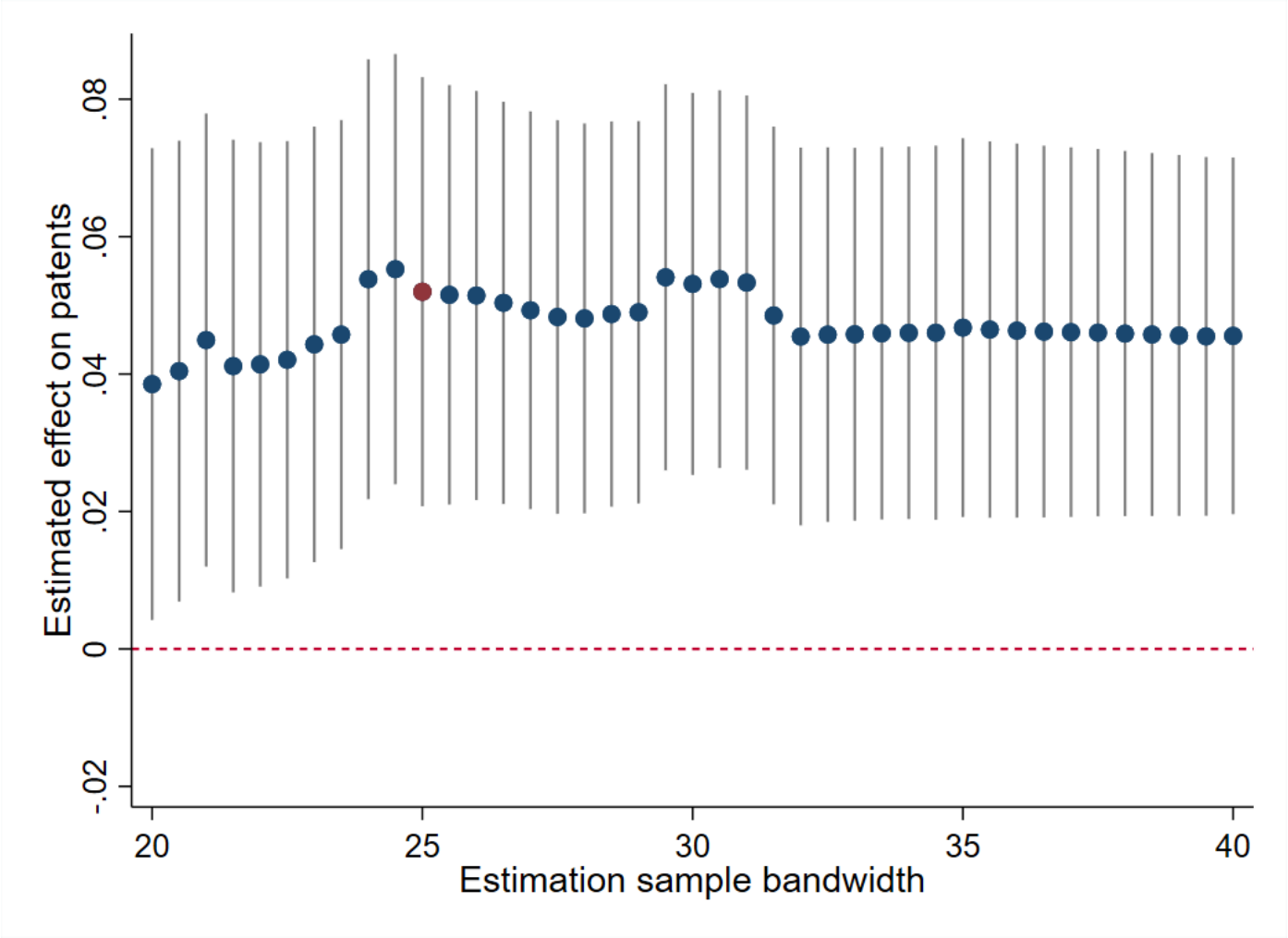
Effects on intensive margin driven by firms already doing R&D or patents

Table A9. Heterogeneous effects of R&D tax relief by past R&D and patents

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable	**R&D expendi-ture (*£ '000*), 2009-11 avg.**		**All patent family count, 2009-13 avg.**		**EPO patent count, 2009-13 avg.**		**UK patent count, 2009-13 avg.**		**US patent count, 2009-13 avg.**	
Subsample	Past > 0	Past = 0	Past > 0	Past = 0	Past > 0	Past = 0	Past > 0	Past = 0	Past > 0	Past = 0
Below-asset-threshold indicator (in 2007)	1,708*	6.3	1.50**	0.002	1.40**	-0.000	1.80**	0.007	1.89***	-0.002
	(885)	(9.6)	(0.68)	(0.005)	(0.63)	(0.002)	(0.91)	(0.005)	(0.66)	(0.002)
Dependent variable mean over 2006-08	*1,682*	*0.0*	*2.18*	*0.00*	*1.51*	*0.00*	*2.96*	*0.00*	*1.42*	*0.00*
Difference	1,702*		1.50**		1.40**		1.79**		1.89***	
	(879)		(0.67)		(0.62)		(0.90)		(0.65)	
Firms	259	5,629	172	5,716	117	5,771	152	5,736	106	5,782

Note: *** significant at 1% level, ** 5% level, * 10% level. 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. Past period is the pre-policy period of 2006-2008.

Figure 4: Policy effect on patents in smaller and larger samples



Notes: RD estimates. Running variable (RV): 2007 assets; threshold: €86m. Controls: (i) 1st order polynomials of RV separately for each side of threshold; (ii) 2006-08 average of dependent variable. 90% confidence intervals based on robust standard errors

Figure A3: Placebo patent effects from different cutoffs than actual eligibility threshold

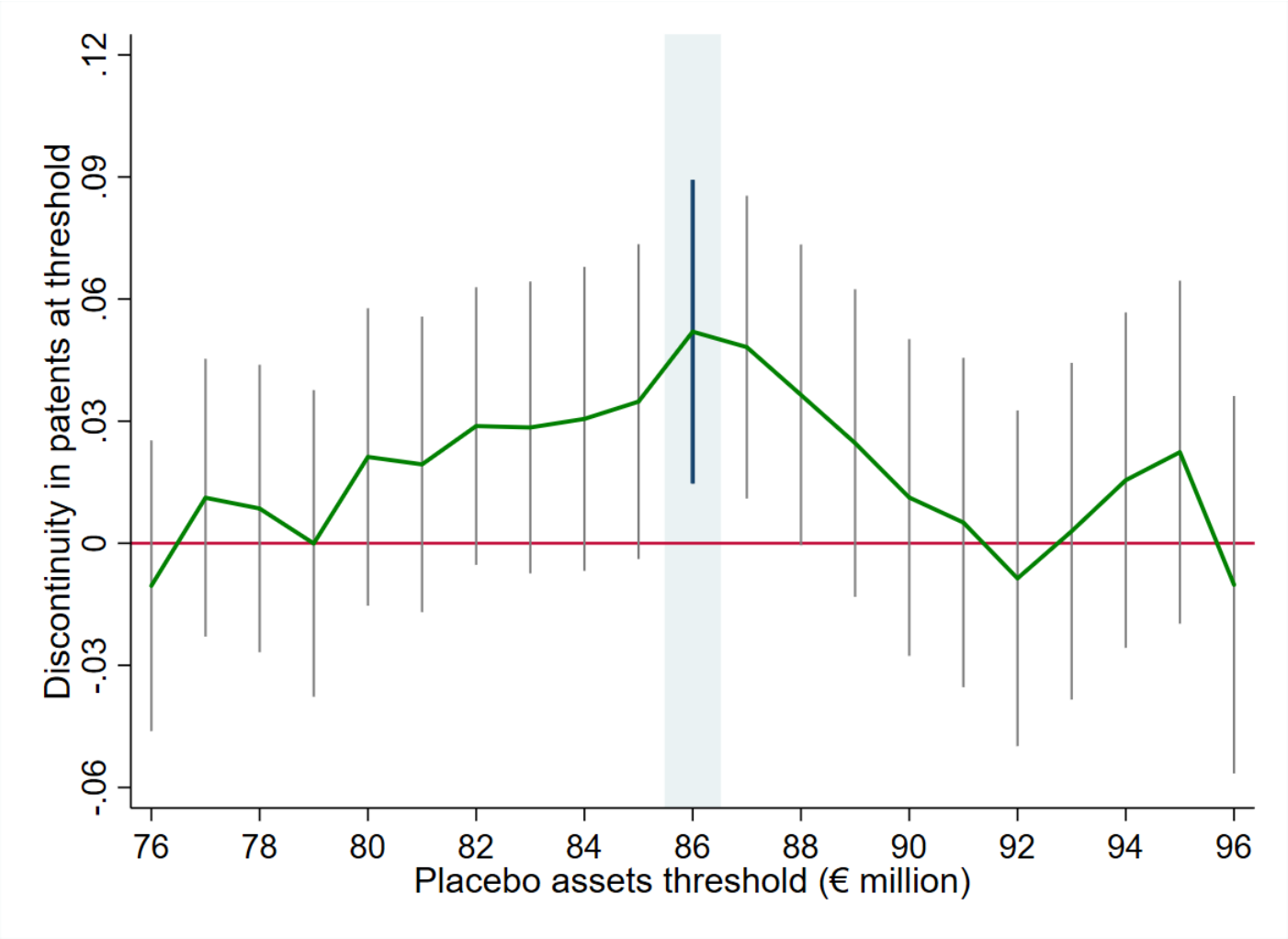
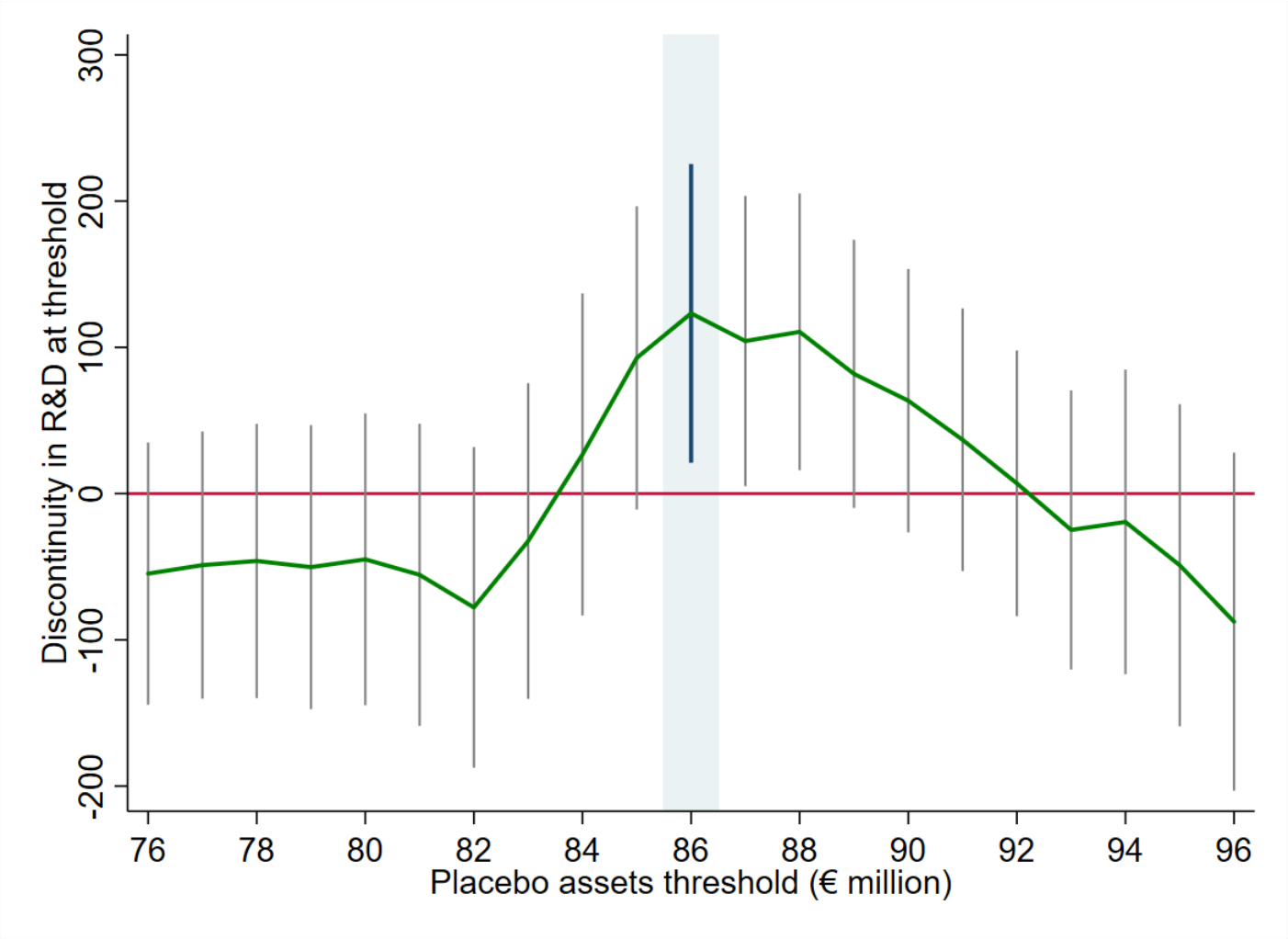


Figure A4: Placebo R&D effects from different cutoffs than actual eligibility threshold



Spillovers: Diff-in-Disc equation

- Consider dyad of 2 firms $\{i, j\}$, if firm i is below new assets threshold, did innovation rise in "connected" firm j?
- Connection = Same 3-digit technology class (& above median Jaffe, 1989, proximity). Use firm population for this.

$$PAT_{jt} = \delta^{Disc} E_i^{2007} \times 1_{\{t>2008\}} + f_{1_{\{t>2008\}}}\left(z_i^{2007}\right) + \theta_j + \tau_t + \varepsilon_{ij}$$

- Compare the discontinuity in technology spillovers from firms below & above the threshold *after* the policy change to the analogous discontinuity *before* the policy change

Simplified tax-adjusted user cost of R&D capital

Discounted value of tax credits and depreciation allowances

interest rate

Inflation rate

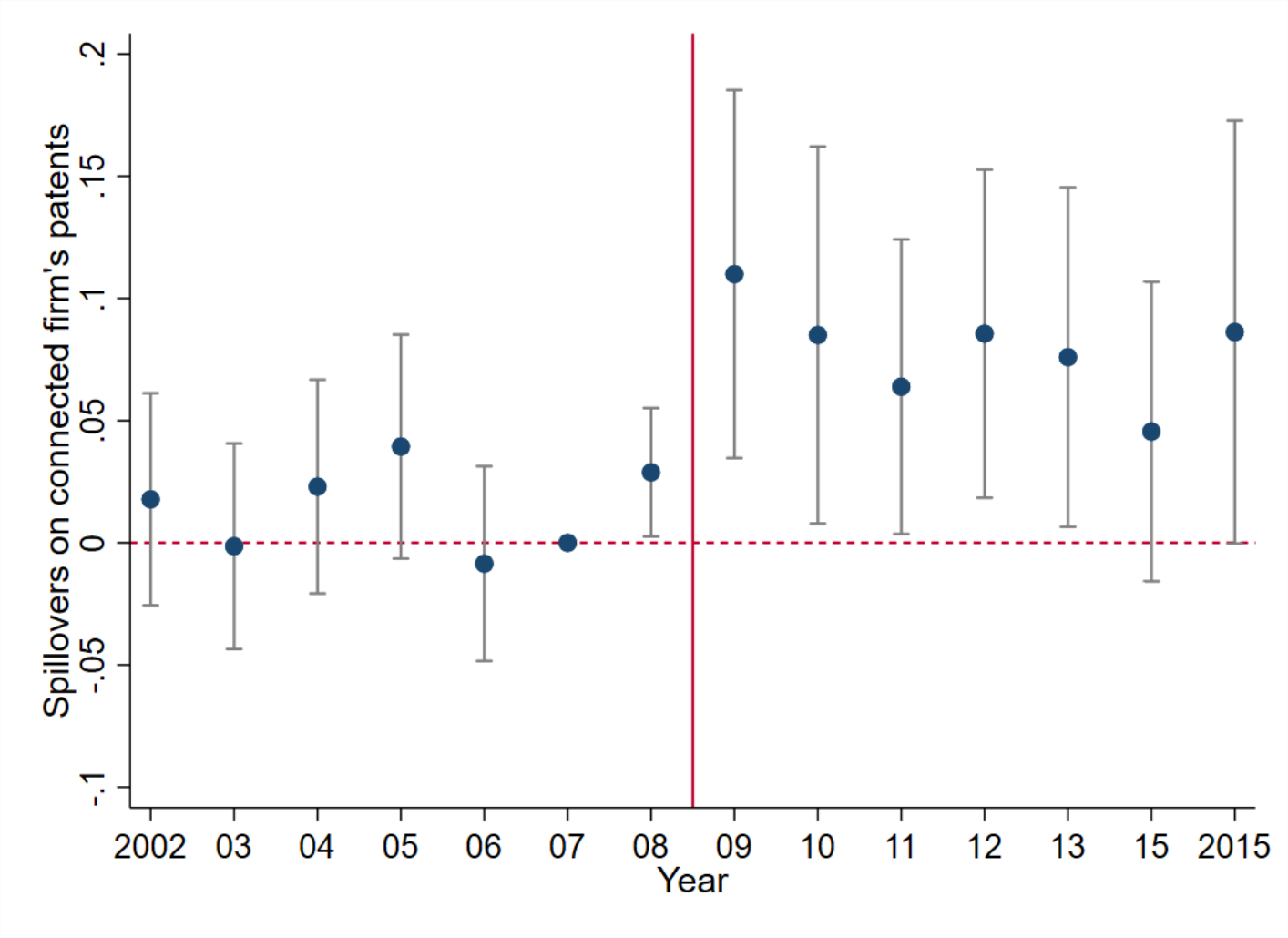
$$\rho_{it} = \left(\frac{1 - D_{it}}{1 - \tau_{it}} \right) \left(i_t + \delta - \frac{\Delta p_t}{p_{t-1}} \right)$$

Statutory corporate tax rate

R&D capital depreciation rate

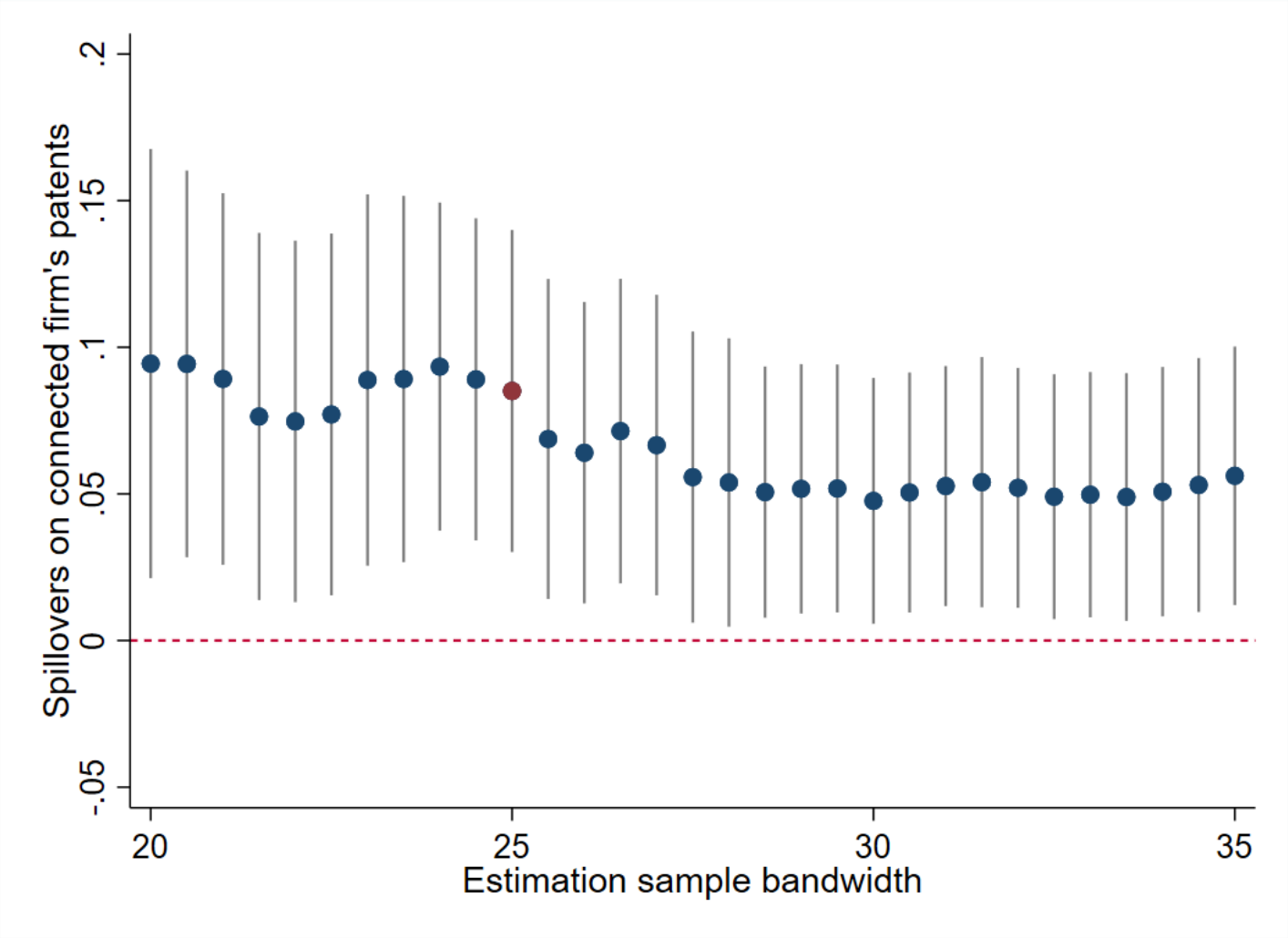
- R&D is a form of intangible capital
- If R&D treated like other capital D = 0
- If R&D just treated as an expense D = τ & tax system neutral (so favoured relative to other forms of capital)

Figure 6: Pre- and post-policy spillovers on connected firms in smaller technology classes



Notes: Spillover Diff-in-Disc estimates relative to 2007. Sample: treated-connected firm pairs in small technology class (below 200 firms) with treated firms' 2007 assets in [€61m, €111m]. 90% confidence intervals based on standard errors clustered by main technology class.

Figure 6: Spillovers on connected firm in smaller and larger samples



Notes: Spillover RD estimates. Sample: treated-connected firm pairs in small technology class (below 200 firms) with varying bandwidth around the SME asset threshold of €86m for treated firms. 90% confidence intervals based on standard errors clustered by main technology class.

Extensions of spillover analysis

- **IO strategic interactions: Business stealing**
  - Does more R&D by firm *i* “steal” product market share of firm *k* (if large, could imply “too much” R&D)
  - What is the effect on R&D incentives of rival firms (strategic complements vs substitutes)?
- Look at rivals in same product market as indicated by 4 digit SIC (as well as technological classes as above)
- Business stealing effects very small in magnitude
  - Qualitatively similar to findings in Bloom et al (2013) and Lucking et al (2020) on US data showing social returns exceed private returns

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 taxes foregone? "Value for money" ratio
- Simulate using:
  - Empirical estimates of treatment effects: elasticity of 2.6 for SMEs & (conservatively) 1.0 for large companies
  - 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 £1 of taxpayer money
  - Business R&D 10% lower without tax policy 2006-11 av.

Definition of R&D

- Formally, has to be consistent with UK GAAP – accounting standards FRS102 s18, IAS38, FRS105 s13 and SSAP13
- "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 in: https://www.gov.uk/hmrc-internal-manuals/corporate-intangibles-research-and-development-manual/cird81300
- https://www.gov.uk/hmrc-internal-manuals/corporate-intangibles-research-and-development-manual/cird81900

Example of how R&D tax relief works

$	Baseline	SME (enhancement rate =100%)	LCO (enhancement rate =25%)
1. Revenue	700	700	700
2. Non-R&D costs	200	200	200
3. R&D spend	100	100	100
4. Enhancement	0	100	25
5. Taxable profit (= 1 – 2 – 3 – 4	400 (700-300)	300 (=700-400)	375 (=700-325)
Tax due (corporate tax rate = 0.25)	100	75	93.75
Tax Saving from R&D tax relief	0	25	6.25

Table 9: Participation/Complier equation

	2009	2010	2011	2009-11
Below-asset-threshold indicator (in 2007)	0.326***	0.301***	0.184*	0.248***
	(0.085)	(0.089)	(0.100)	(0.093)
Firms	215	218	248	333

Note: *** significant at 1% level, ** 5% , * 10%. OLS estimates based on the RD Design. Running variable is 2007 assets with a threshold of €86m. Baseline sample includes firms with assets within €25m below& above the cut-off. Controls for running. SEs clustered by firm in brackets. The sample for a certain year (period) effectively includes firms in the baseline sample with R&D tax relief claims in that year (period).

This macro analysis very rough

- Not accounting for General Equilibrium Effects effects such as higher equilibrium wages of scientists
- Extrapolating away from thresholds. Assume same elasticity for all SMEs, but lower elasticity $\eta_{\boldsymbol{\rho}}^{rd}$= -1 for larger firms
- Taxpayer costs is transfer from consumers to producers, so only deadweight should count in the cost-benefit (ignoring spillovers)
- Not incorporating R&D impact on GDP

What treatment effects do we identify?

- Reduced form RDD (intent to treat)
- IV (fuzzy RD) identifies LATE
  - Impact of R&D on patents, etc.
  - Impact on outcomes (R&D, patents) for the firms at threshold. Estimate in Tab 9. Need to scale by the effect on SME participation (approx. 3x)
- All causal effects (RD not exaggerated), but doesn't tell us impact of this policy on other firms. Could be negative due to:
  - Business stealing (look at via rivalry analysis)
  - Firms become small to take advantage of SME credit. (McCrary on post-policy; employment effects doesn't suggest stopping growth)
  - R&D supply constraints (e.g. scientists). Need GE model (develop with Aghion). NB: BGVR found small/zero effects – can import resources
  - Relocation from other countries (may be part of what policymakers want)