Online Appendix

Effectiveness of fiscal incentives for R&D: quasi-experimental evidence

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A. Summary of recent related literature

Table A.1—. Related literature (since 2000)

Papers	Equation (constants, controls and error terms omitted)	β_1 (SE)	Methodology / Identification	Source of R&D data	Equivalent elasticity of interest
Panel A: Published Work					
Bloom et al. (2002)	$lnR_{it} = \gamma lnR_{it-1} + \beta_0 y_{it} + \beta_1 lnCoC_{it}$	-1.09 (0.02)	First-difference, instrument with lags of lnR_{it} and y_{it} up to date t-2 and lags of $lnCoC^{tax}$ up to $t-1$; country and year FEs	Country-level panel data, 9 OECD countries, 1979-1997	-1.09
Wilson (2009)	$ln(R^{in}_{it}) = \gamma ln(R^{in}_{it-1}) - \beta_1 ln(CoC^{in}_{it}) + \beta_2 ln(CoC^{out}_{it})$	Internal: -2.18 (0.81)	Within-groups (state and year FEs)	US state-level data on industrial R&D from NSF (1981-2004)	-2.18, but implied aggregate-cost elasticity zero
Czarnitzki et al. (2011)	$ln(innovation) = \beta_1 D_i$	N.A.	Mahalanobis distance matching based on observables of beneficiary and non-beneficiary firms in the same year	Canadian Innovation Survey (1999)	N.A.
Mulkay and Mairesse (2013)	$K^{R\&D}_{it} = \beta_0 y_{it} + \beta_1 ln(CoC_{it})$	-0.41 (0.16)	Error-correction model specification; diff GMM; firm and year FEs	French R&D survey (2000-2007)	-0.41
Lokshin and Mohnen (2012)	$K^{R\&D}_{it} = \beta_0 y_{it} + \beta_1 ln(CoC_{it})$	-0.54 (0.20) to -0.79 (0.35) to -0.79	Error-correction model specification; within-groups & IV; instrument with lags of lnK_{it} and y_{it}; policy parameters	Dutch R&D and CIS Surveys (1996-2004)	-0.54
Boler et al. (2015)	$lnR_{it} = \beta_0 + \beta_1 D_i T_t$	Diff-in-diff: 0.29 (0.25) to 0.54 (0.14)	Diff-in-diff (within-groups), firm and year FEs, firm-specific random trends + structural	Norwegian R&D survey (1997-2005)	N.A.
Rao (2016)	$\frac{R_{it}}{S_{it}} = \beta_1 CoC_{it}$	-1.98 (0.47)	First-diff, instrument with synthetic CoC (under policy at t and t-1 using R_{it-2})	US Tax returns and Compustat (1981-1991)	-1.98
Guceri (2017)	$ln(R_{it}) = \beta_1 D_i T_t$	Diff-in-diff: 0.20 (0.07)	Diff-in-diff (within-groups), exploits change in eligibility rule, firm and year FEs	UK R&D Survey (1999-2013)	-0.88 to -1.18

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Table A.1 – *Continued from previous page*

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

B. Conceptual framework

We consider a Cobb-Douglas production function with R&D capital as the sole input[20]. Firms maximise the net present shareholder value subject to the law of motion for the accumulation of R&D capital. For each firm, the production function is:

$$F(K_t) = AK_t^{\alpha} \tag{B1}$$

The firms' optimisation problem is:

$$V_t(K_{t-1}) = \max_{R_t} \{\Pi_t(K_t) + \beta_{t+1}\mathbb{E}_t(V_{t+1}(K_t))\} \tag{B2}$$

$$\text{subject to } K_t = (1-\delta)K_{t-1} + R_t \tag{B3}$$

where δ is the depreciation rate and V_t is the maximised current value of the firm as a function of the knowledge capital accumulated in the firm denoted by K_{t-1}. Knowledge accumulates according to the law of motion expressed in Equation B3, with knowledge capital in time period t determined by the previous period's capital, net of depreciation, plus investment in new R&D, R_t. $\beta_{t+1} = \frac{1}{1+r_{t+1}}$ is the rate at which the firm discounts future revenue, with r_{t+1} being the risk free interest rate representing the outside option of the firm.

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

$$\Pi_t(K_t, R_t) = (1-\tau)[p_t F(K_t) - p_t^K R_t] + c p_t^K R_t \tag{B4}$$

where τ is the corporation tax rate applied to firm profits and c is the tax credit rate on R&D investment[21], p_t is the price of output at time t and p_t^K is the input price.

Substituting the constraint in the firm's objective function, we obtain the following first order condition, yielding that the marginal product of R&D capital

[20] Bloom, Griffith and Reenen (2002), Mulkay and Mairesse (2013) provide applications with constant elasticity of substitution production functions in the R&D context. Bond and Van Reenen (2007) review the literature on investment models of this type, and the notations in Appendix B follow the convention adopted in their chapter.

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

is equal to its user cost and pinning down the optimal level of R&D capital:

$$\text{(B5)} \qquad \frac{\partial V_t}{\partial K_t} = (1-\tau)[p_t F'(K_t) - p_t^K] + cp_t^K + \beta_{t+1}\mathbb{E}_t\left[(1-\tau)p_{t+1}^K - cp_{t+1}^K\right]$$

$$\text{(B6)} \qquad F'(K_t) = \frac{p_t^K(1-\tau-c)}{p_t(1-\tau)}(1-\beta_{t+1}\mathbb{E}_t\frac{p_{t+1}^K}{p_t^K})$$

$$\text{(B7)} \qquad K_t^* = \left(\frac{1}{A\alpha}\frac{p_t^K}{p_t}\frac{(1-\tau-c)}{(1-\tau)}\left[1-\beta_{t+1}\mathbb{E}_t\frac{p_{t+1}^K}{p_t^K}\right]\right)^{\frac{1}{\alpha-1}},$$

where we denote $\kappa \equiv \frac{1}{A}\frac{p_t^K}{p_t}\frac{1}{(1-\tau)}\left[1-\beta_{t+1}\mathbb{E}_t\frac{p_{t+1}^K}{p_t^K}\right]$.[22]

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

$$\text{(B8)} \qquad \frac{\partial K_t^*}{\partial c} = \left(\frac{1}{1-\alpha}\right)\left(\frac{\kappa}{\alpha}\right)^{\frac{1}{\alpha-1}}(1-\tau-c)^{\frac{1}{\alpha-1}-1}$$

Equation B8 shows that firms respond to reductions in their user cost via tax incentives by increasing their R&D capital, as this partial derivative is always positive. In the empirical section, we use the flow variable for R&D instead of generating a conceptual 'R&D capital stock'. Given a short time series, the steady state assumption commonly used in the literature to initialise the R&D capital of the firm (in the spirit of Griliches (1979) and reviewed in Hall, Mairesse and Mohnen (2010)) renders the R&D capital stock to be proportional to the flow measure. Hall and Mairesse (1995) present a comparison of R&D flow and stock variables in the context of estimating production functions and demonstrate that the results do not change between estimates that use stock and flow measures.

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

C. Sample characteristics

Table C.1—. Sample characteristics

	Pooled data before cleaning									
	Means				Medians					
	Turnover	Assets	Employees	R&D	Turnover	Assets	Employees	R&D	Freq	Share of firms with positive R&D
2003	431,339	517,451	2,077	7,593	92,673	84,684	607	106	407	47%
2004	428,116	514,883	2,032	8,926	100,085	89,402	610	288	413	57%
2005	491,255	565,747	2,044	9,831	113,132	102,233	647	525	408	65%
2006	529,082	602,333	2,046	9,950	116,510	100,900	630	819	415	69%
2007	486,071	630,193	1,913	10,277	109,640	106,127	653	1,270	419	83%
2008	572,750	600,443	2,039	12,072	126,232	104,834	637	1,548	414	81%
2009	508,776	563,426	1,931	9,565	104,699	106,041	610	1,474	417	86%
2010	550,253	590,696	1,949	10,568	108,947	109,752	592	1,629	413	86%
2011	592,608	646,421	2,154	9,573	119,946	109,596	604	1,495	398	80%
	Treatment, restricted to the final regression sample									
	Means				Medians					
	Turnover	Assets	Employees	R&D	Turnover	Assets	Employees	R&D	Freq	Share of firms with positive R&D
2003	61,087	54,480	352	1,474	43,172	31,019	322	200	145	52%
2004	62,132	56,276	343	1,873	41,877	33,195	334	246	154	57%
2005	67,204	59,719	359	2,185	46,059	37,510	337	277	151	65%
2006	67,495	57,737	348	2,369	49,159	38,562	341	482	152	66%
2007	73,439	60,443	356	2,380	50,466	42,638	353	490	157	83%
2009	64,753	60,899	333	2,681	51,554	44,685	318	583	165	82%
2010	73,641	63,197	339	2,956	49,657	46,881	314	729	162	85%
2011	78,841	66,147	347	2,923	56,041	49,094	326	660	153	79%
	Control, restricted to the final regression sample									
	Means				Medians					
	Turnover	Assets	Employees	R&D	Turnover	Assets	Employees	R&D	Freq	Share of firms with positive R&D
2003	686,787	832,803	3,227	11,831	226,172	187,638	1,157	50	235	46%
2004	690,428	832,748	3,184	14,132	233,346	194,664	1,151	469	236	58%
2005	777,070	902,319	3,169	15,018	236,466	209,249	1,282	1,006	240	66%
2006	837,073	943,788	3,198	15,328	253,942	226,519	1,407	1,411	242	71%
2007	765,049	1,004,061	2,984	15,928	279,051	246,367	1,331	2,260	241	82%
2009	805,516	892,977	2,979	14,184	281,116	253,653	1,237	2,295	250	88%
2010	877,021	940,826	3,029	15,855	302,072	260,790	1,222	2,839	245	88%
2011	939,088	1,022,005	3,325	14,167	299,467	285,151	1,288	2,984	237	81%

Note: This table presents summary statistics for the key variables in the main sample, which includes companies that were reclassified as SMEs (Medium-Sized Companies) and companies that remain as Large (Large Control) after the 2008 tax reform. R&D, assets and turnover values are reported in thousands, real (2008) GBP.

D. Cross-sectional variation

Assignment to treatment and control groups by firm size is very stable. In our assignment to treatment, we require that companies satisfy both the HMRC's size indicator pre-treatment, as well as a pre-treatment employment criterion (we require firms to have between 250 and 500 employees in the pre-treatment period). In Table D.1, we demonstrate that such assignment to size categories does not change over time for an overwhelming majority of firms.

Table D.1—. Transition between SME and Large Categories

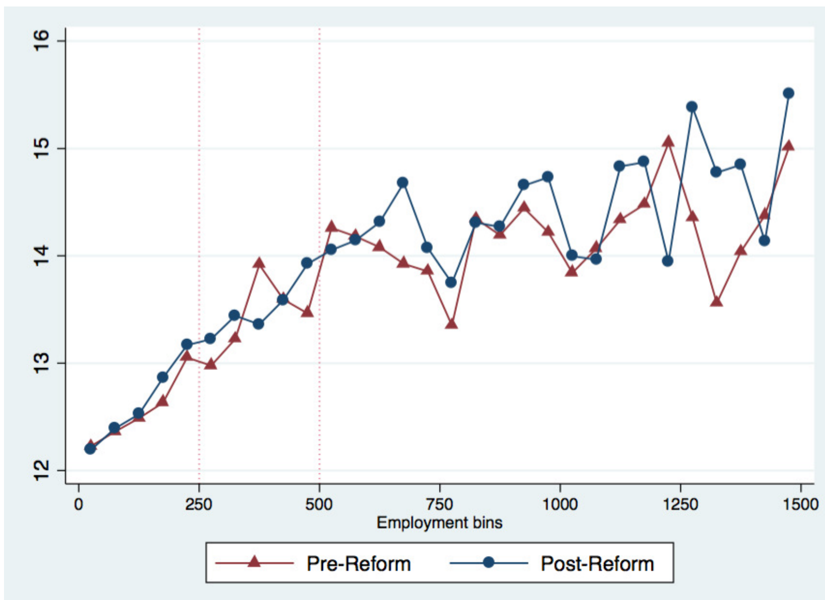
By employment AND HMRC's R&D indicator				
Year	SME to SME	SME to Large	Large to SME	Large to Large
2003-04	247	..	..	129
2004-05	431	..	..	198
2005-06	513	..	..	226
2006-07	560	..	..	232
2007-08	617	..	..	251
2008-09	704	..	..	300
By employment only				
Year	SME to SME	SME to Large	Large to SME	Large to Large
2003-04	5508	62	62	1351
2004-05	5101	68	51	1358
2005-06	4907	77	35	1372
2006-07	4881	72	55	1382
2007-08	5241	100	48	1419
2008-09	5429	89	60	1442

Note: For all the R&D performing firms in our dataset where we can identify size by employment, this table shows the frequency of firms that transition between different size categories. The table includes firms that are not in the treated or control groups to demonstrate the wider applicability of the assignment to different size groups. ".." indicates that the frequency of firms in the particular cell is lower than the HMRC disclosure threshold.

We also check the stability of R&D spending across size bands. In Figure D.1, we plot the levels of R&D spending by firm size. Between pre- and post-treatment periods, if there are large jumps in R&D spending in the lower end of the size distribution, or large falls in R&D spending in the higher end of the size distribution, such falls could drive large average effects. In order to check robustness against this possibility, we examine average R&D spending at 50-employee bins. We observe a rather stable pattern across size bands between pre- and post-reform periods. This check is in a similar spirit to Chetty, Friedman and Saez (2013).[23]

[23]See Chetty, Friedman and Saez (2013), Figure 1.B.

Figure D.1. . Average R&D spending across employment size bands



Note: This figure plots the average R&D spending (in log) for 50-employee size bins in the pre- and post-treatment periods. Each node represents the mean R&D for all the firms in the relevant bin marked at the middle. The dashed lines indicate the employment thresholds for eligibility to the SME scheme in the pre-reform period (250-employee mark) and the post-reform period (500-employee mark).

E. Testing Common Trends

Table E.1 shows the results of the regression that generates Figure 6.

Table E.1—. Test of Common Trends between Treated and Control Groups

Year	N	Beta	Std. Error	Lower bound 90% CI	Upper bound 90% CI
2003	407	-0.193	0.170	-0.526	0.139
2004	413	-0.160	0.149	-0.453	0.132
2005	408	-0.106	0.149	-0.398	0.186
2006	415	0.041	0.096	-0.146	0.228
2007	419	*Normalised to zero*			
2008	414	-0.107	0.129	-0.359	0.145
2009	417	0.253	0.147	-0.034	0.541
2010	413	0.154	0.128	-0.096	0.404
2011	398	0.303	0.200	-0.089	0.694
Joint test with H_0 that all pre-reform β_k coefficients are equal to each other:					
$p-$value	0.341				

Note: This table presents regression results of a common trends test of pre-reform trends between treated and control groups. We estimate the model: $\mathbb{E}[R_{it}|D_{it}] = \exp(\alpha_i + \sum_{t=2003}^{2011} \phi_t + \sum_{k=2003}^{2011} \beta_k D_i T_k)$, where α_i represent firm fixed effects, ϕ_t represent year fixed effects, D_i is a dummy variable that takes the value unity for treated firms and zero otherwise, T_k is a dummy variable that takes the value unity only for one period, that is, year k, and zero otherwise. R_{it} is the level of R&D spending in real, thousand GBP. We normalise the coefficient for the first post-reform year $\beta_{2007} = 0$. In this estimation, the null hypothesis that there is no difference in pre-reform trends is equivalent to the null hypothesis that all pre-reform β_k coefficients are equal to each other. We report the $p-$value for this test in the table. We thank an anonymous referee for suggesting this common trends test.

F. Testing for R&D Relabelling

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

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

To make sure that our results are not driven by changes in the sample, we repeat the analysis using R&D spending as the outcome variable on the same subsample with non-missing investment in Column (1) and with non-R&D input-cost ratio in Column (3), respectively. In each subsample the DD coefficient estimate concerning the increase in qualifying R&D spending is positive and significant at 5 percent level. This assures that our results concerning the response of investment expenditure and non-R&D cost ratio are not an artefact of changes in the regression sample.

Table F.1—. Effect of policy on other outcomes than R&D

	Investment	Real R&D incl. obs. in Column (1)	Cost Ratio	Real R&D incl. obs. in Column (3)
Treated Firm * Post-reform	-0.103	0.288**	-0.049	0.300***
	(0.110)	(0.113)	(0.050)	(0.112)
Revenue (real, lag) control?	Yes	Yes	Yes	Yes
Revenue (real, lag) growth control?	Yes	Yes	Yes	Yes
Firm fixed effects?	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes
N	3142	3142	3144	3144

Note: This table presents regression results on the effect of the R&D tax credits on other outcome variables. These are: physical capital investment in Column (1) and non R&D cost ratio in Column (3). Regressions in Column (2) and (4) check the effect of the R&D tax credits on qualifying R&D spending (outcome variable is real R&D spending in thousand GBP) in the same regression sample in Columns (1) and (3), respectively. The treated group is composed of companies that claimed R&D relief under the large company scheme and had between 250 and 500 employees in the last pre-reform year in which they performed R&D. These companies were reclassified as SMEs after the 2008 reform. The control group are companies that claimed R&D relief under the large company scheme and had more than 500 employees in the last pre-reform year in which they performed R&D. Therefore, the control group companies are those that remained as Large after the 2008 reform. 'Treated Firm' is a dummy variable that takes the value unity for all firms that are in the treated group and zero for all firms in the control group. This is a time-invariant dummy. 'Post-reform' is a dummy variable that takes the value unity for all the periods after 2008. We drop the year 2008 as treatment status for this year is unclear due to the mid-year introduction of the policy reform. In Column (1), the revenue control is significant at 10 percent level. In Column (3), the revenue growth control is significant at 5 percent level. The other coefficients are statistically insignificant at conventional levels. The regression excludes observations in 2007 and 2008 to eliminate any potential anticipation effects. Standard errors are clustered by firm. ***, **, * denote significance at 1%, 5% and 10% level, respectively.

G. Treatment II: SMEs that remained as SMEs after 2008

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

The policy experiment summarised in this section is of interest, as it compares the large companies whose tax component of user cost remained remained stable, to SMEs whose tax component of user cost dropped by around 8-10 percent.

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

It is difficult to make a case for common pre-reform trends for this group. Nevertheless, we present the results from this alternative experiment in Table G.1, and observe a positive and significant effect of the policy.

Table G.1 summarises the regression results, following the same specifications used for regressions in Table 3. Specifically, Column (1) presents results of the baseline specification with no controls. The variable 'Treated Firm * Post-reform' captures the mean differences in R&D spending between treatment and control groups as a result of the reform and is estimated to be positive and highly significant.

Regression results in Table G.1 controls for any potential anticipation effect of firms in response to the early announcement of the policy, by removing observations in years 2007 and 2008 yields similar results. The point estimate of the coefficient on the interaction term in Column (3) is 0.193 and significant at the 5 percent level.

Table G.1—. Results with an Alternative Treatment Group: SMEs that remained SMEs (rate increase experiment)

	(1)	(2)	(3)
Treated Firm * Post-reform	0.191*	0.198**	0.193**
	(0.101)	(0.099)	(0.094)
Post-reform	0.106		
	(0.083)		
Revenue (real, lag) control?	No	No	Yes
Revenue (real, lag) growth control?	No	No	Yes
Firm fixed effects?	Yes	Yes	Yes
Year fixed effects?	No	Yes	Yes
N	7,323	7,323	7,323

Note: This table presents regression results for the effect of the R&D tax credits on qualifying R&D spending based on Equation 1. The dependent variable is the level of qualifying R&D spending (in real, thousand GBP). The treated group is composed of companies that claimed R&D relief under the small and medium sized company (SME) scheme and had fewer than 250 employees in the last pre-reform year in which they performed R&D. These companies were still classified as SMEs after the 2008 reform. The control group are companies that claimed R&D relief under the large company scheme and had more than 500 employees in the last pre-reform year in which they performed R&D. Therefore, the control group companies are those that remained as Large after the 2008 reform. 'Treated Firm' is a dummy variable that takes the value unity for all firms that are in the treated group and zero for all firms in the control group. This is a time-invariant dummy. 'Post-reform' is a dummy variable that takes the value unity for all the periods after 2008. We drop the year 2008 as treatment status for this year is unclear due to the mid-year introduction of the policy reform. We also exclude observations in 2007 to eliminate any potential anticipation effects. The main coefficient of interest, which is the interaction term between being in the treatment group and in post-reform period (labeled Treated Firm * Post-reform), captures the differential changes in the R&D spending by the treated group of companies relative to that of the control group. Additional controls include first lags of real revenue, real revenue growth rate, an interaction term to capture the differential changes in size between pre- and post-reform periods, and the natural logarithm of lagged real revenues and its growth rate. Standard errors are clustered by firm. ***, **, * denote significance at 1%, 5% and 10% level, respectively.