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In ICT, Small is Big: The impact of R&D on ICT firm performance

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Abstract

We compare the effect of R&D on sales performance for ICT and non-ICT firms in Europe. We first illustrate that ICT firms invested €20.6 million more per firm on R&D compared to non-ICT firms in 2013, and that there is wide variation in R&D spending across the main European economies. We investigate how the effect of R&D on sales performance varies by age and size of ICT firms. We suggest that smaller firms spend much more on R&D than larger ones per EUR of sales revenue, and that young and small ICT firms exhibit a disproportionately large impact on innovation vis-a-vis their size and experience.

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ABSTRACT

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Keywords: ICT, R&D, Age, Size

1. Introduction

The effect of research and development (R&D) on firm performance has been much investigated over the years. Early studies identified a direct effect of R&D expenditure on firm output, evident both as separate components of firms' production functions and as contributors of total factor productivity (Mansfield, 1965, 1980). In these studies, the effect of R&D is evaluated by relating R&D and production[1] data and estimating a rate of return of R&D from a production function.[2] More recently, the effects of R&D expenditure have been linked to the innovation performance of a firm (Mairesse & Mohnen, 2005). Here R&D expenditures are primarily an input indicator of the efforts that firms make in establishing knowledge that might eventually lead to outputs (Griliches, 1990, 1998; Hagedoorn & Cloodt, 2003; Hausman, Hall, & Griliches, 1984; Prodan, 2005). Still other studies have shown that R&D expenditure has a significant positive effect on firm value as measured by the capital markets (Griliches, 1981). Together, these studies have provided awareness of the effect of R&D expenditures on firm output and value.

Although these studies have contributed greatly to our understanding of the effects of R&D in manufacturing related industries, there is a paucity of research that explicitly considers the effect of R&D in Information and Communication Technology (ICT) industries (for an exception see Hagedoorn & Cloodt, 2003). Given that the contribution of firms from the ICT sector can comprises a significant proportion of the productivity of countries, and the different productivity rates of countries (McGuckin & Stiroh, 2001; Van Reenen, Draca, & Sadun, 2008), understanding how R&D in these firms influences output is important. The interest in ICT firms is further reinforced by how the output of ICT firms itself influences invention. For instance, scholars have shown that not only is ICT a general purpose technology that can be adopted in many if not all different economic sectors, it also acts as an "invention machine" which induces subsequent invention of additional features and services. (Koutroumpis, Leiponen, & Thomas, 2016a, b). At a more macro level, the output from the ICT sector is also seen as a vital component in the emergence of knowledge based economies (OECD, 1996).

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[1] Or cost or profit.
[2] Usually an extended Cobb-Douglas function; an elasticity is sometimes used rather than a rate of return.

Another area of interest is how the size of the ICT firm impacts the output effect of the R&D. Both anecdotes and the popular press champion the role of both the many small scrappy ICT start-ups on the one hand, and the industry behemoths such as IBM, Microsoft, Cisco, Hewlett Packard, and Google on the other. Although there are many studies (and controversies) which consider firm size distributions (see for instance Marsili, 2005; Simon & Bonini, 1958), few studies have considered the ICT industry specifically (although see OECD, 2013). Furthermore, given that the ICT revolution has occurred only in the last couple of years, in general ICT firms are fairly young, in comparison to other industries, although there are some ICT firms, particularly in telecommunications, who have existed for quite some time. However, there is little empirical work considering the link between R&D and firm age. Although there are some controversial findings in the relationship between firm size and R&D effectiveness (see for instance Revilla & Fernandez, 2012), it is generally accepted that firm size has a positive effect on the level of R&D expenditure (Acs & Audretsch, 1988).

Our goal in this paper is to investigate the impact of R&D expenditure on firm performance comparing ICT and non-ICT firms. Through an analysis of an extensive group of firms from the Orbis/Amadeus dataset, we analyze the difference of R&D investment in firms in Germany, France, Sweden and the United Kingdom, as well as the effects of age and size on the effect of R&D on firm sales. To do so, we develop a production function framework to analyze the output effects of R&D investment. Conditional on the type of R&D activities undertaken, investments in R&D can help firms maintain a competitive advantage allowing them to price differentiate and target specific markets.

We contribute by highlighting a large variation in R&D investment between ICT and non-ICT-firms in Germany, France, Sweden and the United Kingdom. We also contribute by demonstrating that R&D investments in young and small ICT firms exhibits a disproportionately large impact on output vis-a-vis their size and experience. We suggest that this highlights the impressive contribution that small research budgets can have in the ICT technology sector (similar to seed funding). We also highlight the various policy implications for R&D incentives that arise at this point.

This paper is organized as follows: in Section 2 we describe the data sources and methods used to analyze them; section 3 presents the results; in section 4 we discuss our findings and propose practical policy-making actions to utilize this knowledge; section 5 concludes.

2. Method

Labeling a firm as ICT or non-ICT is not straightforward. There are various firms outside of the ICT sector that may have substantial ICT departments but do not produce or offer ICT products and services, and others with a highly diversified internal structure that are within the ICT sector. One way of labelling ICT firms has been through the notion of "ICT-intensity" (Stiroh, 2002b; van Ark, O'Mahony, & Timmer, 2008). This approach amalgamates ICT-producing and ICT-using firms into a single category. ICT-producing firms are by their nature considered ICT, while ICT-using firms are generally considered to be those with above-median ICT capital flows as a proportion of total capital flows (Bloom, Sadun, & Ven Reenen, 2012). However, sourcing data for ICT capital flows can be problematic as they are often not broken out from the overall capital numbers, particularly for smaller firms, a key aspect of investigation of this paper. For this reason, we restrict our definition of ICT firms to include any firm that produces ICT products or services, even if these are classified under different industry classifications (e.g., manufacturing, services, etc.).

Our data source is the Orbis/Amadeus dataset. We analyze 13,417 firms in Germany, France, Sweden and the United Kingdom that report R&D activity for at least one of the years in the ten-year period 2004-2013. We exclude pharmaceutical firms from the sample due to their large investments in R&D, which may confound the results and are mostly non-ICT related. Within this sample there are 864 firms with the European Union's NACE (Nomenclature of Economic Activities) v2.0 ICT industry classifications that report R&D expenditure.[3] To ensure that we include those ICT firms that are not reported in the primary ICT classifications, we further expand this ICT treatment group. Using a pattern matching algorithm within the detailed firm descriptions provided by Orbis/Amadeus records, we identify firms that include in their description the following words as ICT: communication, telecommunication, electronics, information, & ICT. This broaden our treatment group to 1,124 firms.[4]

To build our production function model of how R&D affects firm performance, we consider the R&D knowledge creation as a form of capital. However, R&D capital is different from tangible and

[3] See Table A5 in the Appendix for ICT industry classifications for NACE v.2 codes.
[4] The analysis below uses this extended sample; we provide the results for the NACE ICT firms in the Appendix. These do not demonstrate any significant changes to our results.

human capital since many firms can use the same idea at the same time. As such, we view R&D both as a neoclassical factor of production and as a source of spillovers in the endogenous growth models (Stiroh, 2002a). The former assumes that R&D investments primarily increase internal firm returns (Griliches, 1973, 1979), as firms invest in R&D to improve their own production processes and to raise profits. This means that spillover effects are secondary and unintended consequences. Put differently, there is both internal and external R&D inputs, both of which affect firm performance (Basu & Weil, 1998; Romer, 1994).[5]

In our analysis we assume that all R&D activity primarily affects internal firm output and all potential spillovers accrue to the sector by year effects.[6] To measure the effects of R&D expenditures in firm performance and output we introduce a firm level production function framework looking at the entire panel for the period 2004-2013. Our model is the following:

$$\log(Revenue_{ijt}) = b_1 \log(A_{ijt}) + b_2 \log(K_{ijt}) + b_3 \log(L_{ijt}) + X_{jtn} + \varepsilon_{ijt}$$

where $Revenue_{ijt}$ is the reported revenue for company i in country j at year t, A_{ijt} represents the investment in Research and Development (R&D) in thousand Euros, K_{ijt} are the total assets, L_{ijt} is the total employment and X_{jtn} is a vector of country j, year t and NACE technology classification n fixed effects. We further control for country, year and NACE fixed effects in all models to account for heterogeneity across these dimensions.

Our main goal is to look into the specific effects of R&D expenditures using controls for ICT versus non-ICT, age and size. For this we split our panel into small and large firms, and young and old firms. We base our size thresholds upon the OECD classifications, where companies with less than 100 employees are considered small, and a firm is young if it has less than 10 years their incorporation (OECD, 2015). Thus firms with more than 100 employees are considered large, and those with more than 10 years since incorporation are considered old.

[5] There is extensive literature into what constitutes a production spillover, see Bartelsman et al (1994), Bresnahan (1986) and Keller (1998).

[6] Provided a new discovery becomes available all firms in the same or adjacent sector(s) have the option to use it.

In order to identify the relative impact of production inputs we interact all combinations of these characteristics to produce identifiers for small, young ICT firms and report the results for each subcategory separately. We further look into the patterns in all other sectors (old, large, non-ICT and their combinations).

3. Results

We first present the descriptive data in our sample and compare the differences in R&D investments across ICT and non-ICT firms.

3.1 Descriptive analysis

[Insert Figure 1 and Table 1 around here]

Figure 1 presents R&D investment per ICT and non-ICT firms for the years 20004 to 2013. Overall, ICT firms invest significantly more in R&D than non-ICT firms. However, the level of investment has been decreasing over time, with a rapid drop from 2004 to 2008, and then a more gradual decrease after this. In 2013, firms have been spending approximately 20.4 million EUR per firm more on R&D compared to non-ICT firms.

[Insert Table 2 here]

Next we focus on R&D investment by country for ICT and non-ICT firms. Table 2 presents the R&D per firm for ICT and non-ICT firms in Germany, France, United Kingdom and Sweden for the period 2004-2013. There is variance in these results: ICT firms in Sweden spend almost twelve times compared to non-ICT ones (approximately 25 million EUR more on average); similarly, ICT firms in Germany spend more than three times the amount of non-ICT and in the UK local firms spend 52% more. In contrast, French firms only spend one third of R&D in ICT related firms research. Clearly there is vast heterogeneity in this metric as it includes entities that range from startups with less than 10 employees to established firms with billions EUR revenues. [7]

We now consider the effect of firm age on R&D investment. Figure 2 presents the R&D investment by firm age from 2013.

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[7] For a distribution of firms by country (obs) and a breakdown of capital, labor and R&D expenditure by category (small, young, ICT) see Appendix Tables A1-A3. Also for a full list of ICT NACE codes see Table A4.

[Insert Figure 2 here]

As is to be expected from the results above, ICT firms consistently invest more in R&D than non-R&D firms. However, this R&D investment increases as the firm gets older, ranging from approximately €1.1 million for firms under the age of 20 years, and then rising to approximately €4.9 million for firms 50 years old. In contrast, non-ICT firms invest less than €0.5 million a year until they are approximately 50 years old, when they invest approximately €1.4 million. Taken together, these results suggest that ICT firms increase the amount of R&D they undertake as they get older while non ICT firms maintain the same level of investment regardless of age. However, this effect may be confounded with the higher revenues and employee counts that often come with established firms.

We now consider the effect of firm and firm size on R&D investment. Figure 3 presents the R&D investment per revenue as a percentage for ICT firms that are young and small firms compared to ICT firms that are non-small and young.

[Insert Figure 3 here]

Interestingly, small and young firms invest in more R&D as a proportion of revenue than non-small and young ICT firms. In terms of the trend over time, non-small and young ICT firms maintain approximately the same level of R&D investment from 2004 to 2013, while the rate of investment for small and young, although always higher, varies considerably.

3.2 Effect of R&D investment on firm performance.

We now turn to our econometric model, which investigates the causality of R&D expenditure on firm output. The results are presented in Table 3.

[Insert Table 3 around here]

First we observe that fixed assets and employment counts have the expected behavior across all results (columns 1-6). R&D is also found to be significant with a coefficient of 0.602, which translates into a 0.6 EUR return for every euro spent in R&D. This means that not all firms are successful in turning research investments into actual returns.

To understand this link further we break the firm sample into ICT and non-ICT firms (column 2), young and old firms (column 3), small and large firms (column 4), small ICT and non-small ICT firms (column 5) and small, young and ICT firms and non-small, young and ICT firms (column 6). We also provide the sample statistics for each category in the Appendix (Table A1).

The R&D effects change substantially across these categories. The main R&D effect seems to increase for non-ICT firms and decrease for ICT ones (column 2). Moreover, the young firms in our sample seem to receive almost four times the base R&D effect while older ones do not show any impact from research (column 3). Large firms are also more likely to experience revenue growth from R&D investments whereas small ones are not systematically affected (column 4).

We then look into small ICT firms compared to the rest of the firms in our sample. These represent a small fraction of all firms (3.5%)[8] but the R&D impact we find is almost 100 times higher than the base estimate (column 5). We further expand this by looking into small, young and ICT firms (column 6). The results in this case – for an even smaller fraction of the sample (0.5%) are even higher reaching almost 250 times the base R&D effect on output. In other words, small ICT firms, and more specifically small and young ICT firms, are extremely well placed to take advantage of R&D investments and turn them into real revenue growth.

4. Robustness checks

We identify three sources of potential bias in our results. The first may be linked to small young or young ICT firms having some particular characteristics vis-a-vis their R&D inputs. This may suggest that small, young and ICT firms carry on effects that all small & young or all young ICT firms exhibit. To account for this bias we break our sample into young, and small & young CT firms and interact the binary variables with R&D. The results in Table 4 suggest that there is no effect from small & young or young ICT firms on R&D (columns 1-2). We therefore conclude that all the effect on young, small and ICT firms comes from this combination altogether, and not other residual parts in small ICT, young ICT.

[Insert Table 4 here]

The second may arise from the labeling of ICT firms with our expanded definition based on the firm description. For this purpose, we rerun all the analysis using NACE level classification only. The

[8] Almost 3.5% of our sample (3484 observations).

results are presented in Table 5. While the estimates are slightly smaller in all categories of R&D the effect remains almost unchanged. We also repeat the tests for small & young and young ICT (as in Table 3) and find identical results (Table 6).

[Insert Tables 5 and 6 around here]

Third, it is possible that the effect runs from profitable firms to R&D rather than the opposite way. This means that we may be capturing an effect from successful ICT firms that invest in research rather than the effect of research inputs in firm performance. To account for this potential bias we introduce an instrument that directly affects research inputs but not firm output. The quality and scarcity of research personnel is closely linked to research inputs, i.e. firms located close to research centers and universities are more likely to recruit researchers from these areas. Therefore, the distance from high quality educational institutions is used as a proxy of research quality. For example, firms based in London, Paris, Cambridge or Munich are much more likely to find research staff for their relevant departments compared to other firms based in remote areas far away from universities or research centers.

To construct this instrument, we combine our dataset with information on university ranking and GIS locational data.[9] In particular, we first look into global university rankings for the period of study and focus on the list with the top 100 universities and colleges[10]. Based on the location of each firm (included in the original Orbis/Amadeus data) we compute the distance to the nearest university from the list (up to a maximum of 100 miles).[11] This variable D that we use as an instrument on research input, is defined as the straight line distance from the location (lat_u,lon_u) of the nearest top university *U* to the location (lat_f,lon_f) of each firm *F*.

Using this instrument, we repeat our analysis on ICT, small and young firms. We find that the main effects remain unchanged while both the coefficient on R&D (column 1) and the impact on small, young ICT firms is increased (column 2) compared to the base case. In fact, the magnitude now is

[9] Source of historical University rankings to construct the instrument, http://www.universityrankings.ch/positions_by_fields/qs?region=Europe&year=2010&field=rank_technology&q=; Encoding of distances to universities (with API key), http://www.gpsvisualizer.com/geocoder/.
[10] We look into the top 100 THE and QS lists for the period 2004-2013 (Source: http://www.universityrankings.ch) .
[11] We use this online resource to compute distanced on csv data http://www.gpsvisualizer.com/geocoder/

almost 1,000 times higher compared to 200 times in the base model (between non-small, young and ICT and small, young and ICT). This is mainly linked to the fact that firms in close proximity to universities are more likely to invest in research compared to others based in remote areas that make recruitment harder. [12,13]

[Insert Table 6 here]

5. Discussion and conclusion

This paper investigates the effect of R&D on innovation in European firms, comparing ICT and non-ICT firms. We demonstrated that overall ICT firms have been spending 20.6 million EUR more per firm on R&D compared to non-ICT firms in 2013. We also show that there is wide variation in R&D spending across four of the main economies in Europe, and which also varies by whether a firm is ICT or non-ICT. Although historically there have been data availability issues, this aligns with existing research, which shows that R&D spending varies considerably across European countries (van Pottelsberghe de la Potterie, 2008).

We demonstrated that the previous trends are reversed: smaller firms spend much more on R&D than larger ones per EUR of sales revenue, with young (<10 years) and small (<100 employees) firms spending 10 times more than old and small firms and 100 times more than large firms in R&D per employee. To our knowledge this is the first study that investigates this these characteristics of firms together. It appears that young and small ICT firms exhibit a disproportionately large impact on innovation vis-a-vis their size and experience. This finding indicates the impressive contribution that small research budgets can have in this technology sector (OECD, 2015).

In terms of policy implications, these results suggest that policy makers concerned with maximum firm output should target R&D incentive at ICT firms. Furthermore, research to date has demonstrated that R&D incentives are more effective for smaller than for larger firms. For instance, Bronzini and Piselli (2016) recently find that the smaller the firm, the greater the impact of an R&D policy on the intensity and probability of patenting. Similarly, Criscuolo, Martin, Overman, and Van

[12] First stage results indicate a strong instrument covering all instrument tests (Wald, Stock-Yogo).
[13] We repeat the tests including firm-level effects; these are still preliminary but largely in line with the existing findings

Reenen (2012) find that R&D incentive programs have a positive effect on employment, investment and net entry[14] for smaller firms. Although the mechanisms for this relationship are not clear, we suggest that our findings suggest that such targeting may result in a supercharged effect.

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[14] But not total factor productivity.

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Figure 1 – **R&D investment per ICT/non-ICT firm**

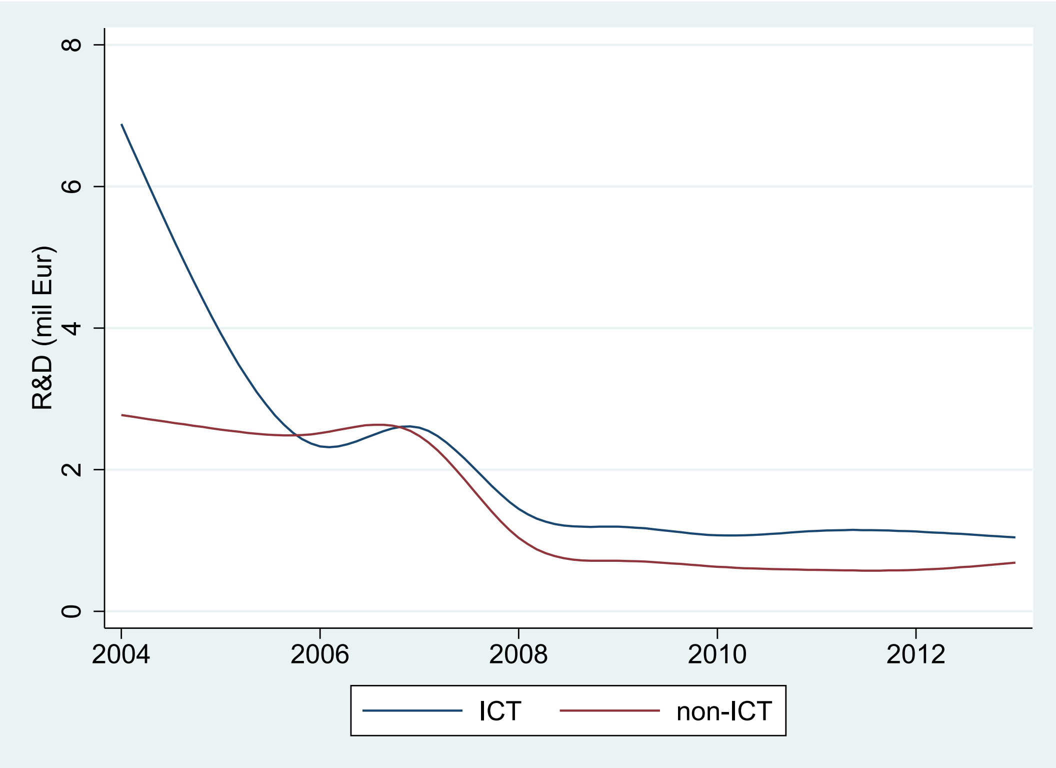

Figure 2 – **R&D investment by firm age**

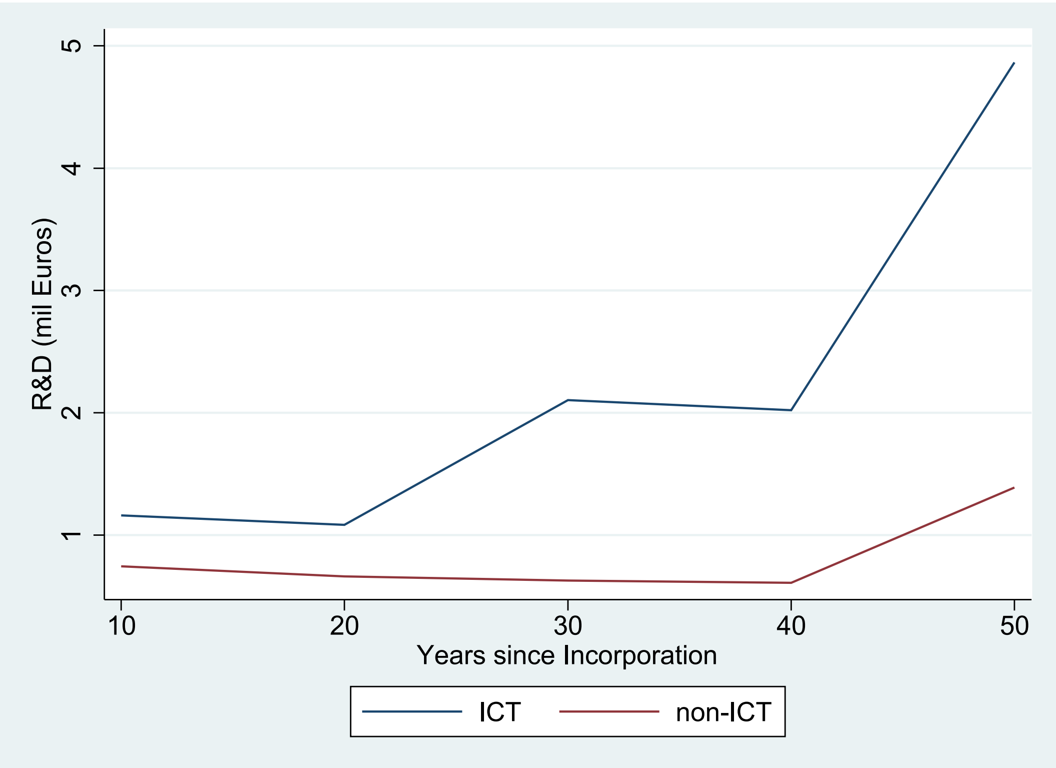

Figure 3 – **Young and small firms R&D expenditure per Revenue (%)**

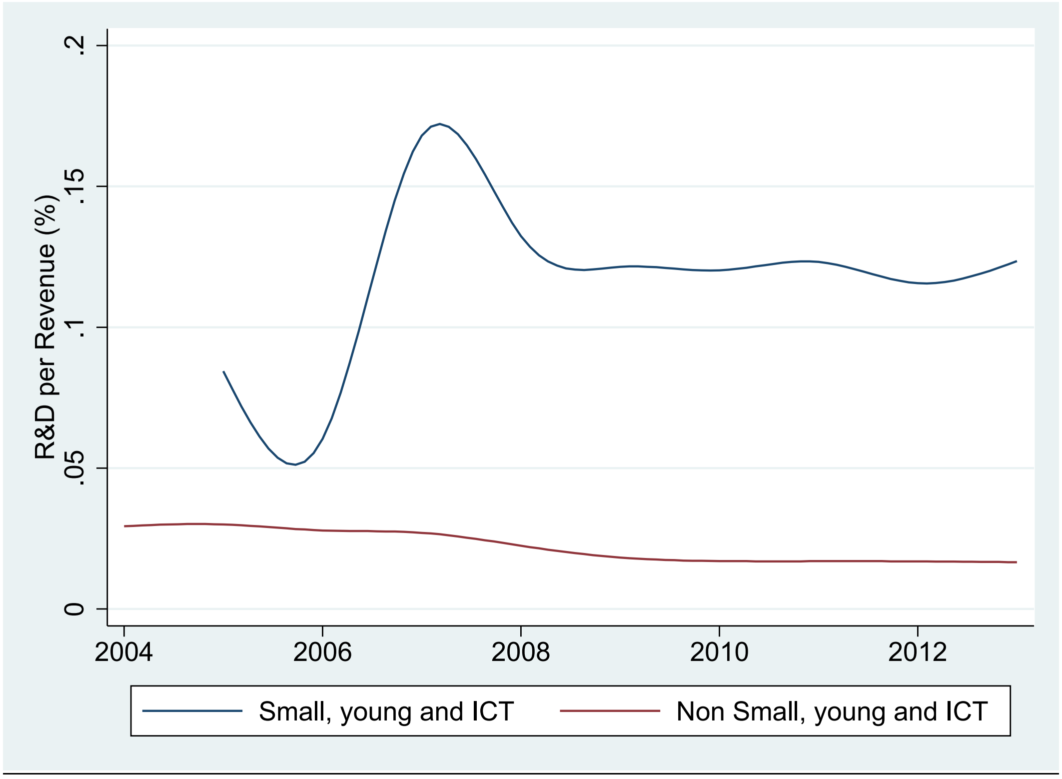

Table 1 – Investment in R&D by firm type and year

Firm Type	*year*	*mean*	*sd*	*min*	*max*	*N*
non-ICT	2004	15.23972	175.5585	-0.604	5649	3368
non-ICT	2005	10.37818	132.8937	-0.2091836	4430	5229
non-ICT	2006	9.982521	138.11	-3.479859	5060.815	5844
non-ICT	2007	9.564511	139.3862	-1.311466	5974.936	6618
non-ICT	2008	8.244662	127.8227	0	6651.224	8506
non-ICT	2009	6.963562	119.5412	-0.0157339	7201.489	11299
non-ICT	2010	6.98238	120.6735	-0.3166524	7406.291	13331
non-ICT	2011	6.791616	121.0982	-38.04703	7898.379	14319
non-ICT	2012	6.756601	122.3876	-1032.907	7539.849	13594
non-ICT	2013	8.274056	144.8544	-29.5679	8239.88	10912
ICT	2004	105.8332	535.6459	0	5155	158
ICT	2005	166.6182	1458.95	0	21160.82	225
ICT	2006	141.8258	1317.537	0	20520.9	263
ICT	2007	136.0661	1374.861	0	22967.53	301
ICT	2008	70.03748	840.5536	0	18187.47	530
ICT	2009	23.42392	226.8871	0	3810	885
ICT	2010	22.21283	225.006	0	4190	1062
ICT	2011	21.44116	230.7249	0	4442	1122
ICT	2012	20.92355	232.3544	0	4543	1074
ICT	2013	28.68681	295.4684	0	4959	707

Table 2 – Investment in R&D by firm type and country

		mean	sd	min	max	N
non-ICT	DE	70.55561	309.3592	0.001875	5649	2115
non-ICT	FR	46.5564	282.2643	-3.662	4905	4353
non-ICT	GB	6.039403	55.00501	-1032.907	2114.979	13265
non-ICT	SE	2.222943	53.61767	-0.2091836	3865.427	48446
ICT	DE	248.9341	866.8398	0.000882	5155	438
ICT	FR	15.27886	98.18165	-0.393	900	701
ICT	GB	9.187844	57.184	0.0000147	1322.914	4409
ICT	SE	27.59779	271.9471	0	3715.726	1551

Table 3 – Impact of R&D on output

	(1)	(2)	(3)	(4)	(5)	(6)
Method	FE	FE	FE	FE	FE	FE
VARIABLES	Revenue	Revenue	Revenue	Revenue	Revenue	Revenue
Assets	0.551***	0.550***	0.551***	0.551***	0.551***	0.551***
	(0.00178)	(0.00181)	(0.00178)	(0.00178)	(0.00178)	(0.00178)
Employment	50.36***	50.74***	50.32***	50.36***	50.36***	50.36***
	(0.675)	(0.682)	(0.675)	(0.675)	(0.675)	(0.675)
R&D	0.602***					
	(0.0718)					
non-ICT firms R&D		0.788***				
		(0.0858)				
ICT firms R&D		0.292***				
		(0.106)				
old firms R&D			0.595***			
>10 years from incorporation			(0.0719)			
young firms R&D			2.496***			
<10 years of incorporation			(0.811)			
large firms R&D				0.602***		
>=100 employees				(0.0718)		
small firms R&D				0.664		
< 100 employees				(5.727)		
non-small ICT-firms R&D					0.603***	
					(0.0718)	
small ICT-firms R&D					66.17***	
					(24.63)	
non-small&young ICT-firms R&D						0.602***
						(0.0718)
small young ICT-firms R&D						150.7**
						(71.97)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year Fe	Yes	Yes	Yes	Yes	Yes	Yes
Nace code FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	71,432	71,432	71,432	71,432	71,432	71,432
R-squared	0.799	0.799	0.799	0.799	0.799	0.799

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4 – Robustness checks for the impact of R&D on output

	(1)	(2)
Method	FE	FE
VARIABLES	revenue	revenue
Assets	0.551***	0.551***
	(0.00178)	(0.00178)
Employment	50.36***	50.36***
	(0.675)	(0.675)
Non-young ICT R&D	0.602***	
	(0.0718)	
Young ICT R&D	2.721	
	(8.606)	
Non-small Young R&D		0.602***
		(0.0718)
Small Young R&D		11.79
		(16.99)
Country FE	Yes	Yes
Year Fe	Yes	Yes
Nace code FE	Yes	Yes
Observations	71,432	71,432
R-squared	0.799	0.799

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 – Impact of R&D on output (NACE only)

	(1)	(2)	(3)	(4)	(5)	(6)
Method	FE	FE	FE	FE	FE	FE
VARIABLES	Revenue	Revenue	Revenue	Revenue	Revenue	Revenue
Assets	0.551***	0.554***	0.551***	0.551***	0.551***	0.551***
	(0.00178)	(0.00178)	(0.00178)	(0.00178)	(0.00178)	(0.00178)
Employment	50.36***	50.23***	50.32***	50.36***	50.36***	50.36***
	(0.675)	(0.673)	(0.675)	(0.675)	(0.675)	(0.675)
R&D	0.602***					
	(0.0718)					
non-ICT firms R&D		0.770***				
		(0.0721)				
ICT firms R&D		-5.246***				
		(0.312)				
old firms R&D			0.595***			
>10 years from incorporation			(0.0719)			
young firms R&D			2.496***			
<10 years of incorporation			(0.811)			
large firms R&D				0.602***		
>=100 employees				(0.0718)		
small firms R&D				0.664		
< 100 employees				(5.727)		
non-small ICT-firms R&D					0.602***	
					(0.0718)	
small ICT-firms R&D					32.51*	
					(17.64)	
non-small&young ICT-firms R&D						0.602***
						(0.0718)
small young ICT-firms R&D						133.4**
						(66.70)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year Fe	Yes	Yes	Yes	Yes	Yes	Yes
Nace code FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	71,432	71,432	71,432	71,432	71,432	71,432
R-squared	0.799	0.800	0.799	0.799	0.799	0.799

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6 – Robustness checks for the impact of R&D on output (NACE only)

	(1)	(2)
Method	FE	FE
VARIABLES	revenue	revenue
Assets	0.551***	0.551***
	(0.00178)	(0.00178)
Employment	50.36***	50.36***
	(0.675)	(0.675)
Non-young ICT R&D	0.602***	
	(0.0718)	
Young ICT R&D	4.854	
	(13.30)	
Non-small Young R&D		0.602***
		(0.0718)
Small Young R&D		11.79
		(16.99)
Country FE	Yes	Yes
Year Fe	Yes	Yes
Nace code FE	Yes	Yes
Observations	71,432	71,432
R-squared	0.799	0.799

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7 – Robustness checks for the impact of R&D on output (IVs)

	(1)	(2)
Method	IV	IV
VARIABLES	revenue	revenue
Assets	0.543***	0.544***
	(0.00513)	(0.00516)
Employment	48.03***	48.07***
	(1.551)	(1.554)
R&D	1.621***	
	(0.614)	
non-small&young ICT-firms R&D		1.579**
		(0.616)
small young ICT-firms R&D		1,465.9**
		(702.7)
Country FE	Yes	Yes
Year Fe	Yes	Yes
Nace code FE	Yes	Yes
Observations	71,432	71,432
R-squared	0.761	0.760

Instruments used for first stage: city level dummies for all cities with at least one higher education institution (University or College) in the top 100 THE or QS lists for the period 2004-2013 (Source: http://www.universityrankings.ch) .
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A1 – Country Frequency and Percentage

Country	Freq.	Percent
DE	4,150	3.09
FR	5,860	4.37
GB	52,800	39.35
SE	71,360	53.19
Total	134,170	100

Table A2 – Descriptive Statistics by firm for each cluster and combinations (small, young, ICT)

All	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Revenue (th. Eur)	104,139	403,666	4,119,679	-225	297,000,000
Assets (th. Eur)	108,626	540,562	5,430,308	0	268,000,000
Employment	101,640	1,607	14,353	0	648,254
R&D (th. Eur)	77,335	10,930	133,457	-1,032,907	5,649,000
Small					
Revenue (th. Eur)	62,350	12,145	62,907	-225	4,477,138
Assets (th. Eur)	63,515	27,828	157,179	0	6,197,609
Employment	63,566	27	29	0	99
R&D (th. Eur)	47,910	251	1,797	-3,480	104,052
Young					
Revenue (th. Eur)	17,797	101,623	811,891	-1	30,100,000
Assets (th. Eur)	18,454	176,981	1,323,021	0	40,000,000
Employment	16,431	484	4,210	0	210,633
R&D (th. Eur)	13,346	2,052	23,364	-919,466	732,810
Nace ICT					
Revenue (th. Eur)	6,642	366,153	3,136,185	0	66,000,000
Assets (th. Eur)	7,123	639,587	7,641,451	0	182,000,000
Employmentr	6,464	1,263	9,734	0	203,008
R&D (th. Eur)	4,038	14,240	113,704	-393	2,331,000
ICT					
Revenue (th. Eur)	8,828	484,009	4,045,756	0	78,400,000
Assets (th. Eur)	9,371	731,269	7,601,348	0	182,000,000
Employment	8,733	1,944	18,501	0	439,400
R&D (th. Eur)	5,012	39,142	311,124	0	5,155,000
Small Young					
Revenue (th. Eur)	12,213	8,260	61,645	0	4,477,138
Assets (th. Eur)	12,309	25,808	150,284	0	2,990,293
Employment	12,345	17	26	0	99
R&D (th. Eur)	9,271	233	1,406	-3,480	46,731
Small Young Nace ICT					
Revenue (th. Eur)	444	9,638	17,213	0	178,017
Assets (th. Eur)	447	19,072	59,454	5	565,788
Employment	448	41	31	0	99
R&D (th. Eur)	292	870	1,706	0	10,944
Small Young ICT					
Revenue (th. Eur)	488	10,691	14,149	0	140,952
Assets (th. Eur)	493	15,272	37,268	0	428,876
Employment	494	46	31	0	99
R&D (th. Eur)	326	868	1,437	0	9,518

Table A3 – NACE v.2 Industry classification

NACE v2 Code	Description
261	Manufacture of electronic components and boards
262	Manufacture of computers and peripheral equipment
263	Manufacture of communication equipment
264	Manufacture of consumer electronics
268	Manufacture of magnetic and optical media
4651	Wholesale of computers, computer peripheral equipment and software
4652	Wholesale of electronic and telecommunications equipment and parts
5820	Software publishing
6110	Wired telecommunications activities
6120	Wireless telecommunications activities
6130	Satellite telecommunications activities
6190	Other telecommunications activities
6201	Computer programming activities
6202	Computer consultancy activities
6203	Computer facilities management activities
6209	Other information technology and computer service activities
6311	Data processing, hosting and related activities
6312	Web portals
9511	Repair of computers and peripheral equipment
9512	Repair of communication equipment

Figure A1 – **R&D investment per ICT/non-ICT firm with NACE values**