ETLA Working Papers
No. 51
2 August 2017

Pantelis Koutroumpis
Aija Leiponen
Llewellyn D W Thomas

THE YOUNG, THE OLD AND THE INNOVATIVE

The Impact of R&D on Firm Performance in ICT versus Other Sectors

Suggested citation: Koutroumpis, Pantelis & Leiponen, Aija & Thomas, Llewellyn D W (2.8.2017). "The Young, the Old and the Innovative: The Impact of R&D on Firm Performance in ICT versus Other Sectors".
ETLA Working Papers No 51. http://pub.etla.fi/ETLA-Working-Papers-51.pdf

ETLA ELINKEINOELÄMÄN TUTKIMUSLAITOS
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY

ISSN-L 2323–2420
ISSN 2323–2420 (print)
ISSN 2323–2439 (online)

NUORET, VANHAT, JA INNOVATIIVISET: T&K TOIMINNAN VAIKUTUS ICT-YRITYSTEN MYYNTIIN JA TUOTTAVUUTEEN

Pantelis Koutroumpis
Imperial College Business School

Aija Leiponen
Cornell University ja ETLA – The Research Institute of the Finnish Economy

Llewellyn D W Thomas
Imperial College Business School

TIIVISTELMÄ

ICT-yritysten innovaatiomahdollisuuksien ajatellaan olevan erityisen hedelmällisiä, koska ICT teknologian kehitys jatkuu nopeana. Tämä tutkimus kuvailee T&K-toiminnan tuottoja eri toimialoilla ja vertailee ICT-aloja muihin aloihin pureutuen samalla yritysten välisiin koko- ja ikäeroihin. Empiirisenä aineistona on laaja eurooppalainen yrityspaneeli. Tulokset vahvistavat että ICT-yritysten T&K-tuotot ovat keskimäärin muita aloja korkeampia, erityisesti pienissä yrityksissä ja internet palveluissa sekä tietotekniikan komponenteissa. Hieman yllättävää on että pienet ja vanhat ICT-yritykset saavat parhaat T&K-tuotot. Julkisissa T&K-ohjelmissa ei ehkä kannatakaan keskittyä vain nuoriin startup-yrityksiin vaan ICT-alalla myös kypsemmät mutta silti pienet ja ketterät yritykset voivat kerätä hyvin tuottoa innovaatiotoiminnastaan.

Asiasanat: ICT, T&K-toiminta, yritysten tuottavuus, teknologiset mahdollisuudet, yrityskoko, yritysten ikä

JEL luokat: O31, O32, D24

THE YOUNG, THE OLD AND THE INNOVATIVE: THE IMPACT OF R&D ON FIRM PERFORMANCE IN ICT VERSUS OTHER SECTORS

ABSTRACT

Although innovation opportunities within the ICT industry are assumed high in comparison with other industries because of their rapidly evolving technological trajectory, little empirical research systematically investigates the distribution of returns to R&D investment across industries and types of firms. Building on the technological opportunity framework, we examine the effect of R&D on firm revenues in a large panel of European firms and study its variation with the age, size, and sub-sector of firms. We confirm that R&D investments in ICT firms have a larger effect on their revenue performance when compared to non-ICT firms and that the effect is higher for small firms and for firms in Internet services and ICT component manufacturing. At the firm level, our results suggest that smaller and, surprisingly, older ICT firms are technologically opportunistic and exhibit the flexibility and adaptability to both identify and respond to technological opportunities and develop innovative products and services. We highlight some implications for R&D investment and policy.

Keywords: ICT, R&D, firm performance, technological opportunity, firm age, firm size

JEL classes: O31, O32, D24

Acknowledgment: This paper was completed while Leiponen was on a sabbatical leave at ETLA. She gratefully acknowledges the support of BRIE-ETLA and SWiPE projects.

1. Introduction

Information and Communication Technologies (ICTs) enable significant improvement in firm productivity across industries and contribute to the economic growth of nations (Bloom, Sadun, & Ven Reenen, 2012; Brynjolfsson & Hitt, 2003; Hitt & Brynjolfsson, 1996; Kohli & Devaraj, 2003; Kudyba & Diwan, 2002; Sabherwal & Jeyaraj, 2015; Tambe & Hitt, 2012). Previous research generally considers ICT as an input into both the production function and the knowledge production (R&D) function (Bardhan, Krishnan, & Lin, 2013; Hall, Lotti, & Mairesse, 2012; Kleis, Chwelos, Ramirez, & Cockburn, 2012; Mittal & Nault, 2009). ICT affects both production and R&D in a wide set of industries because of its characteristics as a "general purpose technology" that can be applied in many contexts (Bresnahan & Trajtenberg, 1995), and as an "invention machine" that facilitates invention of products and services in other sectors (Koutroumpis, Leiponen, & Thomas, 2016, forthcoming). ICT investments both interact with and complement R&D investments leading to significant firm performance (Bardhan et al., 2013): an increase in ICT investment has been found to be associated with an increase in R&D output controlling for innovation-related spending (Kleis et al., 2012).

Despite a long history of scholarship investigating the relationship between R&D and productivity,[1] less is known about R&D performance in the ICT industry. Previous research has focused on the business value of ICT in relation to R&D and has mostly considered ICT intensive industries rather than the ICT sector per se (Bardhan et al., 2013; Chang & Gurbaxani, 2012). These studies have found that in ICT intensive industries ICT investment impacts R&D more substantially than in other industries. For instance, there is a larger interaction effect of ICT and R&D investment on Tobin's Q for ICT intensive firms than for low ICT intensive firms, which is substantially greater when there was a higher R&D intensity (Bardhan et al., 2013). Similarly, firms with high ICT intensity receive greater spillover benefits from the ICT services industry, and for a longer sustained period, than low ICT intensive firms (Chang & Gurbaxani, 2012). Intriguingly, rather than acting directly on the production function as for low ICT intensity industries, the productivity effects of ICT

[1] See Griliches (2007) for a recent review.

investments in ICT intensive industries act through indirect augmentation of non-IT inputs and the underlying production technology, such as knowledge creation and R&D (Mittal & Nault, 2009). These studies suggest that R&D and ICTs interact in determining firm performance. However, there are few, if any, studies focusing on the R&D performance of ICT firms themselves.

We assess R&D performance through the framework of technological opportunities (Klevorick, Levin, Nelson, & Winter, 1995). Technological opportunities comprise the set of possible avenues for technological advancement, and as ICT industries have a close dependence on scientific activity and rapid scientific progress, there is a rapidly moving technological trajectory (Dosi, 1982, 1988) which refreshes the available technological opportunities. Furthermore, spatial and technological proximity among innovators in technology "hotspots", industrial parks, universities, and technology incubators has accelerated technology development and adoption within ICT industries (Adams & Jaffe, 1996; Chang & Gurbaxani, 2012; Tambe & Hitt, 2014). Indeed, knowledge spillovers between ICT firms have attracted considerable policy interest in the economic impact of R&D (Ezell & Andes, 2010), because these technologies make a vital contribution to knowledge-based economies (OECD, 1996).

In this paper, we compare technological opportunities faced by ICT and non-ICT firms using the distribution of returns to R&D as a measure of opportunity (Klevorick et al., 1995). To do so, we use a large panel of firms from Germany, France, Sweden and the United Kingdom for the period 2004-2013 to estimate the causal effect of R&D on revenue using two alternative modeling strategies. First, we use a standard production function framework to estimate R&D elasticity comparing industry, experience, size, and technological subfield effects. We confirm the causal effect of R&D with a set of instruments, lagged estimates, and quantile regression frameworks.

Second, we apply the performance index framework of Klette (1996) that enhances the standard Cobb-Douglas approach. As ICT industries are characterized by quick changes in technology and product design, using common firm deflators results in biased estimates in the production functions. The creation of new markets (smartphones, tablets, Internet of Things, apps, etc.) or the substitution traditional ones (with websites and platforms) creates an environment of imperfect competition with prices for various products reflecting idiosyncratic differences in cost. Our modified framework measures Klette's performance index at the firm level; this is essentially a Solow residual with the total output replaced by revenue. This index represents a metric of total factor productivity that can accommodate complementarities among knowledge components within firms and the persistence of knowledge capital (Klette, 1996). This approach complements the standard production function framework and allows us to confirm our initial findings and interpret the variation across ICT subsectors.

In addition to the industry effects, the performance impact of R&D is moderated by the age and size of firms. In particular, the years of experience in a sector and the knowledge capital acquired can significantly affect management practices, recruitment priorities, and strategic decisions, and hence performance (Herriott, Levinthal, & March, 1985). Similarly, the size of the firm is linked to the effect of technology diffusion within firms and their private returns (Cohen, 1995; Cohen & Klepper, 1996). However, the degree to which R&D drives the performance of entrepreneurial, i.e., small and young firms, as opposed to either older or larger establishments, has rarely been examined (for an exception see Peters, Roberts, Vuong, & Fryges, 2015). Given that entrepreneurship is in a 30-year decline in the United States, despite academic and policy efforts to the contrary (Decker, Haltiwanger, Jarmin, & Miranda, 2015), ICT-based high-technology startups are viewed as the holy grail of economic development. As such, investigating the role of age and size in the context of R&D performance is particularly salient for small and young ICT firms, which tend to attract a lot of attention in policy and academic scholarship (Audretsch, Segarra, & Teruel, 2014; Coad, Segarra, & Teruel, 2016; Czarnitzki & Delanote, 2012; Veugelers & Cincera, 2010).

Our analysis of the effects of industry, firm size, and firm age suggests that R&D investments in ICT firms have a larger impact on revenue when compared to non-ICT firms. Although this difference is significant for both large and small ICT firms, it is stronger for small firms. Counterintuitively, our results also suggest that R&D investments in older ICT firms generate a disproportionate impact on revenue performance and productivity. We also find that ICT firms that focus on internet services (such as websites and apps) or electronic components have had the greatest revenue impact from R&D investment. Our interpretation is that smaller firms have greater capabilities of "technological opportunism" (Mishra & Agarwal, 2010; Srinivasan, Lilien, & Rangaswamy, 2002) to both sense and respond to technological opportunities and market shifts, and hence have greater flexibility and adaptability in their R&D and managerial processes. However, technological opportunism does not seem to necessitate youth—more experienced small firms may be able to make the most of their investments and exhibit greater capabilities of technological opportunism. We highlight the R&D policy implications of these empirical insights.

The paper is organized as follows. In Section 2 we review the existing literature concerning technological opportunities, R&D investment, firm performance, and the effects of firm size and age. In Section 3 we describe the data sources and methods used to analyze them; Section 4 presents the main results and several robustness analyses, including the temporal aspects of our results, the distribution of the effects using quantile regressions, and instrumental variable models to assess the causality of our findings. In Section 5 we discuss the findings and present some practical policy proposals; Section 6 concludes.

2. Technological opportunities, R&D, and firm performance

Technological opportunities comprise the set of possible avenues for technological advancement and are an important aspect of the technological regime within which innovation and R&D occur (Klevorick et al., 1995; Malerba & Orsenigo, 1996; Revilla & Fernandez, 2012). Technological opportunities are used when innovation occurs, that is, when a new technology is launched and commercialized, and hence can be measured as the distribution of returns to R&D (Klevorick et al., 1995). New or improved products and services will expand sales through enhanced demand, whereas new or improved processes allow firms to compete more effectively and thereby gain market share. Technological opportunities are not finite as they are replenished through advances in scientific understanding, technological progress in enabling technologies originating outside the industry, and even positive feedback from the technology itself. The ICT industry is of particular interest. In their comparative study of the manufacturing sector, Klevorick et al. (1995) found that the ICT industry, specifically electronic components, had the greatest sources of opportunity renewal. At that time, semiconductors and electrical equipment had particularly high opportunities for innovation.

Firm age and size influence the ability of firms to take advantage of technological opportunities through R&D investment. Firm size has been found to have a positive effect on the level of R&D investment (Acs & Audretsch, 1988; Czarnitzki & Hottenrott, 2011), however, evidence for scale economies in R&D is mixed (Cohen, 1995; Henderson & Cockburn, 1996). It has been suggested that smaller firms experience a performance boost from R&D investment where there are abundant technological opportunities (Revilla & Fernandez, 2012). Other studies have found that larger, older and more productive firms have higher returns to R&D expenditure, with productivity driving most of the differences (Peters et al., 2015).

In terms of the effect of firm age, the empirical findings are also mixed. On the one hand there are learning effects, as firms gain experience and build on previous routines and capabilities, innovate more effectively, and subsequently achieve better firm performance (Sorensen & Stuart, 2000). In particular, older firms are able to accumulate resources, managerial knowledge and the ability to handle uncertainty (Herriott et al., 1985; Levitt & March, 1988), such that previous R&D experience for older firms results in more persistent and less erratic innovation (Garcia-Quevedo, Pellegrino, & Vivarelli, 2014). Furthermore, with age firms can accumulate reputations and beneficial market positions, which facilitate relationships with suppliers, customers and potential collaborators, leading to improved performance. Other research has found positive effects of firm age on the likelihood of superior organizational outcomes (Argote, 1999), new product development (Hansen, 1999; Sivadas & Dwyer, 2000), and innovative outcomes (Tripsas & Gavetti, 2000).

On the other hand, age may also have negative effects, including the obsolescence of the firms' knowledge base, as the processes of search become outdated and not well-suited to the current technological landscape (Sorensen & Stuart, 2000). Older firms may also experience organizational inertia that may hinder learning (Majumdar, 1997). Aligned with these ideas, firm age is found to be negatively related to the quality of technical innovations, and this effect is greater in rapidly progressing technology areas (Balasubramanian & Lee, 2008). Others have provided evidence that the oldest firms tend to show lower probabilities of successful innovation (Huergo & Jaumandreu, 2004), although R&D investment by younger firms appears to be significantly more risky than R&D investment by more mature firms (Coad et al., 2016).

The study of technological opportunities is related to a larger literature regarding the effects of R&D on economic performance of the firm. R&D investments are primarily viewed as an input into knowledge creation that might eventually lead to patents or new products (Griliches, 1990, 1998; Hagedoorn & Cloodt, 2003; Hausman, Hall, & Griliches, 1984; Prodan, 2005). Early studies found an effect of R&D investment on firm output, evident both directly as a component of firms' production functions and indirectly via total factor productivity (Mansfield, 1965, 1980). Subsequent studies have shown that R&D investment has a positive effect on the value of firms in the capital markets (Griliches, 1981; Hall & Oriani, 2004) and their innovation performance (Mairesse & Mohnen, 2005).

A smaller number of studies have considered the relationship between R&D investment and revenue, and the results are mixed. Some studies identified a positive effect of R&D investment on revenue growth (Del Monte & Papagni, 2003; Mansfield, 1962), while more recently, Coad et al. (2016) found that R&D investment was positively associated with the growth of the number of employees and productivity, but not revenue. Other research has explored the effect of innovation (variously measured) on revenue performance. Seminal papers from Scherer (1965), Geroski and Machin (1992), and Geroski and Toker (1996) found that product innovation has a significant positive effect on revenue growth. In contrast, Freel (2000) and Bottazzi, Dosi, Lippi, Pammoli, and Riccaboni (2001) obtained evidence that innovation has little effect on revenue performance, with Coad and Rao (2008) finding that innovation matters for revenue growth only for high-growth firms. However, none of these studies have focused on the effect of R&D investment on revenue performance in the ICT sector. In this paper, we compare the returns of R&D investment in terms of revenue performance across industries and types of firms to complement the view that ICT drives innovation and productivity in other sectors. We aim for a better understanding of the internal technological dynamics and impact of the ICT sector itself.

3. Data and method

Our data source is the Orbis/Amadeus dataset. We analyze 13,190 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 restrict our sample to Germany, France, Sweden and the United Kingdom due to poor data availability for other European countries.[2] We combine our data with OECD statistics for the same period on country and sub-industry level duties and taxes, and capital and labor shares.

We define an ICT firm as a firm that produces ICT products or services, even if the firm is classified under different industry classifications (e.g., manufacturing, services, etc.). Our sample contains 864 firms with the European Union's NACE 2.0 ICT industry classifications that report R&D investment.[3] We further expand this ICT group by applying a pattern matching algorithm to the detailed firm descriptions provided by Orbis/Amadeus. We include firms that have in their description the following words as ICT: communication, telecommunication, electronics, information, or ICT. This expands the ICT group to 1,124 firms.[4]

3.1 The effect of R&D on revenue performance

Knowledge created through R&D is viewed as a form of capital. Unlike tangible forms of capital, knowledge can be used by more than one firm at the same time. As such, we view knowledge both as a neoclassical factor of production and as a source of spillovers (Stiroh, 2002). Therefore, R&D investments are assumed to generate internal returns (Griliches, 1973, 1979), as firms improve their own products and processes to increase profits, and spillovers that involve unintended positive effects on rivals. In turn, firms may also benefit from rivals' R&D investments. There are thus both internal and external R&D inputs which affect firm performance (Basu & Weil, 1998; Romer, 1994).[5] In this paper we focus on the private returns of research investments.

We assume that R&D creates a stock of knowledge that yields returns in the future. Several studies have used a simple perpetual inventory method with a single or variable depreciation rates (depending on industries, countries or years) to construct the knowledge capital stock:

$$K_{it} = (1 - \delta_{jct})K_{i,t-1} + R_{it} \qquad (1)$$

[2] Country level data and analysis which highlights the heterogeneity of R&D availability data within Europe is available from the corresponding author upon request.

[3] The European Union's Nomenclature of Economic Activities (NACE) v2.0 ICT is available at http://ec.europa.eu/eurostat/. Table S1 in the Supplementary Materials details the NACE v2.0 ICT Industry classifications.

[4] The analysis below uses this extended sample. As a robustness check we also ran the results with the NACE v2.0 ICT firms; these do not demonstrate any significant changes to our results.

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

where K is the knowledge stock of firm i at time t, R is the real investment in R&D at time t, and δ is a depreciation rate of industry j in country c at time t arbitrarily or through a range of econometric methods,￼6 all of which have shortcomings. U7generate biased estimates for the effects of R&D, while the choice of a specific rate (either arbitrarily or via a modeling framework) does not seem to affect the resulting elasticities (Fraumeni & Okubo, 2005; Hall et al., 2010) persistence of R&D investments and the random walk behavior of log R&D time series (both evident in our dataset) suggest that only a linear function of log R&D can be used in the production function, as the resulting elasticities are not sensitive to the choice of depreciation rates (as shown by Hall et al., 2010)(as shown by Hall et al., 2010) As such, we do not take a perpetual inventory approach. As such, we do not take a perpetual inventory approach.[8]

Instead, in our first analysis, we assume that R&D activity primarily affects internal firm output and potential spillovers accrue to the whole sector by year effects.[9] To measure the effects of R&D investments on revenue we introduce a firm-level production function framework (Griliches, 1980; Schankerman, 1981) looking at the entire panel for the period 2004-2013. Our model is the following:

$$\log(Revenue_{ijt}) = b_1 \log(K_{ijt}) + b_2 \log(C_{ijt}) + b_3 \log(L_{ijt}) + X_{ijtn} + \varepsilon_{ijt} \qquad (2)$$

where $Revenue_{ijt}$ is the reported revenue for company i in country j at year t, K_{ijt} represents the knowledge capital as measured by the investment in R&D in thousand Euros, C_{ijt} are the total assets, L_{ijt} is the total employment and X_{ijtn} is a vector of country j, year t and NACE technology classification n fixed effects.

[6] Hall and Hayashi (1989) have suggested that current R&D depends on the level of the current stock.

[7] Hall et al (2010) explain that determining this rate is "difficult if not impossible" for two reasons. First, this depreciation rate is endogenous to firm behavior and depends on the competitive environment and technological progress. Essentially the choice of constant depreciation over time simplifies this relationship. Secondly, finding the depreciation rate independently from R&D returns is hard. Others (Hall, 2007; Hall et al 1986) have shown that the appropriate natural experiments are not possible to replicate in an *in vivo* context.

[8] For completeness, we ran all our analyses with and without the perpetual inventory method. The coefficients remain largely unchanged. Results are detailed in Table S6 in the Supplementary Materials.

[9] If a new technology is discovered, all firms in the same or adjacent sectors have the option to use it.

3.2 *The effect of R&D on productivity*

In addition to the simple R&D elasticity of revenue, we look into the relationship between knowledge creation and productivity. To do so we extend the knowledge production function model of Klette (1996) for a panel dataset. Our extension (a departure from the standard Cobb-Douglas production function that builds on knowledge accumulation as shown in Equation 1) to the original Klette (1996) model concerns a puzzle related to the estimated private rate of return to knowledge capital ρ_{it} (given by: $\rho_{it} = a^K \frac{Q_{it}}{K_{it}} - \delta_{jt}$). This production function translates into a higher rate of return for firms with the lowest knowledge to capital ratio, and hence a negative link between past investments and current rates of return. However this contradicts empirical evidence, as there are several studies that show that firms' R&D intensities tend to be highly persistent over time (Cohen & Klepper, 1992; Hall et al., 1986).

Griliches (1979) proposed complementarity between knowledge production and current R&D investments in the generic format $K_{i,t+1} = K_{it}^{\rho-\upsilon} R_{it}^{\upsilon}$ with υ representing the "innovative opportunities" of the R&D effort (Klette, 1996). Thus for our second analysis, we test the impact of research investments on the productivity performance of a firm relative to the "base firm" or the average firm in each industry. Klette (1996) shows that a performance index – which is a version of the Solow residual where the revenue has replaced real output – alleviates the perpetual inventory method's issues in dealing with the need for long panels and the inconsistencies in knowledge related rates of return and further research investments. The model we estimate is the following:

$$\widehat{\alpha_{i,t}} = \beta_1 \widehat{\alpha_{i,t-1}} + \beta_2 \widehat{x_{i,t}^C} - \beta_3 \widehat{x_{i,t-1}^C} + \beta_4 \widehat{r_{i,t-1}} + \widehat{e_{i,t}} \qquad (3)$$

where $\alpha_{i,t}$ is the performance index of firm *i* at time *t*, $\widehat{x_{i,t}^C}$ is the capital formation of firm *i* at time *t* and $r_{i,t}$ is the R&D investment of firm *i* at time *t.* A caret above the variable denotes the logarithmic deviation from a reference input-output vector, i.e. $\widehat{q_t} = \ln(Q_t/Q_{0t})$. In this model, β_4 measures the effect of R&D investment on changes in productivity performance. We provide a detailed discussion of the derivation of this model in the Appendix.

4. Results

To compare the effects of R&D investments on different types of firms, we create indicators for ICT vs. non-ICT firms; small and large firms; and young and old firms. We base our size thresholds upon the OECD classifications, where companies with fewer than 100 employees are considered small, and firms with less than 10 years since incorporation are considered young (OECD, 2013). Table 1 presents the descriptive statistics of our sample by category.

[Table 1]

We first present the descriptive data for our sample and compare the differences in R&D investments across ICT and non-ICT firms. We then present the results of our main two econometric analyses – estimating the R&D elasticity of revenue (equation 2) and measuring the effect of R&D on the performance index using our adjusted Klette (1996) model (equation 3). For our estimation of the R&D elasticity of revenue, we also propose a new instrument to assess the causality of our findings, investigate the temporal aspect through an analysis of the lag structure, and examine the distribution of the R&D effects across our sample using quantile regressions.

4.1 Descriptive analysis

We first look into R&D investments for ICT and non-ICT firms for the period of study. Using the median firm-level R&D observations and the standard errors for each year, we plot Figure 1 for the years 2004 to 2013.[10] In nominal terms, ICT firms invest significantly more in R&D than non-ICT firms. This is not the case for the share of their revenues though (see Figure 1b). In terms of R&D intensity ICT firms appear to invest less money than non-ICT do and this may be related to the type of activities non-ICT firms often embark on (including manufacturing facilities, new plants or industrial equipment). However, the level of investment has been decreasing over time, with a rapid drop between 2004 and 2008, .11 In 2013, ICT firms were spending approximately €20.4 million more on R&D compared to non-ICT firms. firms.

---

[10] Tables S2 and S3 within the Supplementary Materials provide descriptive country level results.

[11] This aligns with other studies on European R&D investments, see "Monitoring Industrial Research: The 2011 EU Industrial Investment Scoreboard", Joint Research Center, DG Research & Innovation, European Commission.

[Figures 1, 2 and 3]

Figure 2 presents the descriptive results of R&D investment by firm size, with larger firms more than 100 employees considered large. Again, ICT firms consistently invest more in R&D than non-ICT firms. However, ICT firms show greater variability over time, with large ICT firms decreasing their R&D investment from 2004 until 2013. We would expect firms to reduce their R&D investments in response to the 2008 recession, as we can observe for non-ICT firms. In contrast, small ICT firms increased their R&D investment from 2004 to 2010, before reducing their investment until 2013. Small non-ICT firms increased their R&D investment from 2004 to 2013.

We now consider the effect of firm age on R&D investment. Figure 3 presents the R&D investment by firm age from 2013. As before, ICT firms invest more in R&D than non-ICT firms for each age cohort, and both ICT and non-ICT have an inverted U-shaped R&D investment profile over time, peaking around 20-30 years since incorporation. However, ICT firms invest much more in R&D, peaking at €38 million approximately 25 years after incorporation whereas non-ICT firms peak at €8 million approximately 28 years after incorporation.

4.2 Effect of R&D investment on firm performance

We now turn to model (2) which investigates the impact of R&D investment on firm revenue performance. The results are presented in Table 2.

[Table 2]

First, we observe that fixed assets and employment counts have the expected positive and significant impact across all results (columns 1–4). R&D is also found to be a significant explanatory factor implying that, in general, firms successfully convert research investments into revenue. Breaking the sample into ICT and non-ICT firms (column 2), we find that the revenue impact is significantly greater for ICT firms. If R&D doubles sales in ICT firms will grow by 9.21% as compared with 1.57% for non-ICT firms, suggesting that ICT firms may enjoy six times greater revenue return on R&D investment than non-ICT firms.

Column 3 in breaks the sample down further considering small and large firms, both ICT and non-ICT. Here we find that both large and small ICT firms have the largest significant effects; doubling R&D investment yields 8.77% increase in revenues for large ICT firms, and 10.7% for small

ICT firms. In contrast, only small non-ICT firms have a significant effect, with 4.20% increase in revenues from a similar change. Column 4 splits the sample further into young and old, small and large, ICT and non-ICT. Here we find that older ICT firms obtain the largest significant effects, with a 10.0% increase for old, large ICT firms and 12.0% for old, small ICT firms. For non-ICT firms, the effects remain strong for both old and young firms, with 9.33% for young, small non-ICT firms and a coefficient of 3.75% for old, small non-ICT firms. Interestingly, we also find an 8.01% effect for young, large non-ICT firms. Taken together, these results suggest that it is both smaller and older firms that have an outsized effect on revenue performance from R&D investment, particularly small, older ICT firms.

[Table 3]

We further investigate the effects of firm size. Table 3 presents an analysis of several different employment bands comparing ICT and non-ICT firms. Here we find the effect of R&D on revenue performance is particularly strong and significant for firms with fewer than 10 people reaching an effect of 18.2% for ICT firms and 16.5% for non-ICT firms when R&D inputs double. The effect remains for ICT firms with 10 to 20 people (15.5%), ICT firms with 20 to 100 people (11.8%), and ICT firms with 100 to 500 people (9.98%). For non-ICT firms, the effect remains for smaller firms with 10 to 20 employees (8.12%) and 20 to 100 people (3.30%). For both ICT and non-ICT firms there is no effect for firms greater than 500 people. These results suggest that it is the very small firms (fewer than 10 people) who experience the greatest revenue performance effect from R&D, although larger ICT firms also enjoy a substantial revenue boost from R&D up until 500 employees. If causal, the marginal effects of 9.98%–18.2% for every 100% increase in R&D investment are large and imply that there are residual investment opportunities in ICT.

[Table 4]

Table 4 presents the analysis by firm age. Column 1 reports the effect of R&D across several age ranges, indicating an effect of 8.65% for non-ICT firms with less than 10 years of experience, aligning with the earlier finding in Table 3. Column 3 demonstrates that when firms have more than 21 years of experience both ICT (7.93%) and non-ICT firms (3.19%) have a significant effect, and Column 2 shows that only ICT firms with greater than 25 years of experience have a strong effect

(6.86%) for the doubling of R&D. Taken together these results suggest, perhaps surprisingly, that it is older ICT firms that have a greater effect of R&D investment on revenue performance.

[Table 5]

We now consider more specifically which types of ICT firms are the most strongly affected by R&D investments. Table 5 presents the analysis of the effect of R&D on revenue performance by NACE code, as well as by our extended ICT descriptor. The ICT firms that have the strongest effect are those related to the internet, with 23.8% effect from R&D doubling for Web Portals NACE class (NACE code 63.12), which includes the operation of web sites and media sites. The other ICT firms that have a significant effect are those related to the manufacture of magnetic and optical media (NACE code 26.80) with 11.5%, and the wholesale computers and peripheral equipment (NACE code 46.51), with 3.25%. In contrast, firms that deliver ICT services, such as computer consultancy, facilities management and data processing, hosting and related activities (NACE codes 62.02, 62.03 and 63.11 respectively), have a significant negative effect, as well as the Software Publishing of Computer Games (NACE code 58.21). R&D investment in these firms appears to have been an expense that is not recovered through revenue.

4.2.1 Robustness

To account for reverse causality from revenue growth to R&D investments, we introduce an instrument that directly affects R&D inputs but not firm revenue. The quality and availability 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. At the same time, there may be opportunities to form startups close to universities as researchers benefit from access to facilities, interaction with academics and other related resources and networking activities that take place around universities. Based on these we consider a firm's location and its proximity to high quality educational institutions a key variable that affects investments in R&D. We combine the information about the city that firms are located to understand whether a high-quality university is close to the firms. For example, firms based in Cambridge, Munich, or Lund are more likely to find R&D staff compared to firms based in towns far away from universities or research centers.[12]

To construct this instrument, we combine our dataset with information on university ranking and GIS locational data. In particular, we first look into global university rankings for the period of study (2004-2013) and focus on the list with the top 100 universities and colleges, taking the top 100 THE and QS lists for the period 2004-2013.[13] We calculate the straight line distance of each firm in thousands of kilometers (the location is included in the original Orbis/Amadeus data) from each of the top 100 universities.[14] Figure 4 presents the distribution of firms' distances from universities, and reassuringly shows that there is wide heterogeneity in this metric.

[Figure 4]

Using this instrument, we repeat our analysis.[15] In the first stage, we instrument R&D investment on distance and the predicted results are then used in the second stage. We find that the main effect from R&D remains strong and is now much higher compared to the original estimates. This is expected as the prediction of research inputs stems only from the proximity to high quality educational institutions for all firms in the area and not from other characteristics that may affect decisions for research undertakings. Our instrument passes the instrument validity, strength, and identification tests that are also reported.

4.2.2 Temporal Analysis

R&D investment does not have an instantaneous effect. In most industries, R&D results take years to be captured in the revenue figures. This is even more relevant for young firms as these have usually lower revenue volumes and a shorter stream of past investments to build on. Older and more established firms may invest in different projects over the years and increase their odds of success

---

[12] It is possible that being in major metropolitan area also facilitates sales through stronger demand, so that if most of our sample is located in such areas then the instrument is confounded. However, Figure 4 suggests that there are is quite a range of distances between our sample and high quality universities; as such we do not believe the instrument is confounded.

[13] Source: www.universityrankings.ch

[14] We calculate the distances to universities (with API key) using www.gpsvisualizer.com/geocoder/.

[15] Table S4 in the Supplementary Materials presents the results of these robustness checks of the impact of R&D on output (IVs).

whereas this is not often the case for younger and smaller entities. To understand the relationship between the time of investment and revenue performance, we expand our base model into the following format:

$$\log(Revenue_{ijt}) = b_1 \log\left(A_{ij(t-n)}\right) + b_2 \log\left(K_{ijt}\right) + b_3 \log\left(L_{ijt}\right) + X_{ijtn} + \varepsilon_{ijt} \quad (4)$$

where $A_{ij(t-n)}$ represents the investment in R&D in thousand Euros n years before year t. We use lags up to four years for the R&D effects.[16] This analysis suggests that the strongest effect for ICT firms comes from one- and two-year lags. For small/old ICT firms, the one-year lag is significantly positive, and slightly less so for large/old ICT firms respectively. However, the effect for young firms is not significant for the one-year lag, and significantly negative for large and small firms respectively. This shows that the prior investments of smaller and older ICT firms are responsible for the effect captured in the current year and this effect is much higher compared to the same year R&D levels. Furthermore, it suggests that for younger ICT firms, the more recent R&D investments have a greater impact on revenue performance.

In contrast, for non-ICT firms the one-year lag results in small significant effects with large/young and small/old non-ICT firms. Interestingly large/old non-ICT firms obtain a negative and significant effect, suggesting that R&D investments depress revenues. Only small and old non-ICT firms have a significant effect for the two-year lag. The effect of R&D on revenue performance is weakest for the three-year lag, with no significant results for ICT firms and a small significant positive for small/old non-ICT firms, and a smaller significant negative effect large/old non-ICT firms. Taken together, these results suggest that for most firms it takes 1–2 years for R&D investments to influence revenue performance.

4.2.3 Quantile Analysis

Beyond the temporal dimension of R&D investments, we are also interested in the distribution of these effects across our sample. So far, we have tried to explicitly label firms in terms of age and size but there may still be some uncaptured firm effects that help explain this wide variation across

---

[16] Table S5 in the Supplementary Materials presents the results of the lagged impact of R&D on revenue.

small and old ICT firms and the rest of the sample. For this purpose, we undertake a quantile regression analysis using the base model in Equation (2) and plot the findings for different levels of firm revenues.

Table 6 presents the results of the quantile regression of R&D on revenue performance, Figure 5 the illustrates the quantile regression of R&D on revenue performance for large and small firms, and Figure 6 those for young and old firms.[17]

[Table 6 and Figures 5 & 6]

Table 6 clearly demonstrates that the R&D effect grows consistently for ICT firms as revenues increase (ignoring the ends of the distribution that have few observations). Figure 5 shows that the R&D effect is stronger throughout for small firms rather than larger firms, supporting our earlier findings. Figure 6 shows the R&D effect stronger for older ICT firms than their younger counterparts, also supporting our earlier findings. Furthermore, these results suggest that the effect is strongest at the left tail of the revenue distribution; small firms with the smallest revenues enjoying the greatest effect.

4.3 Performance index results

We now turn to equation (3), which is our enhanced Klette (1996) model. Table 7 presents the results of these regressions, with the productivity performance index as the dependent variable. Columns 1 to 3 replicate the findings of Klette's original study, where we observe that the lagged performance index, lagged assets and lagged R&D have the expected positive and significant impact across all results, while the assets and lagged "No R&D" dummy also have the expected negative and significant impact across all results. With these results, we successfully replicate Klette's original findings with a new dataset. [18]

[Table 7]

---

[17] The tabulated data of Figures 5 and 6 are available from the corresponding author upon request.

[18] Table S6 in the Supplementary Materials presents the same 6 regressions as Klette (1996) reports in the same format as the original paper.

In column 4 we observe a significant and positive R&D effect[19] for both ICT (1.73%) and non-ICT firms (1.64%), with a slightly larger effect for ICT firms. Similarly, there is a stronger effect for ICT firms when considering the effects of firm size (column 5). Small ICT firms have the largest effect (2.74%), followed by non-ICT firms (2.60%). For larger firms, ICT firms have a larger effect (1.58%) when compared to non-ICT firms (1.39%). In column 6, introducing the moderating effects of firm age, we observe that the strongest performance effect from R&D is that of old and small ICT firms (2.95%), confirming the findings of our earlier analyses. The next strongest effect is for both young and old small non-ICT firms (2.56% and 2.54% respectively), emphasizing that it is smaller firms that have the greatest performance effect from R&D. Older and larger firms, both ICT (1.74%) and non-ICT (1.55%), have significantly positive but smaller effects of R&D on firm performance, providing additional support for age influencing the performance effects of R&D. Young ICT firms, both large and small, do not have a significant effect, nor do young and large non-ICT firms. Although the differences between ICT and non-ICT firms are no longer statistically significant, taken together, these results provide additional support for our earlier analyses about the returns on R&D investments being greater for ICT firms than for non-ICT firms. However, we note that when estimating the performance index and including the lagged dependent variable in the model, the differences between ICT and non-ICT firms substantially shrink. There may be productivity differences between the sectors that the earlier production function models do not consider. Also, considering that the effect of R&D can derive from knowledge accumulated through past investments, the lagged dependent variable may absorb some of the effect of such previous investments, rather than the R&D variable. Thus, the performance index models should provide a lower bound for the true effects of R&D on firm performance.

As a final robustness check, we reran the dynamic model (eq. 3) replacing the dependent and independent variables with the ones used in the Cobb Douglas specification (eq. 2). In particular, we instrumented lagged assets and employment on lagged revenues (replacing the performance index). The predicted (lagged) dependent variable from the first stage is then regressed with assets,

[19] A 100% increase in R&D investment and its impact on the performance index.

employment and the interaction effects of R&D (with ICT/non-ICT, old/young, small/large). This new specification helps disentangle the variation in the effects from ICT and non-ICT firms in previous models (as presented in Tables 2 and 7). The inclusion of a lagged dependent in the dynamic specification without the performance index variable does not affect the results of Table 2 and the differences are explained through the formula for the performance index per se. [20,21] In other words, the differences between R&D impact on revenue performance for ICT firms versus non-ICT firms do not depend on the methods or models used. While the impact of R&D on revenue is more pronounced than in the case of productivity between ICT firms and non-ICT firms, the results are qualitatively aligned for both performance variables.

5. Discussion

Our major finding is that ICT firms are associated with a greater effect of R&D investment on revenues and performance that non-ICT firms. We interpret this through reference to the notion of technological opportunities (Klevorick et al., 1995). ICTs continue to present rich and valuable technological opportunities for firms to grasp and capitalize upon. We argue that this occurs for two reasons – the special characteristics of ICT goods and services and the effect of ICT adoption on ICT firms. ICT is a general purpose technology (Bresnahan & Trajtenberg, 1995) that can (and has been) be adopted in many if not all economic sectors. ICT products tend to have applications across multiple industry sectors and hence large markets; for instance, think of the broad market appeal of such ICT products and services as the basic personal computer, smartphone, email or search engine. Therefore, R&D investments into ICT products and services may result in greater revenue growth through the absolute size and expansion of the addressable market, whereas R&D investments into non-ICT products and services may have narrower appeal. The strong effect of R&D on revenue performance for firms that supply internet services such as software for websites supports this assertion. Another characteristic of ICT products and services is that they are associated with network effects that may

[20] Table S7 in the Supplementary Materials presents the results of this robustness check.

[21] We also ran other specifications of eq. 2 adding a lagged dependent (log of revenues), instrumenting the lagged dependent on lags of assets and employment and replacing with the performance index. The results remain largely unchanged. These results available upon request from the corresponding author.

induce winner-take-all market dynamics, where a single ICT product or service dominates the market. Network effects occur when the value of the product or service to customers increases the more it is adopted by other customers. Thus, for those ICT products and services are associated with network effects, such as most communication services, investments in R&D can have outsized revenue performance impact as compared to non-networked (and non-ICT) products. This reasoning is supported by the finding that it is internet services that demonstrate exceptional R&D impact through our period of study. In contrast, ICT-based physical service provision, such as consulting, facilities management, and data hosting, which are rarely associated with network effects, do not demonstrate unusual R&D impact.

Given the technical nature of ICT products and services, the firms that create them also tend to be heavy users of ICT products and services themselves (Armstrong & Sambamurthy, 1999). This is, in part, due to the ability of ICT to be used to improve itself (Koutroumpis et al., 2016). ICT usage within a firm has been positively and significantly associated with measures of revenue (Devaraj & Kohli, 2003; Sabherwal & Jeyaraj, 2015). ICT usage in the R&D process has also been found to positively impact the subsequent revenue performance of the new product or service (Barczak, Sultan, & Hultink, 2007). Other studies have considered the positive effect of ICT usage on R&D performance, such as reducing costs and improving efficiency, which would consequently increase the impact of R&D on revenue performance. For instance, the use of the Internet in R&D activities significantly reduces the coordination costs of research (Forman & van Zeebroeck, 2012) as well as increases the utilization of research equipment (Agrawal & Goldfarb, 2008). Hence, ICT firms may be more proficient innovators themselves because of their high degree of ICT usage, thus perpetuating the discovery and exploitation of new technological opportunities.

Our second finding is that smaller firms, in general, have a greater impact of R&D on revenue performance. Although this effect was most pronounced for ICT firms, it was also present for non-ICT firms. Smaller size may confer greater flexibility and adaptability of R&D and managerial processes, enabling exploitation of technological and market shifts. For instance, Rothwell and Dodgson (1994) suggest that smaller organizations enjoy organizational and behavioral advantages, benefiting from more rapid decision-making. Furthermore, smaller firms may allow their R&D personnel to be more creative which the conservatism of larger hierarchical structures limit (Acs & Audretsch, 1990). Our third finding is that for ICT firms it is smaller and *older* firms that have the greatest R&D effect on revenue performance. Extant scholarship has found that older firms are able to accumulate the managerial knowledge and ability to handle uncertainty (Herriott et al., 1985; Levitt & March, 1988). Older firms also have the ability to accumulate reputation and market position and facilitate relationships with suppliers, customers and potential collaborators may lead to improved performance for older firms. We suggest that, perhaps counterintuitively, the size effect is moderated by learning effects. As firms gain experience and build on previous routines and capabilities, they innovate better and achieve better firm performance (Sorensen & Stuart, 2000).

Taken together, these findings suggest that smaller and older ICT firms are more "technologically opportunistic". "Technological opportunism" is the "sense-and-respond capability of firms with respect to new technologies" (Srinivasan et al., 2002: p 47), and has been derived through the integration of the technological opportunity of Klevorick et al. (1995) within the dynamic capabilities literature (Teece, 2007; Teece, Pisano, & Shuen, 1997). This literature argues that higher levels of technological opportunism result in greater levels of technology adoption (Datta, 2011; Mishra & Agarwal, 2010; Srinivasan et al., 2002), which in turn has a positive effect on firm performance (Chen & Lien, 2013; Lucia-Palacios, Bordonaba-Juste, Polo-Redondo, & Grunhagen, 2014). To date, this stream of research has not specifically considered firm attributes such as size and age, and those studies that have included these attributes as control variables have had mixed results. For instance, Sarkees (2011) found that increasing both firm age and firm size had a positive effect on the levels of technological opportunism and firm performance, while Chen and Lien (2013) found no significant influence of firm size on the performance effects of technological opportunism. Although they did not specifically consider firm age, Mishra and Agarwal (2010) suggest that their results suggest that experience with and extensive knowledge about related IT applications enables firms to notice novel opportunities to use new technologies in business processes. Taken together, we speculate that whereas smaller firms are nimbler to exploit dynamic innovation opportunities and hence are more technologically opportunistic, older firms may actually be well positioned to develop new products and services for the shifting markets due to their greater market experience and knowledge base.

For managers of larger ICT firms, our results suggest organizational arrangements that mimic the small-firm environment. Examples of such arrangements include the development of the IBM microcomputer in a small separate unit in Boca Raton, Florida, and the Watson business unit in Manhattan, instead of Armonk in upstate New York where most of IBM innovation has taken place. A small and independent unit allows faster adaptation to technological and market opportunities. The tricky question is whether young and small ICT firms could possibly devise strategies to access or imitate the experience of more mature and experienced innovators. If successful ICT innovation requires industry experience, startup companies can recruit experienced managers. More research is needed, however, to identify what underlying characteristics of older ICT firms allow them to be more effective innovators—e.g., whether it is the accumulated industry experience or customer base that is the distinguishing underlying factor.

In terms of policy implications, these results suggest that policy makers concerned with innovation-driven growth should target R&D incentives at ICT firms. Indeed, our finding indicates the impressive contribution that small research budgets can have in this technology sector (OECD, 2015). Research to date has demonstrated that R&D incentives are more effective for smaller than for larger firms. For instance, Bronzini and Piselli (2016) 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 Reenen (2012) find that R&D incentive programs have a positive effect on employment, investment and net entry (but not total factor productivity) for smaller firms.

However, if smaller and older ICT firms experience a greater revenue boost from R&D investments than other firms, it is surprising that such firms do not grow into large and old firms. In other words, why do small and experienced ICT firms not invest enough in R&D to grow their firms, and in the process, equalize their R&D returns with other types of firms? One possible explanation is financial constraints. Although small and young ICT firms receive a lot of policy attention and various startup funding schemes, older firms might not be able to access such funding mechanisms. However, such smaller firms might also not have sufficient internal financing for R&D projects. As a result, the higher R&D returns for small and old ICT firms may reflect insufficient access to financing for R&D.

Current European policy has been focusing on ICT incentives with such programs as the European Institute of Innovation and Technology EIT Digital, which is charged to deliver digital innovation and digital entrepreneurial education. However, much of the current policy interest is based upon the observation that Europe has fewer startup innovators than the US, in relative terms. Scholars suggest European policy makers should seek to address this (Veugelers & Cincera, 2010). Similarly, many national R&D policies focus on younger firms. Our results suggest that, for ICT firms at least, policies should not exclude smaller and older firms, whereas younger firms might already be engaging in sufficient R&D, at least in view of the performance impact.

One potential national policy would be an R&D Tax Relief Scheme. Recent research into the UK R&D Tax Relief Scheme had a large innovation output impact for smaller firms. In particular, Dechezleprêtre et al.(2016) found that R&D approximately doubled and patenting rose by about 60 percent after the intervention of tax relief, and that this effect was particularly strong for smaller firms who are more responsive to R&D tax credits. Their simple calculations suggest that between 2006 and 2011 the UK R&D Tax Relief Scheme induces £1.7 of private R&D for every £1 of taxpayer money and that aggregate UK business R&D would have been about 10% lower in the absence of the policy.

Policy interventions for older firms are less common. In the US, the Small Business Administration and its SBIR and STTR grant programs do not have formal age criteria for funding, instead requiring less than 500 employees and private ownership.[22] However, such grant funding is restricted to firms before major external capitalization, and only can be sought when venture capital operating companies, hedge funds, private equity firms, or any combination of these, control less than 50% of the equity. Similarly, in the UK there is no formal age criteria. To quality for R&D tax relief, a small or medium-sized enterprise must have fewer than 500 employees with either an annual turnover

[22] US Small Business Administration; https://sbir.nih.gov; retrieved 10/02/2017.

under €100 million or a balance sheet under €86 million.[23] However, these limits also include any linked, partnership or shareholding companies that have a greater than 25% share in the company and/or any company that the company holds a 25% share in.

Both these examples suggest that existing R&D policy interventions have the effect of implicitly preferring younger firms, although they would not preclude all older firms. We recommend relaxing any conditions for R&D funding related to firm age, beginning with a review of existing R&D policy interventions to increase access to R&D funding for smaller, older firms. Particularly in ICT, the optimal firm size for the productivity of innovation may be small, and firms should not be penalized for staying small. Put differently, policies should not focus only on startups but on experienced firms too, so long as they are small and innovative.

6. Conclusion

We find that it is R&D investment in smaller and older ICT firms that has the greatest effect on subsequent revenue performance. Furthermore, we found that ICT firms that focus on software-based services delivered through the internet (such as websites and apps) and electronic components, rather than through physical service provision (such as consultancy, facilities management and data hosting), that have the greatest revenue impact from R&D investment. We suggest our findings result from the special characteristics of ICT goods and services, the effect of ICT usage in R&D, and the positive effects of size and experience in commercializing ICT innovations. As smaller firms are more technologically opportunistic through greater flexibility and adaptability in their R&D and managerial processes, they are better able to take advantage of market shifts in rapidly evolving technology fields. Our findings suggest that policy targeting such firms may result in a supercharged effect, because technological opportunities in ICT continue to evolve more rapidly than R&D efforts are able to address them. We also describe managerial strategies to enhance the R&D performance of different types of ICT firms.

[23] UK HMRC; https://www.gov.uk/guidance/corporation-tax-research-and-development-tax-relief-for-small-and-medium-sized-enterprises; retrieved 10/02/2017.

7. References

Acs, Z. J., & Audretsch, D. B. 1988. Innovation in large and small firms: An empirical analysis. ***American Economic Review***, 78(4): 678-690.

Acs, Z. J., & Audretsch, D. B. 1990. ***Innovaton and Small Firms***. Cambridge, MA: MIT Press.

Adams, J. D., & Jaffe, A. B. 1996. Bounding the effects of R&D: An investigation using matched establishment-firm data. ***RAND Journal of Economics***, 27(4): 700-721.

Agrawal, A., & Goldfarb, A. 2008. Restructuring research: Communication costs and the democratization of university innovation. ***American Economic Review***, 98(4): 1578-1590.

Argote, L. 1999. ***Organizational Learning: Creating, Retaining, and Transferring Knowledge***. Norwell, MA: Kluwer Acadmic Publishers.

Armstrong, C. P., & Sambamurthy, V. 1999. Information technology assimilation in firms: The influence of senior leadership and IT infrastructures. ***Information Systems Research***, 10(4): 304-327.

Audretsch, D. B., Segarra, A., & Teruel, M. 2014. Why not all young firms invest in R&D. ***Small Business Economics***, 43(4): 751-765.

Balasubramanian, N., & Lee, J. 2008. Firm age and innovation. ***Industrial & Corporate Change***, 17(5): 1019-1047.

Barczak, G., Sultan, F., & Hultink, E. J. 2007. Determinants of IT usage and new product performance. ***Journal of Product Innovation Management***, 24(6): 600-613.

Bardhan, I., Krishnan, V., & Lin, S. 2013. Business value of information technology: Testing the interaction effect of IT and R&D on Tobin's Q. ***Information Systems Research***, 24(4): 1147-1161.

Basu, S., & Weil, D. N. 1998. Appropriate technology and gwoth. ***Quarterly Journal of Economics***, 113(4): 1025-1054.

Bloom, N., Sadun, R., & Ven Reenen, J. 2012. Americans do IT better: US multinationals and the productivity miracle. ***American Economic Review***, 102(1): 167-201.

Bottazzi, G., Dosi, G., Lippi, M., Pammoli, F., & Riccaboni, M. 2001. Innovation and corporate growth in the evolution of the drug industry. ***International Journal of Industrial Organization***, 19(7): 1161-1187.

Bresnahan, T. F., & Trajtenberg, M. 1995. General purpose technologies: Engines of growth? ***Journal of Econometrics***, 65(1): 83-108.

Bronzini, R., & Piselli, P. 2016. The impact of R&D subsidies on firm innovation. ***Research Policy***, 45(2): 442-457.

Brynjolfsson, E., & Hitt, L. M. 2003. Computing productivity: Firm-level evidence. ***Review of Economics and Statistics***, 85(4): 793-808.

Chang, Y. B., & Gurbaxani, V. 2012. The impact of IT-related spillovers on long-run productivity: An empirical analysis. ***Information Systems Research***, 23(3-part-2): 868-886.

Chen, C.-W., & Lien, N.-H. 2013. Technological opportunism and firm performance: Moderating contexts. ***Journal of Business Research***, 66(11): 2218-2225.

Coad, A., & Rao, R. 2008. Innovation and firm growth in high-tech sectors: A quantile regression approach. ***Research Policy***, 37(4): 633-648.

Coad, A., Segarra, A., & Teruel, M. 2016. Innovation and firm growth: Does firm age play a role? ***Research Policy***, 45(2): 387-400.

Cohen, W. M. 1995. Empirical studies of innovative activity. In P. Stoneman (Ed.), ***Handbook of the Economics of Innovation and Technological Change***: 182-264. Oxford, UK: Blackwell.

Cohen, W. M., & Klepper, S. 1992. The anatomy of industry R&D intensity distributions. ***American Economic Review***, 82(4): 773-799.

Cohen, W. M., & Klepper, S. 1996. Firm size and the nature of innovation within industries. ***Review of Economics and Statistics***, 78(2): 232-243.

Criscuolo, C., Martin, R., Overman, H., & Van Reenen, J. 2012. The causal effects of an industrial policy, ***NBR Working Papers***.

Czarnitzki, D., & Delanote, J. 2012. Young Innovative Companies: The new high-growth firms? ***Industrial & Corporate Change***, 22(5): 1315-1340.

Czarnitzki, D., & Hottenrott, H. 2011. R&D investment and financing constraints of small and medium-sized firms. ***Small Business Economics***, 36(1): 65-83.

Datta, P. 2011. A preliminary study of ecommerce adoption in developing countries. ***Information Systems Journal***, 21(1): 3-32.

Dechezleprêtre, A., Einiö, E., Martin, R., Nguyen, K.-T., & Van Reenen, J. 2016. To tax incentives for research increase firm innovation? An RD design for R&D, ***NBER Working Paper Series***. Cambridge, MA: National Bureau of Economic Research.

Decker, R. A., Haltiwanger, J., Jarmin, R. S., & Miranda. 2015. Where has all the skewness gone? The decline in high-growth (young) firms in the US, ***NBER Working Paper***.

Del Monte, A., & Papagni, E. 2003. R&D and the growth of firms: Empirical analysis of a panel of Italian firms. ***Research Policy***, 32(6): 1003-1014.

Devaraj, S., & Kohli, A. K. 2003. Performance impacts of information technology: Is actual usage the missing link? ***Management Science***, 49(3): 273-289.

Directorate-General for Research & Innovation, J. R. C. 2011. Monitoring Industrial Research: The 2011 EU Industrial Investment Scoreboard. Luxembourg, Luxembourgh: European Union.

Dosi, G. 1982. Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. ***Research Policy***, 11(3): 147-162.

Dosi, G. 1988. Sources, procedures, and microeconomic effects of innovation. ***Journal of Economic Literature***, 26(3): 1120-1171.

Ezell, S., & Andes, S. 2010. ICT R&D policies: An international perspective. ***IEEE Internet Computing***, 14(4): 76-88.

Forman, C., & van Zeebroeck, N. 2012. From wires to partners: How the Internet has fostered R&D collaborations within firms. ***Management Science***, 58(8): 1549-1568.

Fraumeni, B., & Okubo, S. 2005. R&D in the national income and product accounts: A first look at its effect on GNP. In C. Corrado, J. Haltiwanger, & D. E. Sichel (Eds.), ***Measuring Capital in the New Economy***. Chicago, IL: University of Chicago Press.

Freel, M. S. 2000. To small innovating firms outperform non-innovators? ***Small Business Economics***, 14(3): 195-210.

Garcia-Quevedo, J., Pellegrino, G., & Vivarelli, M. 2014. R&D drivers and age: Are young firms different? ***Research Policy***, 43(9): 1544-1556.

Geroski, P., & Machin, S. 1992. Do innovating firms outperform non-innovators? ***Business Strategy Review***, 3(2): 79-90.

Geroski, P. A., & Toker, S. 1996. The turnover of market leaders in UK manufacturing industry, 1979-86. ***International Journal of Industrial Organization***, 14(2): 141-158.

Griliches, Z. 1973. Research Expenditures and Growth Accounting. In B. R. Williams (Ed.), ***Science and Technology in Economic Growth: Proceedings of a Conference held by the International Economic Association at St Anton, Austria***: 59-95. London: Palgrave Macmillan UK.

Griliches, Z. 1979. Issues in assessing the contribution of research and development to productivity growth. ***The Bell Journal of Economics***, 10(1): 92-116.

Griliches, Z. 1980. Returns to research and development expenditures in the private sector. In J. W. Kendrick, & B. N. Vaccara (Eds.), ***New Developments in Productivity Measurement***: 419-462. Chicago, IL: University of Chicago Press.

Griliches, Z. 1981. Market value, R&D and patents. ***Economics Letters***, 7(2): 183-187.

Griliches, Z. 1990. Patents as economic indicators: A survey. ***Journal of Economic Literature***, 28(4): 1661-1707.

Griliches, Z. 1998. ***R&D And Productivity: The Econometric Evidence***. Chicago, IL: The University of Chicago Press.

Griliches, Z. 2007. ***R&D, Patents and Productivity***. Chicago, IL: University of Chicago Press.

Hagedoorn, J., & Cloodt, M. 2003. Measuring innovative performance: Is there an advantage using multiple indicators? ***Research Policy***, 32(8): 1365-1379.

Hall, B. H. 2007. Patents and patent policy. ***Oxford Review of Economic Policy***, 23(4): 568-587.

Hall, B. H., Griliches, Z., & Hausman, J. A. 1986. Patents and R and D: Is there a lag? ***International Economic Review***, 27(2): 265-283.

Hall, B. H., & Hayashi, F. 1989. Research and development as an investment, ***NBER***. Cambridge, MA: National Bureau of Economic Research.

Hall, B. H., Lotti, F., & Mairesse, J. 2012. Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. ***Economics of Innovation and New Technology***, 22(3): 300-328.

Hall, B. H., Mairesse, J., & Mohnen, P. 2010. Measuring the returns to R&D. In B. H. Hall, & N. Rosenberg (Eds.), ***Handbook of the Economics of Innovation***, Vol. 2: 1033–1082. Amsterdam, NL: Elsevier BV.

Hall, B. H., & Oriani, R. 2004. Does the market value R&D investment by European firms? Evidence from a panel of manufacturing firms in France, Germany and Italy. ***International Journal of Industrial Organization***, 24(5): 971-993.

Hansen, M. T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. ***Administrative Science Quarterly***, 44(1): 82-111.

Hausman, J., Hall, B. H., & Griliches, Z. 1984. Econometric models for count data with an application to the patents-R&D relationship. ***Econometrica***, 52(4): 909-938.

Henderson, R. M., & Cockburn, I. M. 1996. Scale, scope, and spillovers The determinants of research productivity in drug discovery. ***RAND Journal of Economics***, 27(1): 32-59.

Herriott, S. R., Levinthal, D., & March, J. G. 1985. Learning from experience in organizations. ***American Economic Review***, 75(2): 298-302.

Hitt, L. M., & Brynjolfsson, E. 1996. Productivity, business profitability, and consumer surplus: Three different measures of information technology value. ***MIS Quarterly***, 20(2): 121-142.

Huergo, E., & Jaumandreu, J. 2004. How does probability of innovation change with firm age? ***Small Business Economics***, 22(3): 193-207.

Kleis, L., Chwelos, P., Ramirez, R. V., & Cockburn, I. M. 2012. Information technology and intangible output: The impact of IT investment on innovation productivity. ***Information Systems Research***, 23(1): 42-59.

Klette, T. J. 1996. R&D, scope economies, and plant performance. ***RAND Journal of Economics***, 27(3): 502-522.

Klevorick, A. K., Levin, R. C., Nelson, R. R., & Winter, S. G. 1995. On the sources and significance of interindustry differences in technological opportunities. ***Research Policy***, 24: 185-205.

Kohli, R., & Devaraj, S. 2003. Measuring information technology payoff: A meta-analysis of structural variables in firm-level empirical research. ***Information Systems Research***, 14(2): 127-145.

Koutroumpis, P., Leiponen, A., & Thomas, L. D. W. 2016. Invention machines: How instruments and information technologies drive global technological progress, ***Working Paper***.

Koutroumpis, P., Leiponen, A., & Thomas, L. D. W. forthcoming. How important is "IT"? Assessing the influence of information and communication technologies over a century of invention. ***Communications of the ACM***.

Kudyba, S., & Diwan, R. 2002. Increasing returns to information technology. ***Information Systems Research***, 13(1): 104-111.

Levitt, B., & March, J. G. 1988. Organizational learning. ***Annual Review of Sociology***, 14(319-340).

Lucia-Palacios, L., Bordonaba-Juste, V., Polo-Redondo, Y., & Grunhagen, M. 2014. Technological opportunism effects on IT adoption, intra-firm diffusion and performance: Evidence from the U.S. and Spain. ***Journal of Business Research***, 67(6): 1178-1188.

Mairesse, J., & Mohnen, P. 2005. The importance of R&D for innovation: A reassessment using French survey data. ***Journal of Technology Transfer***, 30(1-2): 183-197.

Majumdar, S. K. 1997. The imapct of size and age on firm-level performance: Some evidence from India. ***Review of Industrial Organization***, 12(2): 231-241.

Malerba, F., & Orsenigo, L. 1996. Schumpeterian patterns of innovation are technology-specific. ***Research Policy***, 25(3): 451-478.

Mansfield, E. 1962. Entry, Gibrat's law, innovation, and the growth of firms. ***American Economic Review***, 52(5): 1023-1051.

Mansfield, E. 1965. Rates of return from industrial research and development. ***American Economic Review***, 55(1/2): 310-322.

Mansfield, E. 1980. Basic research and productivity increase in manufacturing. ***American Economic Review***, 70(5): 863-873.

Mishra, A. N., & Agarwal, R. 2010. Technological frames, organizational capabilities and IT use: An empirical investigation of electronic procurement. ***Information Systems Research***, 21(2): 249-270.

Mittal, N., & Nault, B. R. 2009. Investments in information technology: Indirect effects and information technology intensity. ***Information Systems Research***, 20(1): 140-154.

OECD. 1996. The knowledge-based economy. Paris, France: Organisation for Economic Co-operation and Development.

OECD. 2013. OECD Science, Technology and Industry Scoreboard 2013. Paris, France: Organisation for Economic Co-operation and Development.

OECD. 2015. OECD Science, Technology and Industry Scoreboard 2015. Paris, France: Organisation for Economic Co-operation and Development.

Peters, B., Roberts, M. J., Vuong, V. A., & Fryges, H. 2015. Estimating dynamic R&D choice: An analysis of costs and long-run benefits. Washington, DC: NBER.

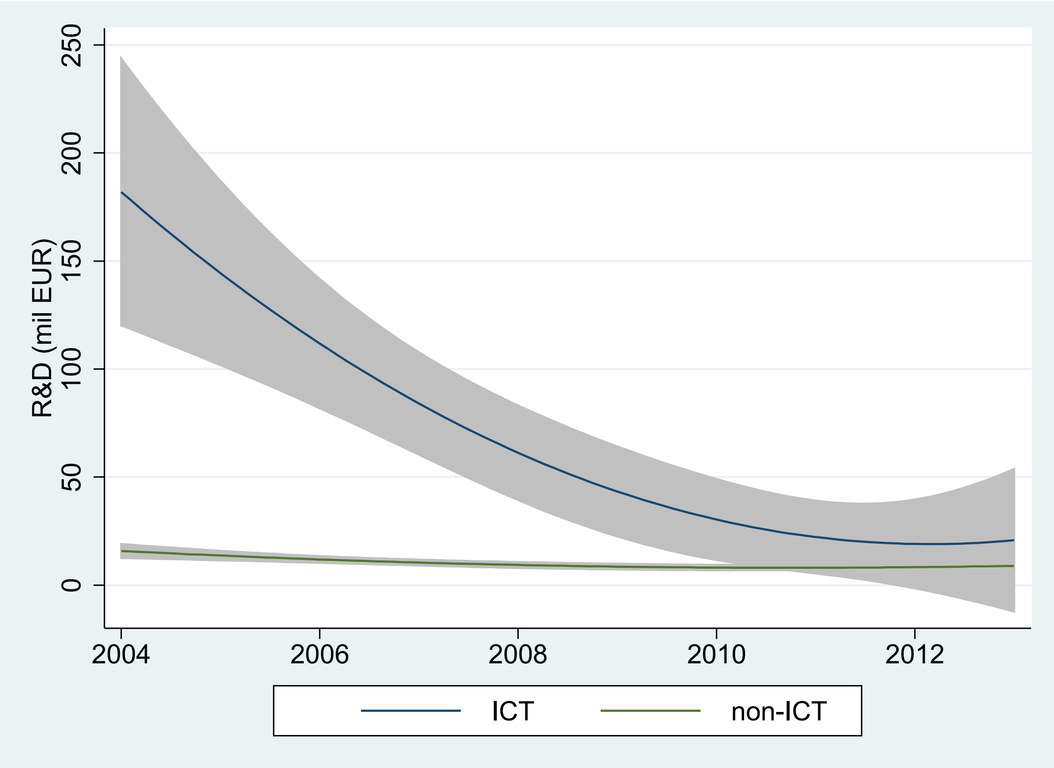
Prodan, I. 2005. Influence of research and development expenditures on number of patent applications: Selected case studies in OECD countries and central Europe, 1981-2001. ***Applied Econometrics and International Development***, 5(4): 5-22.

Revilla, A. J., & Fernandez, Z. 2012. The relation between firm size and R&D productivity in different technological regimes. ***Technovation***, 32(11): 609-623.

Romer, P. M. 1994. The origins of endogenous growth. ***Journal of Economic Perspectives***, 8(1): 3-22.

Rothwell, R., & Dodgson, M. 1994. Innovation and size of firm. In M. Dodgson, & R. Rothwell (Eds.), ***The Handbook of Industrial Innovation***: 310-324. Aldershot, UK: Edward Elgar.
Sabherwal, R., & Jeyaraj, A. 2015. Information technology impacts on firm performance: An extension fo Kohli & Devaraj (2003). ***MIS Quarterly***, 39(4): 809-836.
Sarkees, M. 2011. Understanding the links between technological opportunism, marketing emphasis and firm performance: Implications for B2B. ***Industrial Marketing Management***, 40(5): 785-795.
Schankerman, M. 1981. The effects of double-counting and expensing on the measured returns to R&D. ***Review of Economics and Statistics***, 63(3): 454-458.
Scherer, F. M. 1965. Firm size, market structure, opportunity, and the output of patent innovations. ***American Economic Review***, 55(5): 1097-1125.
Sivadas, E., & Dwyer, R. F. 2000. An examination of organizational factors influencing new product success in internal and alliance-based processes. ***Journal of Marketing***, 64(1): 31-49.
Sorensen, J. B., & Stuart, T. E. 2000. Aging, obsolescence, and organizational innovation. ***Administrative Science Quarterly***, 45(1): 81-112.
Srinivasan, R., Lilien, G. L., & Rangaswamy, A. 2002. Technological opportunism and radical technology adoption: An application to e-business. ***Journal of Marketing***, 66(3): 47-60.
Stiroh, K. 2002. Are spillovers driving the new economy? ***Review of Income and Wealth***, 48(1): 33-58.
Tambe, P., & Hitt, L. M. 2012. The productivity of information technology investments: New evidence from IT labor data. ***Information Systems Research***, 23(3-part-1): 599-617.
Tambe, P., & Hitt, L. M. 2014. Measuring information technology spillovers. ***Information Systems Research***, 25(1): 53-71.
Teece, D. J. 2007. Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. ***Strategic Management Journal***, 28(13): 1319-1350.
Teece, D. J., Pisano, G. P., & Shuen, A. 1997. Dynamic capabilities and strategic management. ***Strategic Management Journal***, 18(7): 509-533.
Tripsas, M., & Gavetti, G. 2000. Capabilities, cognition, and inertia: Evidence from digital imaging. ***Strategic Management Journal***, 21(10/11): 1147-1161.
Veugelers, R., & Cincera, M. 2010. Europe's missing yollies, ***Bruegal Policy Brief***. Brussels, Belgium.

<u>Figure 1</u> – R&D investment per ICT/non-ICT firm



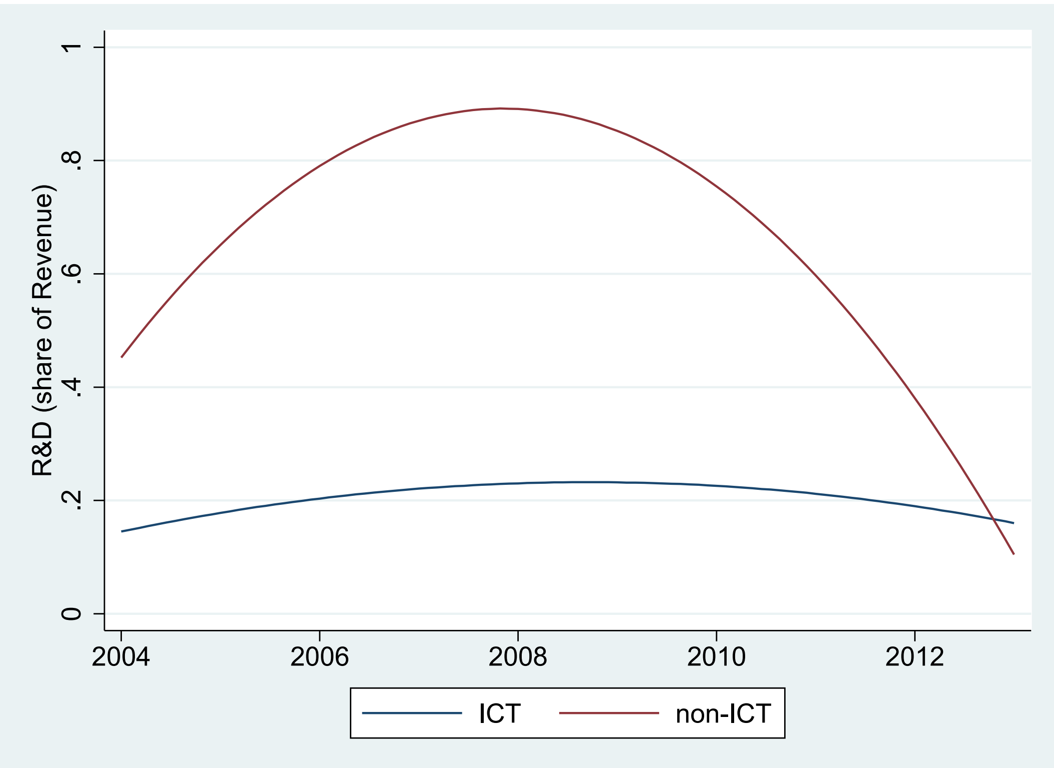


Figure 2 – R&D investment by firm size

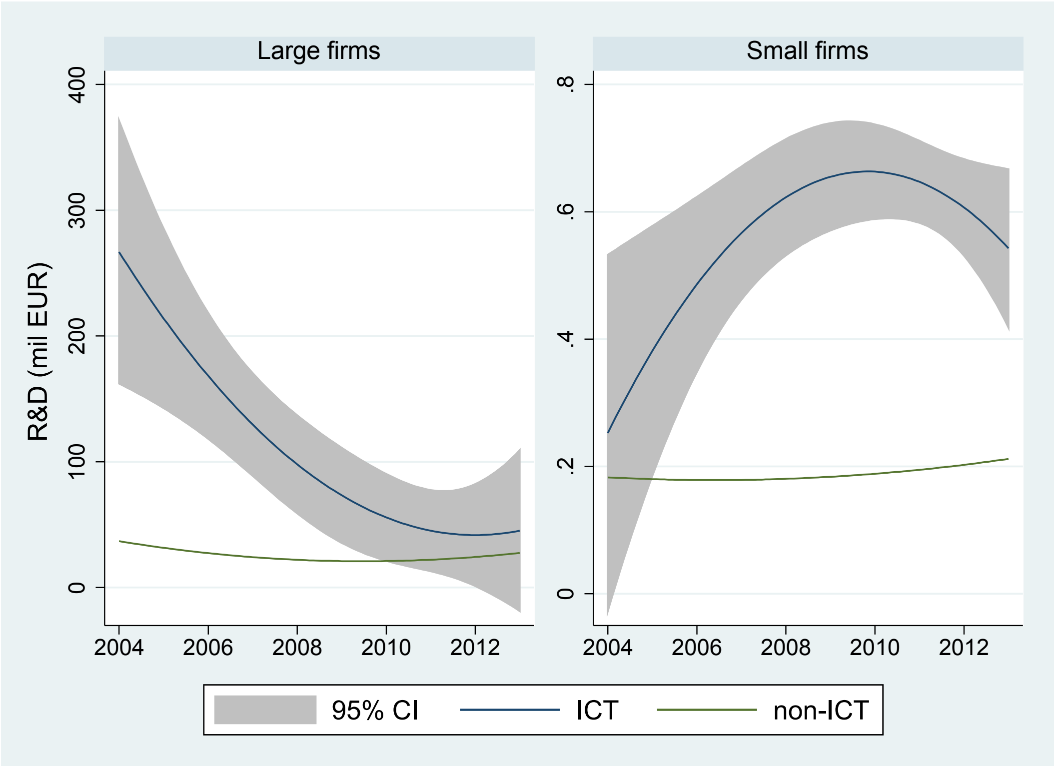


Figure 3 – R&D investment by firm age

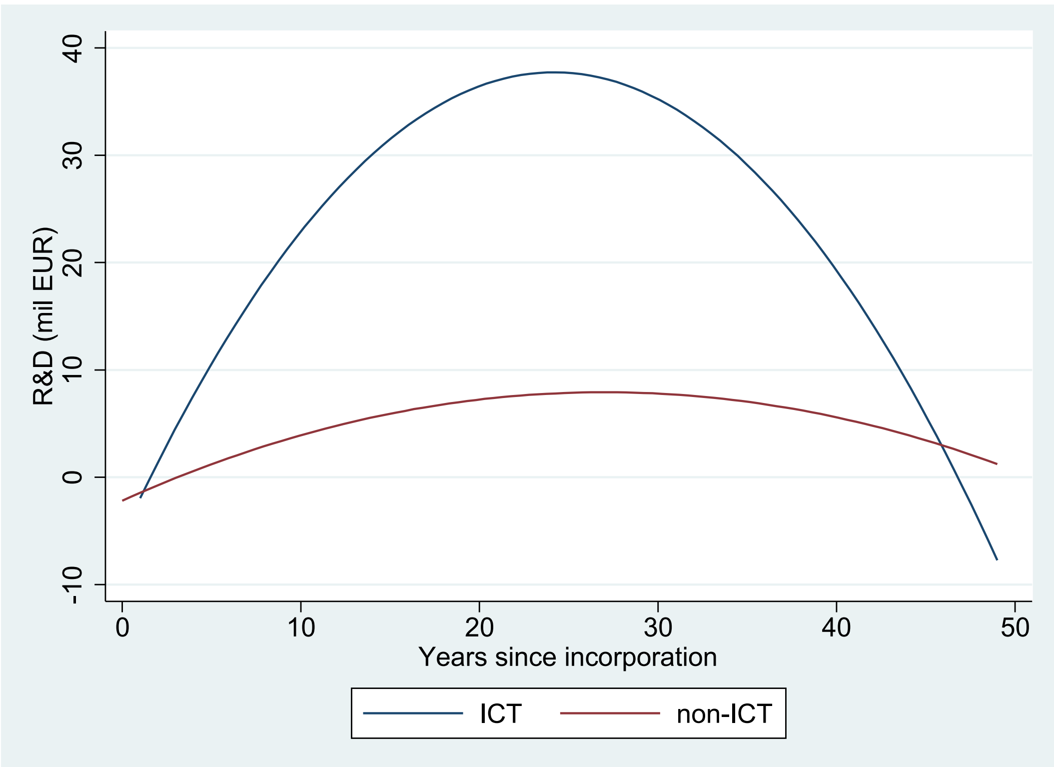


Figure 4 – Distance kernel densities

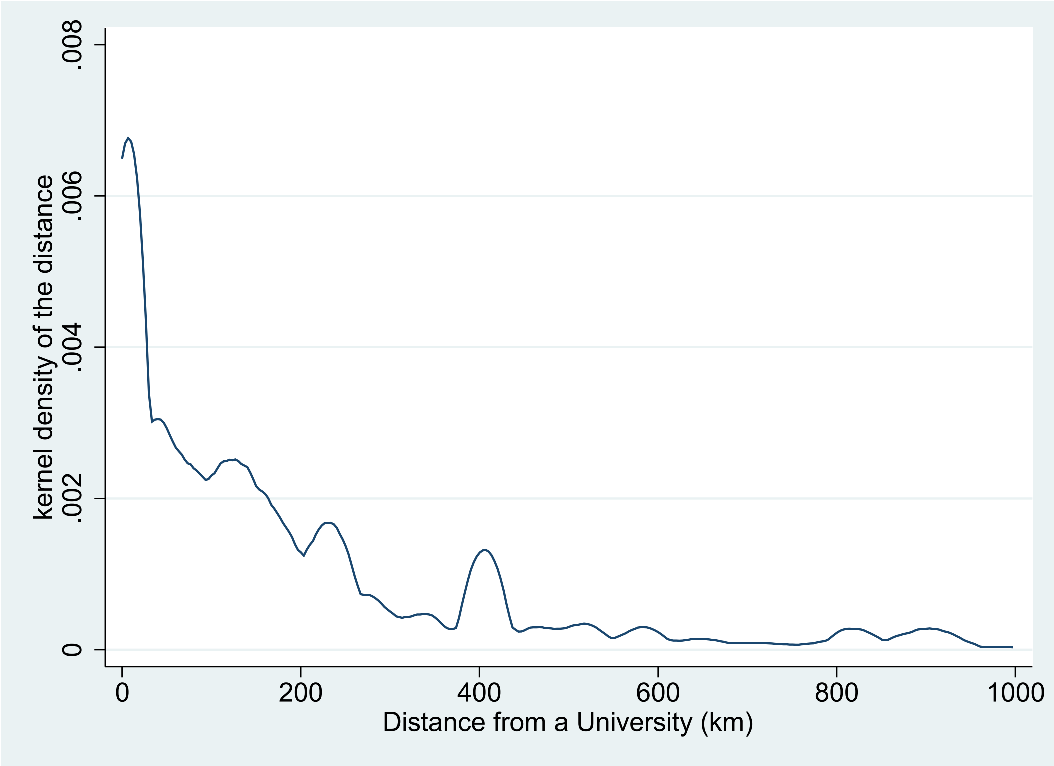
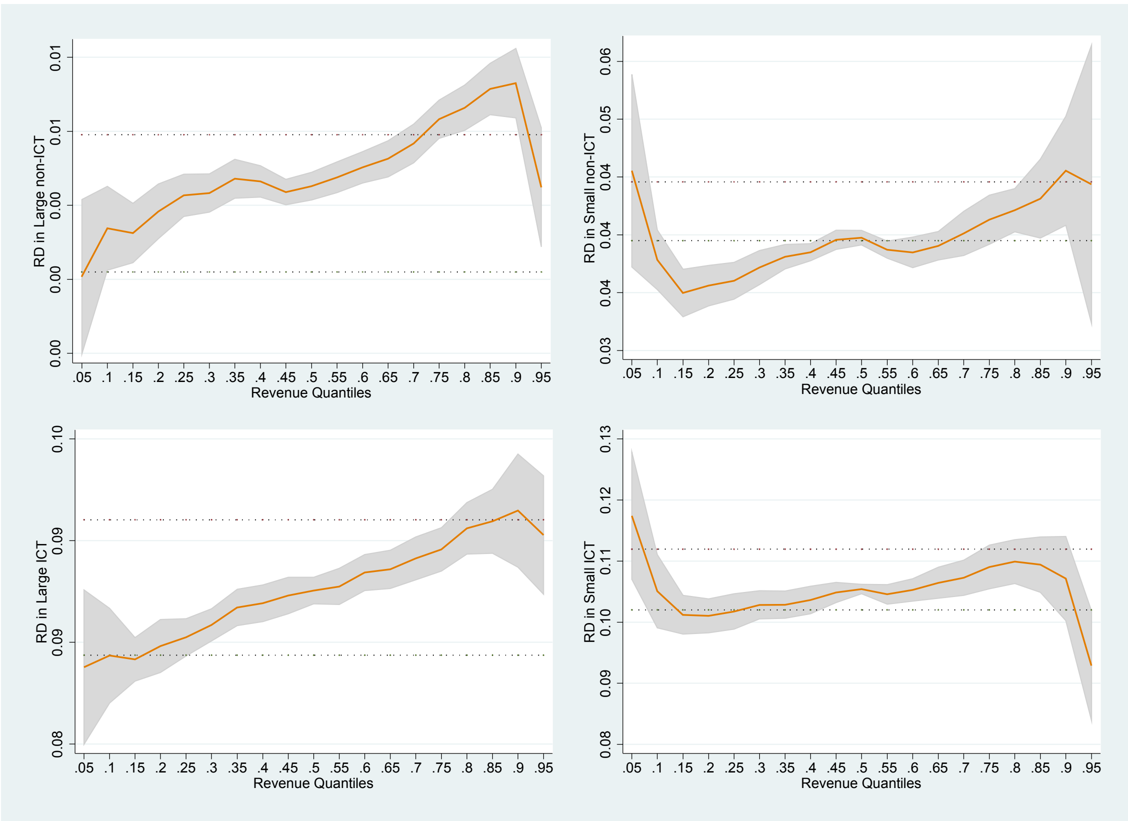


Figure 5 – R&D quantile regression plots for small and large ICT and non-ICT firms



<u>Figure 6</u> – R&D quantile regression plots for old and young ICT and non-ICT firms

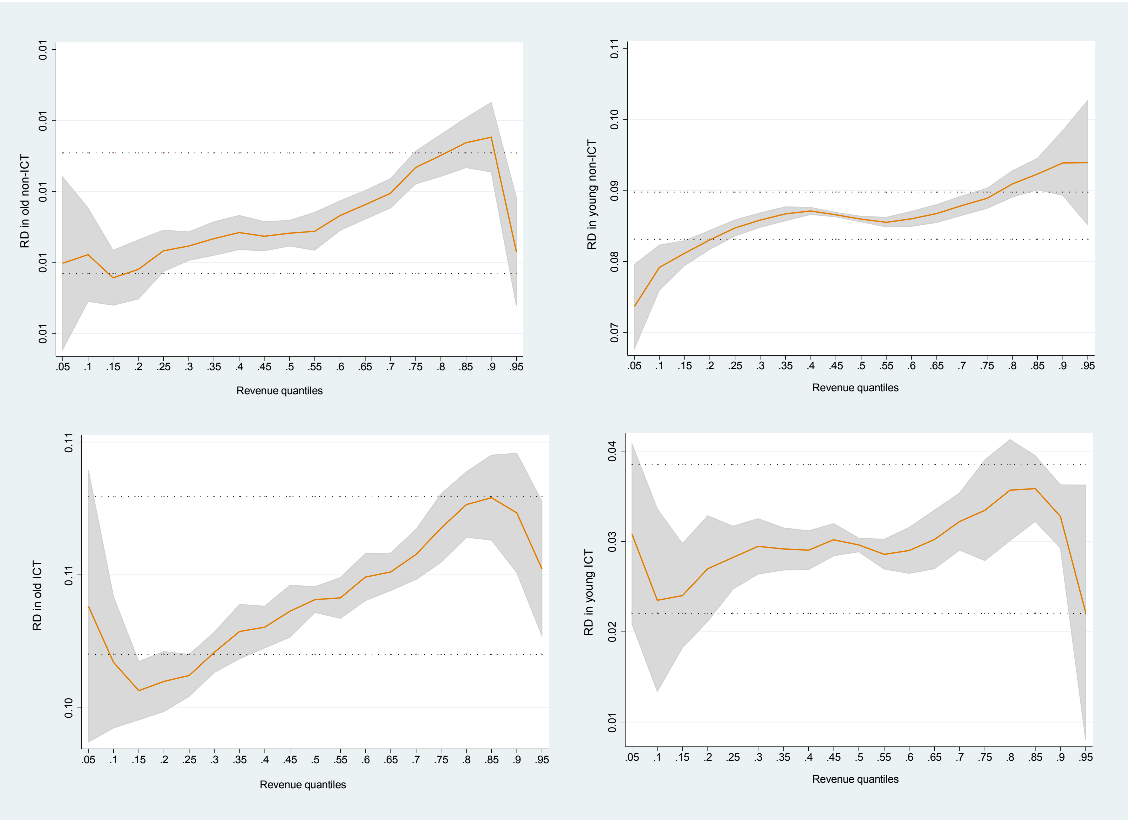


Table 1 – Descriptive Statistics by firm for each [Small/Young/ICT] cluster

	Obs	*Mean*	*Std. Dev.*	*Min*	*Max*
All					
Revenue (th. Eur)	104,139	403,666	4,119.679	0	297,000
Assets (th. Eur)	108,626	540,562	5,430.308	0	268,000
Employment	101,640	1,607	14,353	0	648,254
R&D (th. Eur)	77,335	10,930	133.457	0	5,649
Small					
Revenue (th. Eur)	62,350	12,145	62.907	0	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	0	104.052
Young					
Revenue (th. Eur)	17,797	101,623	811.891	0	30,100
Assets (th. Eur)	18,454	176,981	1,323.021	0	40,000
Employment	16,431	484	4,210	0	210,633
R&D (th. Eur)	13,346	2,052	23.364	0	732.810
ICT					
Revenue (th. Eur)	8,828	484,009	4,045.756	0	78,400
Assets (th. Eur)	9,371	731,269	7,601.348	0	182,000
Employment	8,733	1,944	18.501	0	439,400
R&D (th. Eur)	5,012	39,142	311.124	0	5,155

Table 2 – Impact of R&D on revenue

VARIABLES	(1) log(Revenue) FE	(2) log(Revenue) FE	(3) log(Revenue) FE	(4) log(Revenue) FE
log(Assets)	0.518***	0.518***	0.519***	0.518***
	(0.0298)	(0.0297)	(0.0297)	(0.0297)
log (Employment)	0.821***	0.819***	0.827***	0.826***
	(0.0372)	(0.0370)	(0.0368)	(0.0367)
log (R&D)	0.0195**			
	(0.00898)			
non-ICT firms log(R&D)		0.0157*		
		(0.00909)		
ICT firms log(R&D)		0.0921*		
		(0.0474)		
large & non-ICT firms log(R&D)			0.00405	
			(0.00935)	
small & non-ICT firms log(R&D)			0.0420***	
			(0.0109)	
large & ICT firms log(R&D)			0.0877*	
			(0.0475)	
small & ICT firms log(R&D)			0.107**	
			(0.0460)	
old & large & non-ICT firms log(R&D)				-0.00228
				(0.00986)
young & large & non-ICT firms log(R&D)				0.0801***
				(0.0266)
old & small & non-ICT firms log(R&D)				0.0375***
				(0.0116)
young & small & non-ICT firms log(R&D)				0.0933***
				(0.0299)
old & large & ICT firms log(R&D)				0.100*
				(0.0557)
young & large & ICT firms log(R&D)				0.0274
				(0.0426)
old & small & ICT firms log(R&D)				0.120**
				(0.0538)
young & small & ICT firms log(R&D)				0.0446
				(0.0443)
Constant	1.003***	0.990***	0.958***	0.950***
	(0.247)	(0.247)	(0.247)	(0.247)
Company FE	yes	yes	yes	yes
NACE FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Observations	74,241	74,241	74,241	74,241
R-squared	0.328	0.328	0.329	0.330
Number of id	13,190	13,190	13,190	13,190

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 3 – Impact of R&D on output – Employment breakdown

VARIABLES	(1) log(Revenue) FE
log(Assets)	0.517***
	(0.0296)
log (Employment)	0.846***
	(0.0366)
non-ICT R&D firms <10 people	0.165***
	(0.0393)
non-ICT R&D firms >10 and <20 people	0.0812***
	(0.0179)
non-ICT R&D firms >20 and <100 people	0.0330***
	(0.00952)
non-ICT R&D firms >100 and <500 people	0.00809
	(0.00860)
non-ICT R&D firms >500 and <1000 people	-0.0103
	(0.0116)
ICT R&D firms <10 people	0.182***
	(0.0662)
ICT R&D firms >10 and <20 people	0.155***
	(0.0473)
ICT R&D firms >20 and <100 people	0.118***
	(0.0440)
ICT R&D firms >100 and <500 people	0.0998**
	(0.0451)
ICT R&D firms >500 and <1000 people	0.0665
	(0.0522)
Constant	0.896***
	(0.246)
Company FE	yes
NACE FE	yes
Year FE	yes
Observations	74,241
Number of id	13,190
R-squared	0.332

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 4 – Impact of R&D on output – Age breakdown

VARIABLES	(1) log(Revenue) FE	(2) log(Revenue) FE	(3) log(Revenue) FE
log(Assets)	0.518***	0.518***	0.518***
	(0.0297)	(0.0297)	(0.0297)
log (Employment)	0.819***	0.818***	0.819***
	(0.0369)	(0.0369)	(0.0370)
non-ICT (R&D) with <10 years experience	0.0865***		
	(0.0266)		
non-ICT (R&D) with >10 and <20 years experience	0.0183		
	(0.0250)		
non-ICT (R&D) with >20 and <50 years experience	0.00687		
	(0.00997)		
ICT (R&D) with <10 years experience	0.0303		
	(0.0423)		
ICT (R&D) with >10 and <20 years experience	0.112		
	(0.0755)		
ICT (R&D) with >20 and <50 years experience	0.102		
	(0.0735)		
non-ICT (R&D) with <25 years experience		0.0126	
		(0.0115)	
ICT (R&D) with <25 years experience		0.140	
		(0.112)	
non-ICT (R&D) with >25 years experience		0.0206	
		(0.0146)	
ICT (R&D) with >25 years experience		0.0686*	
		(0.0364)	
non-ICT (R&D) with <21 years experience			0.00853
			(0.0103)
ICT (R&D) with <21 years experience			0.103
			(0.0756)
non-ICT (R&D) with >21 years experience			0.0319*
			(0.0181)
ICT (R&D) with >21 years experience			0.0793*
			(0.0480)
Constant	0.983***	0.988***	0.990***
	(0.246)	(0.247)	(0.246)
Company FE	yes	yes	yes
NACE FE	yes	yes	yes
Year FE	yes	yes	yes
Observations	74,228	74,228	74,228
R-squared	0.329	0.328	0.328
Number of id	13,188	13,188	13,188

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5 – Description of firms and NACE code analysis

VARIABLES	*log(Revenue)* *FE*
log(Assets)	0.519*** (0.0297)
log (Employment)	0.816*** (0.0368)
log (R&D) & ICT & Computer consultancy activities	-0.0132* (0.00765)
log (R&D) & ICT & Computer facilities management activities	-0.0281*** (0.00621)
log (R&D) & ICT & Computer programming activities	0.0484 (0.0615)
log (R&D) & ICT & Data processing, hosting and related activities	-0.0858* (0.0484)
log (R&D) & ICT & Manufacture of communication equipment	0.251 (0.218)
log (R&D) & ICT & Manufacture of computers and peripheral equipment	0.0162 (0.0200)
log (R&D) & ICT & Manufacture of consumer electronics	0.0245 (0.0648)
log (R&D) & ICT & Manufacture of electronic components and boards	0.105 (0.0708)
log (R&D) & ICT & Manufacture of magnetic and optical media	0.115*** (0.00351)
log (R&D) & ICT & Other information technology and computer services	0.0176 (0.0576)
log (R&D) & ICT & Other telecommunications activities	0.0938 (0.110)
log (R&D) & ICT & Repair of communication equipment	0 (0)
log (R&D) & ICT & Repair of computers and peripheral equipment	0.221 (0.177)
log (R&D) & ICT & Satellite telecommunications activities	-0.0157 (0.0380)
log (R&D) & ICT & Web portals	0.238*** (0.00413)
log (R&D) & ICT & Wholesale of computers, computer peripheral equipment	0.0325*** (0.00995)
log (R&D) & ICT & Wholesale of electronic and telecommunications equipment	-0.0188 (0.0147)
log (R&D) & ICT & Wired telecommunications activities	0.0754 (0.0674)
log (R&D) & ICT & Wireless telecommunications activities	-0.0259 (0.0325)
log (R&D) & ICT & Software other publishing	-0.0446 (0.0319)
log (R&D) & ICT & Software publishing of computer games	-0.0657* (0.0364)
log (R&D) & ICT & description contains "Electronic"	0.190 (0.115)
log (R&D) & ICT & description contains "ICT"	-0.0678* (0.0367)
log (R&D) & ICT & description contains "Information"	-0.0866* (0.0492)
log (R&D) & ICT & description contains "Communications"	0.0864 (0.106)
log (R&D) & ICT & description contains "Telecommunications"	0.00944 (0.102)

log (R&D) & not ICT	0.0197**
	(0.0100)
Constant	0.990***
	(0.246)
Company FE	yes
NACE FE	yes
Year FE	yes
Observations	74,241
R-squared	0.329
Number of id	13,190

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 6 – Revenue quantiles and the impact of R&D

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	*(18)*
VARIABLES	*.05*	*.1*	*.15*	*.2*	*.25*	*.3*	*.35*	*.4*	*.45*	*0.5*	*0.55*	*.6*	*.65*	*0.7*	*0.75*	*0.8*	*0.85*	*0.9*
									Quantile Regression									
log(Assets)	0.4024	0.4547	0.4781	0.4939	0.5038	0.5094	0.5130	0.5154	0.5172	0.5178	0.5191	0.5211	0.5238	0.5273	0.5320	0.5399	0.5547	0.5785
	(0.0061)	(0.0025)	(0.0015)	(0.0010)	(0.0009)	(0.0007)	(0.0006)	(0.0005)	(0.0002)	(0.0003)	(0.0005)	(0.0006)	(0.0006)	(0.0007)	(0.0008)	(0.0011)	(0.0015)	(0.0025)
log (Employment)	1.0086	0.9188	0.8811	0.8567	0.8408	0.8314	0.8254	0.8213	0.8191	0.8179	0.8148	0.8104	0.8050	0.7984	0.7889	0.7755	0.7513	0.7115
	(0.0060)	(0.0028)	(0.0017)	(0.0011)	(0.0009)	(0.0007)	(0.0006)	(0.0005)	(0.0003)	(0.0004)	(0.0005)	(0.0006)	(0.0006)	(0.0007)	(0.0009)	(0.0012)	(0.0018)	(0.0029)
non-ICT firms log(R&D)	0.0133	0.0137	0.0136	0.0138	0.0145	0.0148	0.0150	0.0152	0.0152	0.0151	0.0151	0.0155	0.0158	0.0163	0.0171	0.0175	0.0180	0.0182
	(0.0016)	(0.0005)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0005)
ICT firms log(R&D)	0.0910	0.0885	0.0878	0.0883	0.0886	0.0894	0.0902	0.0904	0.0910	0.0913	0.0910	0.0919	0.0922	0.0929	0.0938	0.0947	0.0948	0.0942
	(0.0026)	(0.0013)	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0005)	(0.0004)	(0.0004)	(0.0001)	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0006)	(0.0004)	(0.0006)	(0.0011)
Constant	0.7329	0.8965	0.9385	0.9565	0.9703	0.9902	1.0090	1.0238	1.0241	1.0275	1.0431	1.0663	1.0865	1.1065	1.1339	1.1613	1.1866	1.2340
	(0.0390)	(0.0133)	(0.0086)	(0.0062)	(0.0052)	(0.0047)	(0.0040)	(0.0029)	(0.0013)	(0.0021)	(0.0037)	(0.0042)	(0.0041)	(0.0048)	(0.0052)	(0.0069)	(0.0073)	(0.0142)
Observations	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241	74,241

Robust standard errors in parentheses; **all coefficients significant at the 1% level.**

Table 7 – Performance index baseline results

VARIABLES	(1) GMM	(2) 2SLS	(3) Onclude extra IV	(4) GMM	(5) GMM	(6) GMM
Performance Index (t-1)	0.910***	0.922***	0.915***	0.910***	0.910***	0.909***
	(0.00754)	(0.00767)	(0.00735)	(0.00754)	(0.00764)	(0.00765)
Assets	-0.0679***	-0.0538***	-0.0539***	-0.0679***	-0.0690***	-0.0711***
	(0.00755)	(0.00777)	(0.00775)	(0.00755)	(0.00764)	(0.00779)
Assets (t-1)	0.0645***	0.0499***	0.0496***	0.0645***	0.0682***	0.0695***
	(0.00677)	(0.00709)	(0.00709)	(0.00677)	(0.00672)	(0.00685)
R&D (t-1)	0.0165***	0.0149***	0.0152***			
	(0.00267)	(0.00268)	(0.00267)			
"No R&D" (t-1) dummy	-0.00897***	-0.00836***	-0.00873***	-0.00896***	-0.0143***	-0.0138***
	(0.00252)	(0.00252)	(0.00252)	(0.00253)	(0.00273)	(0.00276)
non-ICT firms R&D (t-1)				0.0164***		
				(0.00274)		
ICT firms R&D (t-1)				0.0173***		
				(0.00328)		
large & non-ICT firms R&D (t-1)					0.0139***	
					(0.00292)	
small & non-ICT firms R&D (t-1)					0.0260***	
					(0.00312)	
large & ICT firms R&D (t-1)					0.0158***	
					(0.00367)	
small & ICT firms R&D (t-1)					0.0274***	
					(0.00451)	
old & large & non-ICT firms R&D (t-1)						0.0155***
						(0.00288)
young & large & non-ICT firms R&D (t-1)						0.00388
						(0.00683)
old & small & non-ICT firms R&D (t-1)						0.0254***
						(0.00325)
young & small & non-ICT firms R&D (t-1)						0.0256***
						(0.00333)
old & large & ICT firms R&D (t-1)						0.0174***
						(0.00377)
young & large & ICT firms R&D (t-1)						0.000431
						(0.0137)
old & small & ICT firms R&D (t-1)						0.0295***
						(0.00476)
young & small & ICT firms R&D (t-1)						0.0140
						(0.00967)
Constant	-0.00812**	-0.00626	-0.00619	-0.00815**	-0.00851**	-0.00847**
	(0.00411)	(0.00412)	(0.00411)	(0.00411)	(0.00413)	(0.00412)
Year FE	yes	yes	yes	yes	yes	yes
Country FE	yes	yes	yes	yes	yes	yes
Company FE	yes	yes	yes	yes	yes	yes
Hansen J-stat	68.231	68.231	80.612	68.243	81.96	80.655
Observations	42,811	42,811	42,811	42,811	42,811	42,811
R-squared	0.698	0.696	0.697	0.698	0.698	0.699

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1