

Knowledge for Growth – Industrial Research & Innovation (IRI)

Quantile estimates of the impact of R&D intensity on firm performance

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Abstract

This paper investigates the relationship between initial R&D intensity and firm growth using a unique data set for firms with R&D activities in Austria during the period 1995–2006. Results based on the LAD estimator show that the initial R&D intensity has a positive and significant impact on both employment and sales growth in the subsequent two years. Quantile regressions for each cross-section reveal that the impact of R&D intensity is only significant from 0.3 to the highest quantile of the conditional distribution of employment growth. Furthermore, the elasticity of employment growth with respect to R&D intensity is highest for firms at or slightly below the median of the distribution of firm size. Finally, we find that the R&D coefficient decreases significantly over time.

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Key words: R&D activities, firm growth, quantile regressions.

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Annex 1

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1 - Introduction

Quantile regressions are increasingly used in empirical studies on firm growth and the effects of innovation activities (see amongst others Coad and Rao, 2006; Coad and Rao, 2008; Goedhuys and Sleuwaegen, 2009; Hölzl, 2009 and Kaiser, 2009). These studies show that the impact of innovation activities (measured either as patents and/or R&D activities) tends to increase when moving from the bottom to the top part of the conditional distribution of firm growth. In particular, Coad (2009) shows that innovation activities have a strong impact on employment and/or sales growth for fast growing firms while the average effect is quite small and often insignificant. However, despite the increasing number of studies in this area there is still no consensus on the magnitude of the effects of innovation activities along the conditional firm growth distribution.

The aim of this paper is to examine the relationship between initial R&D intensity and firm performance in subsequent years. In particular, using quantile regressions, one can explore the parameter heterogeneity in the relationship between R&D and firm growth across the conditional growth distribution. We also provide empirical evidence on the magnitude of the effects by calculating the elasticities of employment (sales) growth with respect to R&D intensity. In addition, the stability of the parameter over time will be investigated. It may be possible that the impact of R&D intensity of firm growth rises or falls over time. Another aim of this paper is to check the robustness of the results with respect to different lags for the R&D intensity and different functional forms (log-linear or semi-log linear specification for the R&D intensity). We also use two different measures of R&D intensity (i.e. the ratio of R&D expenditures to sales and the ratio of R&D employment to total employment). To answer these research questions this study draws on a unique database of firms with R&D activities provided by the Austrian Research Promotion Agency (FFG) for the period 1996–2006. The relationship between R&D activities and company growth is estimated using the OLS, median and simultaneous quantile regression methods.

The impact of R&D activities on firm performance has been of considerable interest to scholars, for a long time (for a survey of the empirical literature see Coad, 2009).¹ Most studies focus on the employment effects of R&D activity rather than its effects on output growth. For instance, a number of studies find that initial R&D intensity (or initial R&D spending) is significantly positively related to employment growth in subsequent years (see Hall, 1987, for US manufacturing, Yasuda, 2005, for Japanese companies in manufacturing, wholesale and retail trade; Yang and Huang, 2005, for industrial firms in Taiwan). Studies investigating the impact of R&D activity on growth of sales include, amongst others, Del Monte and Papagni (2003).

Some studies find that R&D activities do not lead to higher firm growth. This is in particular to be expected when firm growth is measured as employment growth rather than growth of sales. For instance, Brouwer, Kleinknecht and Reijnen (1993) find that the growth of R&D intensity has a slightly negative impact on employment growth based on 859 Dutch manufacturing firms over the period 1983–1988. Using firm level data for Norwegian manufacturing plants, Klette and Forre (1998) also find no clear-cut positive relationship between net job creation and the R&D intensity of the firm.

In recent years, quantile estimators have been increasingly used to study the impact of R&D activities on firm growth. For instance, Coad and Rao (2008) use the quantile regression technique to analyze the impact of an innovativeness composite index on the growth rate of sales, where the index is composed of R&D and patent intensity as well as

¹ For a survey on the various channels through which innovation affects employment see Spiezia and Vivarelli (2000).

the corresponding stock values. The findings indicate that patents and R&D activities have a strong impact on sales growth for fast growing firms while the average effect is quite small and often insignificant. Using firm level data drawn for the manufacturing industry from the Community Innovation Survey for 16 EU countries between the period 1998–2000, Hölzl (2009) finds that R&D activities are more important for the growth of fast-growing SMEs than for those with moderate or declining growth rates. This result particularly holds for firms in the EU-15 countries. Similar evidence is reported by Stam and Wennberg (2009) investigating the impact of initial R&D intensity (percentage of labour spent on R&D activities) on employment growth based on a Dutch start-up survey. The authors find initial R&D intensity has no impact on firm growth using OLS. However, initial R&D intensity is highly significant for the 10 per cent fastest growing firms. Five points can be noted from the literature. Firstly, very few studies seem to have included the very small firms with fewer than 10 employees. However, small businesses often have a high R&D intensity and should be included in the estimation sample. Secondly, service firms are not included in most of the cases. Thirdly, until recently few studies addressed the heterogeneity of the R&D impact at different points of the distribution instead of the conditional mean function (e.g., average effects of R&D for the average firm). Rare exceptions are the studies of Coad and Rao (2008), Hölzl (2009) and Stam and Wennberg (2009). Fourthly, no study is available that investigates whether the impact of R&D activities on firm growth is constant over time in a country with strongly rising R&D expenditures. This is particularly important for Austria, since it is one of the few industrialized countries that experienced a rapid increase in R&D expenditures in the last 15 years.² Fifthly, possible lag effects of the R&D intensity are insufficiently addressed in most studies at the firm level.

Another stream of the literature examines the impact of product and process innovations on employment (for a seminal contribution see Van Reenen, 1997). In addition, simultaneous equation models are introduced that analyse jointly the decision to engage in R&D activities, the link between R&D and innovation output, and the impact of innovation output on productivity (see Crépon, Duguet and Mairesse, 1998, Hall et al., 2008, and Harrison et al., 2008). Since data on innovation output is not available, this paper focuses on the link between initial R&D intensity and firm growth in the future period. Knowledge of the strength of the relation between R&D and firm performance is important because a positive and significant association helps us in justifying R&D subsidies to firms conducting R&D activities. To the best of my knowledge no empirical study at the firm level in this area is available for Austria. Previous studies on the determinants of firm growth typically do not employ a measure of R&D activities. Finally, the database of the paper is more detailed and comprehensive than those used in previous studies for other countries, in that it takes into account the very small firms and service firms. Note that one quarter of the firms have 10 or less employees. In addition, the sample size is quite large compared to the total number of firms with R&D activities.

The structure of the paper is as follows: In section 2, we present the empirical model and the hypotheses; while in section 3, we present some summary statistics; in section 4, the empirical results for the impact of R&D on firm growth are presented; and in section 5, we make some concluding remarks.

² For instance, R&D intensity in the business sector (measured as the ratio of R&D expenditures in the business sector to GDP) doubled since the beginning of the 1990s (from 0.9 per cent in 1993 to 1.7 per cent in 2009).

2 - Empirical model and hypothesis

Investment in R&D normally generates new products, processes and techniques that help a firm to achieve a competitive advantage in the market and thereby increase firm growth and market shares. In order to investigate the average effect of R&D, one model uses firm growth as a function of size and age and a measure of R&D activity (Evans, 1987a, 1987b; Hall, 1987):

$$gr_{it} = \alpha_0 + \alpha_1 \ln L_{it-2} + \alpha_2 (RD_{it-\tau} / Y_{it-\tau}) + \alpha_3 dyoung_{it-2} + u_{it},$$

where i and t are indexes of the firm and the year, with $\tau = 2, 3$ and 4 . The dependent variable is either the average employment growth rate or the average growth rate of sales calculated for several two year periods over the period 1996–2006. In particular, the growth rate is calculated as the geometric growth rate over a two year period:

$$gr_{it} = (L_{it} / L_{it-2})^{1/(t-(t-2))} - 1. L \text{ is employment and } R\&D/Y \text{ is the ratio of R\&D expenditures to sales. Alternatively, we employ the ratio of R\&D employment to total employment. The company's growth not only depends on R\&D spending but also on other factors. Jovanovic (1982) presents a theoretical model of firm growth and finds that firm growth depends negatively on firm age given its size. In order to measure age effects, we include a dummy variable for young firms, } dyoung , \text{ that equals 1 if the firm has been founded between } t-2 \text{ and } t-5 \text{ and zero otherwise. Since R\&D intensity is highly skewed, one can employ log R\&D intensity. It is well documented that R\&D activities will affect firm performance only with a long and uncertain time lag (Ravencraft and Scherer, 1982; Pakes, 1985). Therefore, we also consider a one (t-3) and two year time lag (t-4) for the impact of R\&D intensity on firm growth besides initial R\&D intensity (t-2).}^3 \text{ The growth equation can be estimated by OLS. Note that a selection bias may arise from using the sample of firms conducting R\&D activities. However, since nothing is known about firms with no R\&D activities, empirical techniques to correct for sample selection bias cannot be used. The main hypothesis is that R\&D intensity has a positive and significant impact on firm growth. However, OLS only allows us to estimate the mean effects. It is likely that the impact of R\&D intensity differs between low and high growth firms. The quantile regression method allows one to focus on specific parts of the distribution of conditional growth rates and is suitable to detect differences in the effects of R\&D intensity at various quantiles (see Koenker and Bassett, 1978; Koenker and Hallock, 2001; Koenker, 2005). For a given cross-section, the quantile regression model can be written as:}$$

$$gr_i = Z_i \beta_\theta + u_{i\theta}; Q_\theta(gr_i | Z_i) = Z_i \beta_\theta,$$

where gr_i denotes firm growth and Z_i the vector of explanatory variables. β_θ is the vector of parameters to be estimated for a given value of the quantiles θ . $Q_\theta(gr_i | Z_i)$ is the θ th quantile of the conditional distribution of the growth rate given the vector of explanatory variables Z_i . The estimation of the quantile parameters can be done by solving a minimization problem where the corresponding residuals have to be weighted. For $\theta=0.5$ the median is obtained and the least absolute deviation estimator can be employed. In this application, we use the simultaneous quantile regression model that allows us to test whether the coefficients are similar across the conditional quantiles. Standard errors are obtained by using the bootstrap method (see Gould, 1997). Another advantage of the quantile regression technique is that it is consistent and robust when the error term is heteroscedastic and non-normally distributed. The latter is important in our case since the

³ We use a two year lag of R&D intensity since employment and sales growth rate are calculated over a two year period and to avoid a simultaneous bias. Foray et al. (2007) also use the R&D to sales ratio lagged two years.

Shapiro-Wilk test rejects the null hypothesis that the growth rates of sales and employment are normally distributed. In this study we consider regression estimates at 9 different quantiles ranging from the 0.1 to 0.9 quantiles. We provide estimations for several sub-periods as well as for the pooled sample.

In the empirical section of this paper we investigate the following research questions: (i) What is the impact of the initial R&D intensity on the change in sales and/or employment in subsequent years at the firm level, controlling for age and initial size? (ii) Are there differences in the performance effect of R&D between fast and slow-growing companies? (iii) Is the relationship between R&D activities and firm growth stable over time or is there evidence of a rising or falling impact of R&D? and (iv) What is the impact of firm age and size on firm growth of firms doing R&D? Finally, we expect that the coefficient on R&D intensity is greater on sales growth than on employment growth. This can be justified by the fact that R&D investments are often associated with increases in labour productivity at the expense of employment.

3 - Data and descriptive results

The data used in this study are based on a unique data set containing firms with R&D activities applying for R&D grants from the Austrian Industrial Research Promotion Fund (FFG). The FFG is one of Austria's most important sources of finance for R&D projects carried out by business enterprises. Firms applying for an R&D project are requested to give information on (i) total sales (in thousand €), (ii) the share of exports in sales, (iii) the number of employees (full-time equivalents), (iv) the number of R&D employees (full-time equivalents), (v) expenses for research and development (in thousand €) and (vi) cash flow (in thousand €). In addition, there is information on the legal form and geographic location of the firm.⁴ These data have to be provided for the last three years prior to the application for a R&D project. The database includes all firms with at least one employee. The sample size ranges between 620 and 830 for each two year period. It can be considered as approximately representative of all firms doing R&D given the number of 2190 firms doing R&D in Austria in the private sector (NACE 10-72 and 74) for the year 2006 according to Statistics Austria. The database is one of the most detailed in terms of coverage and data quality among most studies conducted so far. Each respondent has to provide complete and correct information on R&D expenditures and R&D employment. Data are more accurate than data from ordinal surveys. However, the database also has some limitations. For instance, there is no information on physical investment and industry affiliation.

Table 1 reports the median of the key variables. The median employment growth rate for each two year interval varies between 2.3 and 4.6 per cent per year, whereas the median of the average annual growth rate of sales in current prices varies between 6.5 and 10.6 per cent. The median ratio of R&D expenditures to sales ranges between 4.0 and 5.2 per cent. Also, firms are becoming more R&D-intensive over time. This is consistent with the evolution of the aggregate R&D intensity in the business sector based on the R&D survey provided by Statistics Austria.

⁴ Regional dummy variables are never significant and are therefore not included in the final specification.

Table 1: Descriptive statistics for employment and sales (median) growth rates by time

time period	<u>Dependent variables:</u>		<u>Explanatory variables:</u>					
	av. annual growth rates of employment (median)	av. annual growth rates of sales (median)	time	initial employment (median)	ratio of R&D employment to total employment (median)	ratio of R&D expenditures to sales (median)	share of young firms founded in the last three years (percentages)	# of obs.
1996–1998	3.4	8.4	1996	67	7.9	4.1	17	619
1998–2000	4.6	9.5	1998	57	8.3	4.0	18	698
2000–2002	3.2	6.5	2000	54	8.0	4.7	22	704
2002–2004	2.3	8.0	2003	53	9.5	4.8	21	830
2004–2006	4.0	10.6	2004	49	10.5	5.2	18	822

Source: FFG, own calculations.

Table 2 presents descriptive statistics for nine different quantiles. At the lower quantiles (0.1 and 0.2) we can observe negative growth rates of both employment and sales while at the 0.4 quantile and above we can observe positive growth rates. Table 3 presents the breakdown of firm growth by both R&D intensity and firm size. For each firm size class we observe that the median of the average employment growth rate increases with R&D intensity. For example, in the largest class (250 employees and more), the median employment growth rate ranges between 4.1 per cent for firms with an R&D intensity between 10 and 20 per cent and -0.2 for firms with an R&D intensity of 1.5 per cent or less. Figure 1 in the appendix shows that the distributions of both sales and employment growth have relatively thicker right tails and hence depart from normality. OLS is not an appropriate technique to apply with such data.

Table 2: Descriptive statistics at various quantiles

	average growth rates of employment (t-2,t)	average growth of sales (t-2/t)	initial employment (t-2)	ratio of R&D expenditures to sales (t-2)	ratio of R&D employment to total employment (t-2)
Mean	9.3	18.4	273	26.3	22.2
Standard deviation	25.1	51.6	874	183.9	30.2
p10	-6.5	-9.4	4	0.6	0.0
p20	-2.2	-2.0	9	1.3	1.8
p25	-0.7	0.2	12	1.7	2.7
p30	0.0	1.9	16	2.1	3.6
p40	0.9	5.3	29	3.1	6.0
p50=median	3.4	8.7	52	4.6	8.9
p60	6.1	12.6	96	7.0	13.4
p70	10.2	18.2	168	10.9	22.2
p75	13.0	21.5	218	14.7	29.3
p80	16.4	26.3	287	19.4	37.5
p90	30.9	46.4	584	40.0	68.4
# of obs.	3695	3673	3695	3695	3695

Notes: Pooled data for the period 1996–2006. Growth rates refer to the periods 2004/2006, 2002/2004, 2000/2002, 1998/2000, 1996/1998. The remaining variables refer to the years 1996, 1998, 2000, 2002, 2004. Source: FFG, own calculations.

Table 3: Median of the average employment growth rates in the next two years by initial firm size and initial R&D sales ratio

ratio of R&D expenditures to sales:	firm size measured by employment classes:			
	1–9	10–49	50–249	>250
1.5% or less	8.0	4.1	1.7	-0.2
1.5% to under 4%	5.4	4.1	2.9	0.4
4% to under 10%	13.4	6.9	2.5	0.6
10% to under 20%	15.5	8.9	6.0	4.1
20% or more	18.3	8.2	5.0	n.a

Notes: Calculations are based on pooled data for the sub-periods 2004–2006, 2002–2004, 2000–2002, 1998–2000 and 1996–1998 with respect to employment growth, while the different categories of R&D intensity are measured in the initial year.

4 - Empirical results

4.1 Median regression results for each sub-period

Tables 4 and 5 show the coefficients and the (bootstrap) t-values of the median regressions of the impact of R&D intensity on employment growth based on the pooled sample for the period 1996–2006. The difference between Table 4 and Table 5 is that R&D intensity is defined as either the ratio of R&D expenditures to sales or the ratio of R&D employment to total employment. Table 6 shows the corresponding results for sales growth as the dependent variable.⁵ In each table, one can find separate estimation results for five different periods, different lags of the R&D intensity (i.e. initial R&D intensity and two different lags) and two different functional forms for the R&D intensity (logarithmic and non-logarithmic form). Standard errors are based on the bootstrap method with 1000 replications.

The main result is that the (logarithmic) R&D intensity in the initial year has a significant impact ($p < 0.05$) on sales and employment growth in the subsequent two years in almost all cases. This means that the sales and employment growth in the subsequent two years is higher, when the firm's expenditures in R&D increase, given total sales. The results for the growth equation where the dependent variable is the average annual employment growth rate show that log R&D intensity is significant at the 5 per cent level in 19 out of 28 cases (see Table 4 and 5). The corresponding coefficients range between 0.003 and 0.02. For the sales growth equation we find that log R&D intensity is significant at the 5 per cent level in 12 out of 14 cases and significant at the 10 per cent level in the remaining two cases with coefficients ranging between 0.009 and 0.031 (see Table 6). Accordingly, a rise in R&D intensity of 10 per cent (e.g. from 5 to 5.5 per cent) leads to an increase in the rate of growth of sales from 0.1 to 0.3 percentage points per year. Furthermore, the results show minimal change when different lags of the R&D intensity are used.

While the results in terms of size and significance are similar with respect to the alternative measure of R&D intensity, there is apparent heterogeneity in the strength of the R&D intensity across time. For example, for the periods 2002/2004 and 2004/2006, the R&D coefficient is much lower as compared to the periods 1996/1998, 1998/2000 and 2000/2000. However, the decrease in the R&D coefficient is less pronounced when the R&D employment ratio is employed as the measure of R&D intensity (see Table 5).

⁵ OLS estimates are reported in Table 9 in the appendix for comparison purposes.

Table 4: Median regression estimates for the impact of the ratio of R&D expenditures to sales on employment growth

Sub-period for the dep. var.	no logarithm of R&D intensity				with logarithm of R&D intensity				# of obs.
	log employment (t-2)	R&D intensity (t-2)	newly founded (t-2,t-5)	cons.	log employment (t-2)	log R&D in-intensity (t-2)	newly founded (t-2,t-5)	cons.	
R&D intensity measured in the initial year (t-2)									
2004–2006 ((t-2)–(t))	-0.012 ^{***} (-4.21)	0.021 (1.38)	0.067 ^{***} (3.08)	0.090 ^{***} (5.87)	-0.012 ^{***} (-4.20)	0.003 (1.37)	0.069 ^{***} (3.15)	0.103 ^{***} (5.38)	822
2002–2004 ((t-2)–(t))	-0.012 ^{***} (-3.32)	0.000 (0.06)	0.038 ^{**} (2.46)	0.077 ^{***} (4.06)	-0.011 ^{***} (-3.42)	0.003 (1.32)	0.037 ^{**} (2.28)	0.083 ^{***} (4.79)	830
2000–2002 ((t-2)–(t))	-0.021 ^{***} (-5.33)	-0.001 (-0.04)	0.077 ^{***} (3.40)	0.127 ^{***} (5.69)	-0.019 ^{***} (-5.15)	0.012 ^{***} (2.83)	0.067 ^{***} (3.31)	0.160 ^{***} (6.46)	704
1998–2000 ((t-2)–(t))	-0.018 ^{***} (-5.10)	0.022 (0.59)	0.054 ^{**} (2.02)	0.121 ^{***} (6.44)	-0.014 ^{***} (-4.26)	0.015 ^{***} (3.97)	0.067 ^{**} (2.45)	0.164 ^{***} (7.16)	698
1996–1998 ((t-2)–(t))	-0.025 ^{***} (-5.41)	-0.004 (-0.09)	0.031 (1.38)	0.152 ^{***} (5.76)	-0.019 ^{***} (-5.15)	0.014 ^{***} (4.06)	0.013 (0.54)	0.17 ^{***} (8.21)	619
R&D intensity measured lagged minus one (t-3)									
2004–2006 ((t-2)–(t))	-0.011 ^{***} (-3.42)	0.008 (0.45)	0.041 (1.25)	0.088 ^{***} (5.05)	-0.01 ^{***} (-3.58)	0.006 ^{**} (2.14)	0.043 (1.48)	0.110 ^{***} (5.22)	580
2002–2004 ((t-2)–(t))	-0.014 ^{***} (-3.40)	-0.002 (-0.12)	0.013 (0.79)	0.090 ^{***} (4.06)	-0.010 ^{***} (-2.62)	0.004 (1.56)	0.014 (0.82)	0.085 ^{***} (4.03)	561
2000–2002 ((t-2)–(t))	-0.014 ^{***} (-3.24)	0.120 ^{***} (3.56)	0.087 ^{***} (3.85)	0.083 ^{***} (3.35)	-0.016 ^{***} (-3.90)	0.013 ^{***} (2.91)	0.084 ^{***} (2.92)	0.149 ^{***} (5.19)	483
1998–2000 ((t-2)–(t))	-0.016 ^{***} (-3.48)	0.084 (1.51)	0.033 (0.90)	0.120 ^{***} (4.37)	-0.017 ^{***} (-3.86)	0.018 ^{***} (4.23)	0.030 (0.91)	0.197 ^{***} (6.57)	461
1996–1998 ((t-2)–(t))	-0.023 ^{***} (-4.38)	0.129 (1.67)	-0.017 (-0.72)	0.145 ^{***} (4.33)	-0.022 ^{***} (-5.03)	0.018 ^{***} (3.89)	-0.012 (-0.45)	0.213 ^{***} (8.62)	397
R&D intensity measured lagged minus two (t-4)									
2004–2006 ((t-2)–(t))	-0.013 ^{***} (-3.76)	0.006 (0.24)	0.035 (0.88)	0.103 ^{***} (5.12)	-0.013 ^{***} (-3.67)	0.008 ^{***} (2.33)	0.021 (0.63)	0.129 ^{***} (5.59)	470
2002–2004 ((t-2)–(t))	-0.015 ^{***} (-3.14)	-0.001 (-0.05)	0.028 (1.19)	0.095 ^{***} (3.68)	-0.012 ^{***} (-2.80)	0.004 (1.61)	0.033 (1.41)	0.093 ^{***} (3.83)	451
2000–2002 ((t-2)–(t))	-0.014 ^{***} (-3.17)	-0.001 (-0.02)	0.083 (3.06)	0.090 ^{***} (3.54)	-0.013 ^{***} (-2.94)	0.007 (1.63)	0.082 ^{***} (3.09)	0.113 ^{***} (3.66)	396
1998–2000 ((t-2)–(t))	-0.011 ^{**} (-2.11)	0.126 ^{**} (2.02)	0.008 (0.20)	0.089 ^{***} (2.96)	-0.013 ^{***} (-2.79)	0.013 ^{***} (2.23)	0.028 (0.62)	0.157 ^{***} (4.70)	367

Notes: ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively. Dependent variable is the geometric annual change in employment over each two year period. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications.

Table 5: Median regression estimates for the impact of the share of R&D employment on employment growth

Sub-period for the dep. var.	no log form for R&D intensity				with log form for R&D intensity				# of obs.
	R&D intensity measured in the initial year (t-2)								
	log employment (t-2)	R&D employment ratio (t-2)	newly founded (t-2,t-5)	cons.	log employment (t-2)	log R&D employment ratio (t-2)	newly founded (t-2,t-5)	cons.	
2004–2006 ((t-2)–(t))	-0.012*** (-4.46)	0.058** (2.05)	0.065*** (2.96)	0.086*** (5.53)	-0.012*** (-4.49)	0.006*** (2.21)	0.063*** (2.80)	0.112*** (5.93)	780
2002–2004 ((t-2)–(t))	-0.009*** (-3.17)	0.046** (1.84)	0.030* (1.95)	0.058*** (3.58)	-0.009*** (-3.12)	0.006*** (2.40)	0.032** (2.08)	0.081*** (5.20)	778
2000–2002 ((t-2)–(t))	-0.018*** (-5.05)	0.111** (2.59)	0.079*** (4.02)	0.102*** (4.88)	-0.019*** (-5.23)	0.010*** (2.13)	0.087*** (4.33)	0.148*** (6.52)	653
1998–2000 ((t-2)–(t))	-0.014*** (-3.20)	0.089** (2.52)	0.063* (1.67)	0.094*** (3.69)	-0.014*** (-3.19)	0.018*** (3.91)	0.082** (2.13)	0.153*** (5.81)	602
1996–1998 ((t-2)–(t))	-0.018*** (-4.15)	0.108*** (2.81)	0.014 (0.60)	0.104*** (3.89)	-0.018*** (-4.63)	0.017*** (4.02)	0.016 (0.65)	0.165*** (7.44)	500
R&D intensity measured lagged minus one (t-3)									
	log employment (t-2)	R&D employment ratio (t-3)	newly founded (t-2,t-5)	cons.	log employment (t-2)	log R&D employment ratio (t-3)	newly founded (t-2,t-5)	cons.	# of obs.
2004–2006 ((t-2)–(t))	-0.011*** (-3.73)	0.027 (0.90)	0.055* (1.74)	0.087*** (4.70)	-0.011*** (-3.62)	0.006* (1.85)	0.055* (1.74)	0.109*** (5.06)	563
2002–2004 ((t-2)–(t))	-0.009*** (-2.59)	0.059** (2.03)	0.019 (1.12)	0.052*** (2.65)	-0.009** (-2.50)	0.006** (1.95)	0.021 (1.17)	0.078*** (4.06)	544
2000–2002 ((t-2)–(t))	-0.015*** (-3.77)	0.025 (0.61)	0.085*** (3.49)	0.092*** (3.77)	-0.013*** (-3.27)	0.010** (2.38)	0.080*** (3.25)	0.112*** (4.61)	441
1998–2000 ((t-2)–(t))	-0.012 (-1.77)	0.110*** (3.16)	0.04 (1.22)	0.082** (2.00)	-0.014** (-2.59)	0.020*** (3.72)	0.071 (1.43)	0.163*** (5.02)	410
1996–1998 ((t-2)–(t))	-0.015*** (-3.63)	0.120** (2.55)	0.004 (0.18)	0.093*** (3.41)	-0.018*** (-4.30)	0.020*** (3.35)	-0.004 (-0.20)	0.173*** (7.54)	359
R&D intensity measured lagged minus two (t-4)									
	log employment (t-2)	R&D employment ratio (t-4)	newly founded (t-2,t-5)	cons.	log employment (t-2)	log R&D employment ratio (t-4)	newly founded (t-2,t-5)	cons.	# of obs.
2004–2006 ((t-2)–(t))	-0.011*** (-3.30)	-0.001 (-0.05)	-0.004 (-0.10)	0.093*** (4.51)	-0.010*** (-3.16)	0.005 (1.41)	-0.006 (-0.16)	0.102*** (4.46)	457
2002–2004 ((t-2)–(t))	-0.008** (-2.21)	0.047 (1.44)	0.013 (0.58)	0.052** (2.58)	-0.008** (-2.07)	0.006** (2.12)	0.014 (0.54)	0.073*** (3.66)	436
2000–2002 ((t-2)–(t))	-0.010** (-2.31)	0.006 (0.26)	0.089*** (2.67)	0.069** (2.56)	-0.009* (-1.91)	0.006 (1.49)	0.084*** (2.61)	0.080*** (3.05)	363
1998–2000 ((t-2)–(t))	-0.008 (-1.27)	0.106** (2.19)	0.057 (1.05)	0.063 (1.59)	-0.012** (-2.04)	0.016** (2.06)	0.084 (1.41)	0.139*** (4.10)	323

Notes: ***, **, and * denote significance at the 1, 5 and 10 per cent levels, respectively. Dependent variable is the geometric annual change in employment over each two year period. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications.

Table 6: Median regression estimates for the impact of R&D intensity on the average growth rate of sales in the two subsequent years

Sub-period for the dep. var.	no logarithm of R&D intensity				with logarithm of R&D intensity				# of obs
	R&D intensity measured in the initial year (t-2)								
	log employ-ment (t-2)	R&D in-tensity (t-2)	newly founded (t-2,t-5)	cons.	log employ-ment (t-2)	log R&D intensity (t-2)	newly founded (t-2,t-5)	cons.	
2004–2006 ((t-2)–(t))	-0.009 [*] (-1.80)	0.078 (1.48)	0.084 ^{***} (2.61)	0.133 ^{***} (5.10)	-0.006 (-1.20)	0.014 ^{***} (3.04)	0.084 ^{**} (2.57)	0.174 ^{***} (5.87)	822
2002–2004 ((t-2)–(t))	-0.005 (-1.32)	0.087 ^{**} (2.02)	0.068 ^{***} (3.13)	0.084 ^{***} (4.21)	-0.004 (-1.36)	0.011 ^{***} (3.53)	0.095 ^{***} (3.73)	0.127 ^{***} (6.53)	830
2000–2002 ((t-2)–(t))	-0.016 ^{**} (-2.37)	0.076 (0.41)	0.114 ^{***} (4.72)	0.119 ^{***} (2.65)	-0.010 [*] (-1.93)	0.025 ^{***} (4.56)	0.119 ^{***} (4.24)	0.183 ^{***} (6.04)	704
1998–2000 ((t-2)–(t))	-0.005 (-1.05)	0.251 ^{***} (3.66)	0.110 ^{***} (2.73)	0.094 ^{***} (3.42)	-0.005 (-1.45)	0.031 ^{***} (5.03)	0.116 ^{***} (3.05)	0.229 ^{***} (6.34)	698
1996–1998 ((t-2)–(t))	-0.013 ^{**} (-2.48)	0.087 (0.65)	0.112 ^{***} (3.67)	0.132 ^{***} (4.26)	-0.010 ^{**} (-2.41)	0.030 ^{***} (4.20)	0.102 ^{***} (4.23)	0.235 ^{***} (6.29)	619
R&D intensity measured lagged minus one (t-3)									
	log employ-ment (t-2)	R&D in-tensity (t-3)	newly founded (t-2,t-5)	cons.	log employ-ment (t-2)	log R&D intensity (t-3)	newly founded (t-2,t-5)	cons.	# of obs
2004–2006 ((t-2)–(t))	-0.004 (-0.88)	0.060 [*] (1.70)	0.034 (1.04)	0.116 ^{***} (4.24)	-0.002 (-0.37)	0.010 [*] (1.85)	0.034 (1.05)	0.143 ^{***} (4.65)	580
2002–2004 ((t-2)–(t))	-0.001 (-0.14)	0.047 (0.90)	0.037 [*] (1.70)	0.066 ^{***} (2.96)	-0.002 (-0.54)	0.014 ^{***} (3.06)	0.038 (1.55)	0.120 ^{***} (4.96)	561
2000–2002 ((t-2)–(t))	-0.010 (-1.63)	0.083 (0.74)	0.094 ^{***} (3.20)	0.084 ^{**} (2.23)	-0.011 (-1.82)	0.014 ^{***} (2.93)	0.099 ^{***} (3.26)	0.145 ^{***} (4.69)	483
1998–2000 ((t-2)–(t))	0.000 (0.05)	0.304 ^{***} (2.41)	0.109 ^{**} (1.99)	0.070 [*] (1.87)	-0.002 (-0.36)	0.018 ^{***} (2.44)	0.116 ^{***} (2.02)	0.161 ^{***} (3.86)	461
1996–1998 ((t-2)–(t))	-0.006 (-0.86)	0.287 (1.46)	0.062 (1.29)	0.094 [*] (1.95)	-0.008 (-1.32)	0.024 ^{***} (3.35)	0.060 (1.31)	0.205 ^{***} (5.43)	397
R&D intensity measured lagged minus two (t-4)									
	log employ-ment (t-2)	R&D in-tensity (t-4)	newly founded (t-2,t-5)	cons.	log employ-ment (t-2)	log R&D intensity (t-4)	newly founded (t-2,t-5)	cons.	# of obs
2004–2006 ((t-2)–(t))	-0.003 (-0.50)	0.045 [*] (1.90)	0.030 (0.65)	0.117 ^{***} (3.04)	-0.003 (-0.52)	0.012 ^{**} (2.08)	0.046 (1.01)	0.160 ^{***} (4.39)	470
2002–2004 ((t-2)–(t))	0.000 (-0.04)	0.003 (0.07)	0.047 (1.57)	0.072 ^{***} (2.94)	0.002 (0.33)	0.009 [*] (1.85)	0.049 (1.44)	0.093 ^{***} (3.31)	451
2000–2002 ((t-2)–(t))	-0.015 (-2.73)	0.043 (0.56)	0.098 ^{***} (3.79)	0.117 ^{***} (3.50)	-0.013 ^{**} (-2.30)	0.015 ^{***} (2.65)	0.120 ^{***} (4.40)	0.164 ^{***} (5.33)	396
1998–2000 ((t-2)–(t))	0.003 (0.35)	0.208 (1.44)	0.090 (0.99)	0.060 (1.31)	-0.002 (-0.33)	0.020 ^{**} (2.54)	0.085 (0.87)	0.167 ^{***} (3.61)	367

Notes: ^{***}, ^{**} and ^{*} denote significance at the 1, 5 and 10 percent levels, respectively. Dependent variable is the geometric annual change in sales over each two year period. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications.

In a related study, Hall (1993) found strong evidence in favor of a declining rate of return to R&D from 1979–1983 and 1986–1991 based on US data.

Having found that the impact of R&D intensity on firm growth decreases over time, it is important to investigate the possible reasons for this. One reason is a change in the composition of the sample over time. The data reveals that there is a decrease in the number of newly founded firms (founded in the last three years) from 23 per cent in 2001 to 18 per cent in 2006. To quantify this effect, we re-estimated the growth equation based on a balanced sample. Unreported results show that one can again find a decrease in the R&D coefficient over time, indicating that change in the coefficient is not due to a change in the composition of the sample. Another reason for the decline in the impact of R&D intensity on firm growth is the position of the business cycle. However, the periods 1998–2000 and 2004–2006 correspond to a roughly similar position in the business cycle. We thus conclude that the return to R&D falls over time.

Finally, the estimated coefficient on firm size is negative and statistically significant ($p < 0.05$) in almost all specifications. This suggests that Gibrat's law does not hold for firms in our estimation sample.

4.2 Quantile regression results for the pooled sample

Tables 7 and 8 show the results of the simultaneous quantile regressions for the employment and sales growth equation at various quantiles using pooled data covering five cross-sections for the period 1996–2006.⁶ Again, the growth rates are measured as the annual geometric growth rate based on a two year period. Estimates are reported for nine different quantiles (0.1, ..., 0.9). Each table contains three specifications: in the basic equation we include the initial R&D intensity, while the second and third specifications include R&D intensity (t-3) and R&D intensity (t-4). The t-values are based on bootstrapped standard errors with 1000 replications. Table 10 in the appendix shows the quantile regression results for the employment growth equation with the R&D employment ratio instead of the ratio of R&D expenditures to sales as the measure of R&D intensity. The estimated coefficients can be interpreted as the partial derivative of the conditional quantile of firm growth with respect to the dependent variable.

The results for the employment growth equation show that the impact of R&D intensity varies across the conditional growth distribution. This is confirmed by F-tests that reject the null hypothesis that the coefficients are equal between the pairwise quantiles. Our findings are consistent with earlier studies (see Coad and Rao, 2008, Hölzl, 2009, and Stam and Wennberg, 2009). In particular, R&D intensity is positive and statistically significant at the five per cent level only at the middle and upper quantiles, i.e. between $q=0.4$ and the highest quantile ($=0.9$) (see Table 7). At the 0.1, 0.2 and 0.3 quantiles, R&D intensity is not significantly different from zero. This indicates that R&D intensity matters only when a certain level of firm growth is achieved. In other words, R&D activities are not effective in firms that are shrinking. Overall, the results are consistent with Kaiser (2009) who finds that patents have a significantly positive effect on the ratio of profits to sales for the 50, 25, and 10 per cent most profitable firms but it has a negative impact on the 10 per cent least profitable firms.

Turning to the magnitude of the effects, we observe that the coefficient continuously increases from the lower to upper quantile of the employment growth distribution. For example, a 1 per cent increase in the R&D intensity leads to an acceleration of the average annual employment growth rate between 0.5 percentage points at the 0.4 quantile and 2.7 percentage points at the 0.9 quantile. The coefficient of 0.005 for the 0.4 quantile regression is sizable given the value of the average annual employment rate of 0.9 per cent per year at the 0.4 quantile. To get further insights into the magnitude of the effect,

⁶ Estimation is performed using the SQREG command in STATA 10.0.

one can calculate the elasticity of firm growth with respect to the R&D intensity. This is done by dividing the coefficients by the value of the corresponding quantile of the employment growth distribution. Table 10 shows that the elasticity of employment growth with respect to R&D intensity is highest for q=0.4, followed by the median.

Table 7: Quantile regression estimates for the impact of R&D-to-sales ratio on employment growth

specification with R&D intensity measured in the initial year (t-2); # of obs.: 3695									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.005 (-1.56)	-0.006*** (-10.02)	-0.003*** (-4.16)	-0.008*** (-5.04)	-0.015*** (-9.80)	-0.021*** (-14.22)	-0.029*** (-16.48)	-0.037*** (-14.53)	-0.056*** (-14.77)
log R&D intensity (t-2)	-0.005 (-1.64)	0.000 (0.41)	0.001 (1.16)	0.005*** (3.33)	0.008*** (5.40)	0.010*** (9.22)	0.015*** (9.11)	0.019*** (9.09)	0.027*** (7.06)
newly founded (t-2,t-5)	0.011 (0.60)	0.001 (0.26)	0.006 (0.68)	0.036*** (4.52)	0.047*** (5.20)	0.062*** (7.18)	0.092*** (5.60)	0.135*** (5.55)	0.239*** (7.20)
constant	-0.060*** (-3.16)	0.005* (1.90)	0.007*** (2.65)	0.065*** (6.71)	0.131*** (12.73)	0.191*** (20.77)	0.270*** (22.92)	0.365*** (22.82)	0.555*** (19.57)
pseudo R ²	0.002	0.014	0.004	0.017	0.045	0.079	0.116	0.161	0.228
growth R&D elasticity	0.077	0.000		0.556	0.235	0.164	0.147	0.116	0.087
specification with R&D intensity measured lagged minus one (t-3); # of obs.: 2501									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.005 (-1.63)	-0.006*** (-7.98)	-0.003*** (-3.22)	-0.009*** (-6.08)	-0.015*** (-9.72)	-0.021*** (-12.11)	-0.027*** (-13.85)	-0.036*** (-12.84)	-0.050*** (-12.61)
log R&D intensity (t-3)	-0.003 (-1.00)	0.002 (1.64)	0.003** (2.02)	0.007*** (5.08)	0.011*** (6.66)	0.013*** (7.53)	0.016*** (7.95)	0.020*** (8.03)	0.028*** (6.95)
newly founded (t-2,t-5)	-0.005 (-0.22)	0.000 (0.08)	0.006 (0.72)	0.023** (2.18)	0.027** (2.42)	0.044*** (4.15)	0.056*** (3.50)	0.082*** (3.87)	0.142*** (3.07)
constant	-0.051*** (-2.60)	0.010*** (3.44)	0.017 (2.21)	0.082*** (8.54)	0.144*** (12.54)	0.198*** (17.45)	0.269*** (19.81)	0.362*** (20.51)	0.529*** (18.45)
pseudo R ²	0.002	0.012	0.007	0.021	0.048	0.079	0.114	0.150	0.195
specification with R&D intensity measured lagged minus two (t-4); # of obs.: 1700									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	0.000 (0.00)	-0.006*** (-4.61)	-0.002** (-2.51)	-0.007*** (-3.66)	-0.012*** (-5.88)	-0.016*** (-8.98)	-0.020*** (-7.17)	-0.028*** (-9.84)	-0.045*** (-9.23)
log R&D intensity (t-4)	-0.006* (-1.70)	0.000 (0.08)	0.001 (0.95)	0.005*** (3.15)	0.008*** (4.34)	0.011*** (6.81)	0.015*** (8.01)	0.018*** (5.75)	0.016** (2.48)
newly founded (t-2,t-5)	0.014 (0.39)	0.005 (0.78)	0.003 (0.39)	0.016 (1.03)	0.033** (2.13)	0.044*** (3.79)	0.041** (2.29)	0.058*** (2.78)	0.041 (1.03)
constant	-0.092*** (-3.25)	0.004 (0.62)	0.007 (1.77)	0.063*** (5.00)	0.120*** (7.73)	0.169*** (14.24)	0.226*** (12.93)	0.312*** (19.85)	0.461 (11.77)
pseudo R ²	0.002	0.007	0.005	0.011	0.030	0.056	0.081	0.106	0.134

Notes: ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications. Pooled estimates for the sub-periods 2004–2006, 2002–2004, 2000–2002, 1998–2000 and 1996–1998 with respect to the dependent variable. Log employment and log R&D intensity refer to year t-2 (upper panel). In addition, we also use R&D intensity t-3 and t-4 (middle and lower panel).

Table 8: Quantile regression estimates for the impact of R&D intensity on average growth rate of sales in the two subsequent years

specification with R&D intensity in the initial year (t-2); # of obs.: 3710									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	0.018*** (5.90)	0.010*** (4.76)	0.005*** (2.84)	0.000 (-0.12)	-0.007*** (-4.01)	-0.012*** (-5.22)	0.017*** (-6.98)	-0.026*** (-8.06)	-0.042*** (-8.66)
log R&D in tensity (t-2)	0.000 (0.06)	0.004* (1.98)	0.010*** (5.08)	0.013*** (6.34)	0.019*** (9.55)	0.027*** (9.08)	0.035*** (11.63)	0.046*** (13.02)	0.065*** (11.27)
newly founded firms (t-2,t-5)	0.005 (0.29)	0.037*** (3.10)	0.057*** (5.78)	0.082*** (6.90)	0.099*** (8.40)	0.138*** (6.86)	0.226*** (7.32)	0.331*** (8.63)	0.736*** (7.32)
constant	-0.171*** (-9.33)	-0.050*** (-4.16)	0.024*** (2.40)	0.091*** (7.92)	0.175*** (15.16)	0.265*** (18.14)	0.354*** (24.66)	0.495*** (21.52)	0.742*** (22.73)
pseudo R ²	0.013	0.005	0.009	0.018	0.033	0.055	0.086	0.130	0.204
growth R&D elasticity	0.000	-0.200		0.245	0.218	0.214	0.192	0.175	0.140
specification with R&D intensity lagged minus one (t-3); # of obs.: 2510									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employ- ment (t-2)	0.014*** (2.99)	0.009*** (3.53)	0.005*** (2.29)	0.000 (0.21)	-0.004 (-1.54)	-0.010*** (-3.88)	-0.014*** (-5.43)	-0.021*** (-5.07)	-0.032*** (-7.09)
log R&D in- tensity (t-3)	-0.009*** (-2.12)	-0.003*** (-0.91)	0.006*** (2.32)	0.011*** (4.50)	0.015*** (6.38)	0.021*** (6.47)	0.030*** (9.46)	0.042*** (8.75)	0.059*** (13.12)
newly founded (t-2,t-5)	0.007 (0.31)	0.013 (0.65)	0.036*** (2.59)	0.042*** (3.08)	0.060*** (4.36)	0.074*** (4.10)	0.107*** (4.54)	0.180*** (5.18)	0.201*** (3.22)
constant	-0.184*** (-8.28)	-0.072*** (-5.55)	0.011 (0.73)	0.080*** (6.63)	0.144*** (10.5)	0.228*** (13.46)	0.323*** (20.62)	0.456*** (14.67)	0.654*** (21.31)
pseudo R ²	0.017	0.0055	0.004	0.0097	0.0189	0.0342	0.0616	0.098	0.1586
specification with R&D intensity lagged minus two (t-4); # of obs.: 1705									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employ- ment (t-2)	0.012*** (1.83)	0.010*** (3.49)	0.008*** (3.03)	0.001 (0.49)	-0.003 (-0.84)	-0.010*** (-2.87)	-0.015*** (-4.46)	-0.020*** (-4.21)	-0.034*** (-6.31)
log R&D in- tensity (t-4)	-0.012*** (-2.19)	-0.003 (-1.02)	0.004*** (1.71)	0.009*** (2.97)	0.014*** (5.51)	0.017*** (4.66)	0.028*** (6.21)	0.030*** (5.40)	0.048*** (8.08)
newly founded (t-2,t-5)	-0.014 (-0.38)	0.010 (0.33)	0.046*** (2.94)	0.045*** (2.19)	0.073*** (4.33)	0.065*** (3.92)	0.084*** (3.01)	0.162*** (2.84)	0.200*** (2.22)
constant	-0.186*** (-7.21)	-0.076*** (-4.96)	-0.009 (-0.64)	0.073*** (4.27)	0.138*** (7.56)	0.215*** (9.04)	0.321*** (15.43)	0.396*** (10.85)	0.627*** (15.53)
pseudo R ²	0.016	0.007	0.006	0.007	0.016	0.027	0.046	0.070	0.122

Notes: ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications. For further notes see Table 7.

For the sales growth equation, it also appears that R&D intensity is not significant in the lower part of the distribution, but highly significant in the middle and upper part of the distribution (see Table 10). For instance, at the 10% conditional quantile of the sales growth distribution, the R&D intensity is not significant. From the 30% to 90% conditional quantile, both the coefficient and its significance increase considerably along the conditional growth distribution. However, at the 80% and 90% quantiles, the reported coefficients are quite low when compared to the value of the 0.8 and 0.9 quantiles of the

distribution of the sales growth rate. The upper panel in Table 10 shows that the growth R&D elasticity is highest at the 0.3 and 0.4 quantiles, and then continuously decreases with rising quantiles.

The dummy variable for young firms is significant in the employment growth equation from the 0.4 and upper quantiles, suggesting that young firms tend to have higher growth rates but only for firms with positive conditional growth rates. Furthermore, the coefficient of the dummy variable increases as one moves from the 0.4 to the 0.9 quantiles. For example, in the upper panel of Table 7 the dummy variable for young firms increases from 0.036 to 0.239. Similarly, the negative coefficient on initial firm size in absolute terms increases steadily from lower to upper quantiles indicating that smaller firms grow faster and this effect is more pronounced for fast growing firms.

Figures 2 and 3 in the appendix show the quantile estimates for selected periods. For the 10%, 20%, 80% and 90% quantiles, the coefficient for the R&D intensity is outside the 95% confidence interval of the OLS regression in the majority of cases. This means that the growth effect of R&D intensity (in absolute terms) in this part of the distribution differs significantly from that of the OLS estimates. For the 0.3 to 0.7 quantiles the estimates are not much different from the OLS estimate because they all fall in the 95% confidence interval of the OLS estimate.

Tables 11 and 12 in the appendix show the estimation results of both the employment growth and sales growth equation for two selected cross-section periods; namely the periods 2004–2006, and 1998–2000, respectively. Here R&D intensity shows a significant effect only at 0.50 quantile or at higher quantiles, suggesting that only firms at and above median growth rates benefit from R&D investment.

5 - Conclusions

The main objective of this paper was to examine the relationship between R&D intensity and firm growth, using a large and unique data set for Austrian firms for the period 1995–2006. The quantile regression methodology was used to explore whether the impact of R&D activities differed along the conditional firm growth distribution. Results of the least-absolute-deviation (LAD) estimator for the median-regression model show that the initial R&D intensity has a significant and positive impact on both employment and sales growth in the two subsequent years. This finding is robust with respect to the measurement of R&D intensity (i.e. ratio of R&D employment to total employment and ratio of R&D expenditures to sales), different lags of R&D intensity and different time periods. However, R&D investment is much more closely linked for the periods 1996–1998, and 1998–2000, as compared to the more recent time periods 2000–2002, 2002–2004, and 2004–2006, indicating that the impact of R&D decreases over time. For instance, the coefficient on the logarithm of R&D intensity (measured as the R&D employment ratio) in the employment growth equation decreases from 0.018 for the period 1998–2000 to 0.006 for the period 2004–2006.

Another important aspect of the paper is that there is a sizable variation in the impact of R&D intensity on firm performance between firms with low and high growth rates. In particular, quantile estimates for the 0.1 to 0.9 quantiles show that R&D intensity has a positive and significant effect only in the middle and upper range of the growth distribution. Shrinking firms do not benefit from investment in R&D. The R&D coefficient in the upper quantiles (e.g. fast growing firms) can be as large as 0.04, while the effect in the lower quantiles (e.g. shrinking firms) is not significantly different from zero. A new and important finding of the paper is that the elasticity of firm growth with respect to R&D intensity is highest for firms slightly below or at the median of the conditional growth distribution.

The findings have some important implications for innovation policy. Since the majority of firms with R&D activities benefit from R&D activities, then increasing R&D subsidies is a reasonable policy objective. On the negative side, the lack of any significant relationship between R&D intensity and firm growth at the lower conditional firm growth distribution raises potential concerns. In particular, for one third of the firms, R&D activities do not seem to matter for firm growth. In order to enhance firm growth, one priority of the R&D funding agency could be to target firms located in the middle tail of the conditional growth distribution since the marginal impact is highest in this part of the distribution. However, it is extremely difficult for R&D program managers to target their intervention at this particular group.

Explanations of the decrease in the impact of R&D intensity over time are hard to find. It would be interesting to repeat this study in other industrialized countries that also experienced a rapid increase in R&D intensity since the early 1990s such as China, Finland, Korea, Singapore and Taiwan. The study is not free from limitations. One limitation is that investment and other important determinants of firm growth are not included in the empirical model due to data availability. This study can be extended in a number of ways. One extension, for instance, is the use of other performance measures such as the profit-to-sales ratio.

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6 - Annex 1

Graph 1: Kernel density estimates of the growth rate of employment and total sales

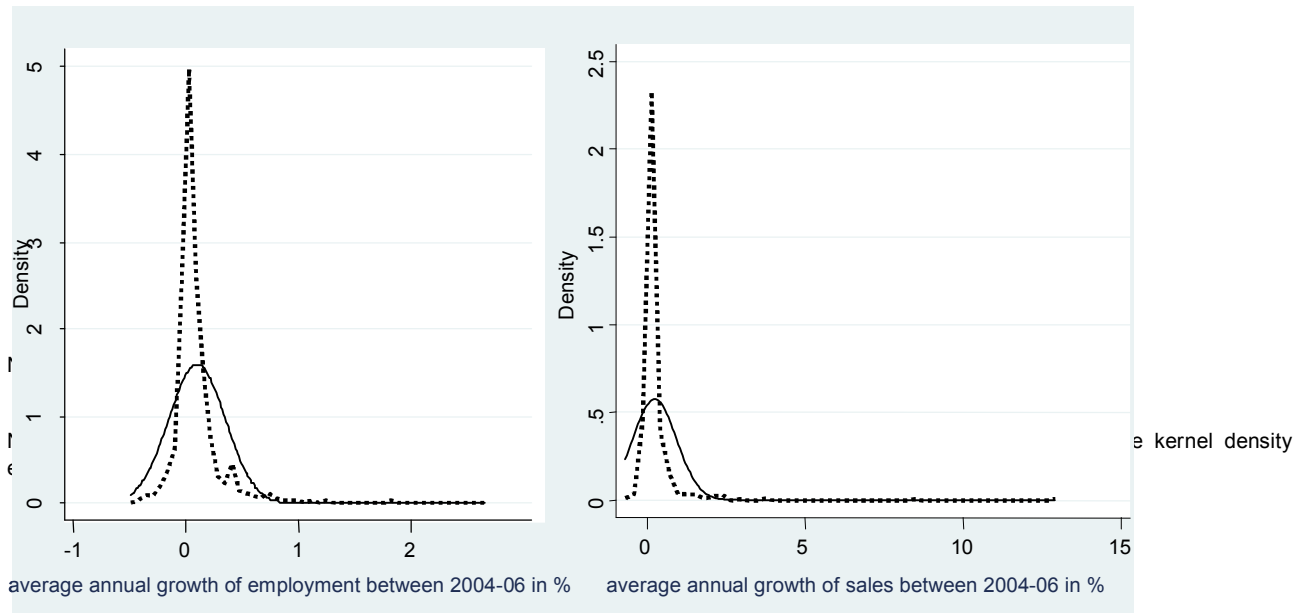


Table 9: OLS results of the impact of R&D intensity on firm performance

	no logarithmic specification					With logarithmic specification				
	<u>impact of initial/lag R&D intensity on employment growth (t-2,t)</u>									
	measure of R&D intensity: R&D expenditures in % of sales									
	2004– 2006	2002– 2004	2000– 2002	1998– 2000	1996– 1998	2004– 2006	2002– 2004	2000– 2002	1998– 2000	1996– 1998
R&D sales ratio (t-2)	0.010 (1.39)	-0.010 (-1.27)	-0.002 (-1.60)	0.012*** (2.01)	-0.003 (-0.59)	0.004 (0.79)	-0.003 (-0.46)	0.015*** (2.80)	0.023*** (3.22)	0.019*** (2.88)
R&D sales ratio (t-3)	0.007** (2.00)	-0.012 (-1.10)	0.104*** (5.52)	0.078*** (1.96)	0.158*** (2.74)	0.001 (0.19)	-0.001 (-0.23)	0.023*** (3.52)	0.020*** (3.01)	0.026*** (2.86)
R&D sales ratio (t-4)	0.011 (1.27)	-0.001 (-1.57)	0.016 (1.07)	0.056 (1.21)		0.004 (0.65)	0.000 (0.05)	0.018** (2.50)	0.018** (2.13)	
	measure of R&D intensity: R&D employment in % of total employment									
R&D employ. ratio (t-2)	0.075 (1.53)	0.056 (1.27)	0.107** (2.23)	0.107*** (2.60)	0.086** (2.34)	0.004 (0.73)	0.004 (0.96)	0.019*** (3.44)	0.030*** (4.06)	0.022*** (3.29)
R&D employ. ratio (t-3)	0.014 (0.41)	0.087 ⁺ (1.88)	0.055 (1.26)	0.122*** (3.22)	0.072 ⁺ (1.86)	0.005 (0.99)	0.010 ⁺ (1.92)	0.012** (2.11)	0.027*** (3.73)	0.021*** (2.74)
R&D employ. ratio (t-4)	-0.008 (-0.20)	0.037 (0.95)	0.035 (0.96)	0.106*** (2.78)		0.002 (0.41)	0.006 (1.15)	0.010 ⁺ (1.73)	0.022*** (2.71)	
	<u>impact of initial/lag R&D intensity on sales growth (t-2,t)</u>									
	measure of R&D intensity: R&D expenditures in % of sales									
	2004– 2006	2002– 2004	2000– 2002	1998– 2000	1996– 1998	2004– 2006	2002– 2004	2000– 2002	1998– 2000	1996– 1998
R&D sales ratio (t-2)	0.047** (2.06)	0.122*** (3.59)	0.087*** (5.62)	0.221*** (9.67)	0.102*** (5.37)	0.042*** (3.28)	0.049*** (3.72)	0.096*** (4.40)	0.081*** (3.66)	0.075*** (3.67)
R&D sales ratio (t-3)	0.072*** (5.12)	0.093** (2.46)	0.116** (2.23)	0.395*** (2.84)	0.485*** (2.90)	0.023** (2.40)	0.041*** (3.02)	0.034*** (3.68)	0.047*** (3.18)	0.061*** (2.84)
R&D sales ratio (t-4)	0.035*** (3.98)	0.004 (1.03)	0.036*** (6.69)	0.220 (1.41)		0.016** (1.73)	0.018 ⁺ (1.78)	0.043*** (4.36)	0.050*** (2.89)	
	measure of R&D intensity: R&D employment in % of total employment									
R&D employ. ratio (t-2)	-0.083 (-0.50)	0.181 ⁺ (1.99)	0.418** (2.55)	0.287*** (2.68)	0.171** (2.60)	-0.013 (-0.65)	0.032** (2.14)	0.048*** (3.41)	0.057*** (3.79)	0.038*** (3.47)
R&D employ. ratio (t-3)	0.186 (1.64)	0.196** (2.38)	0.141 (1.64)	0.277*** (3.37)	0.212*** (2.59)	0.033 ⁺ (1.79)	0.027** (2.30)	0.023** (2.37)	0.053*** (3.82)	0.048*** (3.74)
R&D employ. ratio (t-4)	-0.016 (-0.24)	0.272*** (2.75)	0.055 (0.85)	0.232*** (3.90)		0.002 (0.22)	0.023 ⁺ (1.82)	0.020 ⁺ (1.98)	0.054*** (4.26)	

Note: ***, ** and ⁺ denote significance at the 1, 5 and 10 percent levels, respectively. All equations include initial employment and a dummy variable for young firms. T-statistics are in parentheses and are based on heteroscedasticity-consistent standard errors.

Table 10: Quantile regression estimates for the impact of the ratio of R&D employment on employment growth (pooled estimates for the period 1996–2006)

specification with R&D employment ratio measured in the initial year (t-2); # of obs.: 3396									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.002 (-0.53)	-0.005*** (-4.61)	-0.002*** (-2.15)	-0.008*** (-5.65)	-0.014*** (-9.44)	-0.020*** (-12.11)	-0.026*** (-14.37)	-0.033*** (-15.11)	-0.045*** (-10.75)
log ratio of R&D employment to total employment (t-2)	-0.001 (-0.36)	0.002 (1.36)	0.003*** (2.12)	0.007*** (4.29)	0.010*** (6.33)	0.013*** (9.63)	0.019*** (9.56)	0.023*** (10.86)	0.036*** (7.63)
newly founded (t-2,t-5)	0.000 (0.00)	0.003 (1.03)	0.016 (1.66)	0.038*** (4.14)	0.050*** (5.79)	0.068*** (6.60)	0.107*** (5.68)	0.141*** (5.80)	0.248*** (7.64)
constant	-0.063*** (-3.69)	0.004 (1.42)	0.008*** (2.81)	0.071*** (8.37)	0.128*** (13.5)	0.187*** (18.38)	0.255*** (23.31)	0.337*** (24.65)	0.497*** (18.78)
pseudo R ²	0.000	0.012	0.005	0.022	0.052	0.088	0.126	0.175	0.240
R&D growth elasticity	0.015	-0.091		0.778	0.294	0.213	0.186	0.140	0.117
specification with R&D employment ratio measured lagged minus one (t-3); # of obs.: 2356									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.002 (-0.48)	-0.005*** (-3.78)	-0.002*** (-1.84)	-0.007*** (-4.24)	-0.013*** (-7.85)	-0.017*** (-10.41)	-0.024*** (-12.07)	-0.029*** (-12.42)	-0.041*** (-10.37)
log ratio of R&D employment to total employment (t-3)	-0.002 (-0.54)	0.003 (1.27)	0.003*** (2.12)	0.007*** (4.89)	0.010*** (5.39)	0.014*** (6.42)	0.017*** (8.06)	0.023*** (10.15)	0.035*** (7.62)
newly founded (t-2,t-5)	-0.005 (-0.24)	0.000 (0.05)	0.005 (0.68)	0.023*** (1.86)	0.034*** (3.66)	0.039*** (3.33)	0.054*** (3.21)	0.078*** (3.78)	0.094*** (3.03)
constant	-0.064*** (-3.13)	0.005 (1.63)	0.007*** (2.00)	0.064*** (6.45)	0.122*** (9.93)	0.172*** (16.65)	0.241*** (19.91)	0.316*** (24.48)	0.476*** (17.33)
pseudo R ²	0.001	0.009	0.006	0.016	0.041	0.071	0.106	0.143	0.179
specification with R&D employment ratio measured lagged minus two (t-4); # of obs.: 1604									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	0.001 (0.15)	-0.006*** (-4.28)	-0.002 (-1.50)	-0.006*** (-2.65)	-0.010*** (-4.89)	-0.015*** (-7.77)	-0.019*** (-7.07)	-0.025*** (-7.13)	-0.035*** (-6.15)
log ratio of R&D employment to total employment (t-4)	-0.008 (-1.68)	-0.001 (-0.25)	0.001 (0.82)	0.005*** (2.92)	0.007*** (3.04)	0.010*** (4.78)	0.016*** (5.41)	0.021*** (6.59)	0.029*** (5.44)
newly founded (t-2,t-5)	0.018 (0.57)	0.002 (0.38)	0.002 (0.28)	0.006 (0.43)	0.036*** (1.99)	0.041*** (3.33)	0.052*** (2.70)	0.063*** (2.65)	0.093*** (2.14)
constant	-0.094*** (-3.73)	0.004 (0.69)	0.004 (1.37)	0.054*** (4.21)	0.098*** (8.05)	0.147*** (12.88)	0.210*** (12.79)	0.293*** (15.67)	0.424*** (11.78)
pseudo R ²	0.002	0.007	0.005	0.008	0.024	0.048	0.076	0.109	0.146

Note: ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively. t-values in parentheses. Pooled estimates for the sub-periods 2004–2006, 2002–2004, 2000–2002, 1998–2000, and 1996–1998, with respect to the dependent variable. The explanatory variables are measured in the initial year and for R&D intensity, also for lagged minus one and lagged minus two years.

Table 11: Quantile regression estimates of the determinants of employment and sales growth from 2004–2006

impact of R&D to sales ratio on average employment growth from 2004–2006; #of obs.: 831									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.002	-0.003 [*]	0.000	-0.006	-0.012 ^{***}	-0.017 ^{***}	-0.024 ^{***}	-0.029 ^{***}	-0.045 ^{***}
	(-0.28)	(-1.71)	(0.00)	(-1.65)	(-4.30)	(-6.46)	(-6.67)	(-5.88)	(-5.20)
log ratio of R&D to sales (t-2)	-0.007	-0.001	0.000	0.003	0.004	0.006 ^{***}	0.011 ^{***}	0.013 ^{***}	0.024 ^{***}
	(-1.13)	(-0.73)	(0.00)	(0.97)	(1.42)	(3.00)	(3.63)	(3.46)	(2.50)
newly founded (t-2,t-5)	0.048 ^{***}	0.008	0.006	0.064 ^{***}	0.068 ^{***}	0.095 ^{***}	0.118 ^{***}	0.233 ^{***}	0.307 ^{***}
	(2.09)	(0.70)	(0.31)	(2.36)	(3.22)	(3.91)	(2.72)	(2.55)	(2.74)
constant	-0.083 ^{***}	-0.007	0.000	0.056 ^{***}	0.105 ^{***}	0.159 ^{***}	0.236 ^{***}	0.305 ^{***}	0.499 ^{***}
	(-2.36)	(-0.51)	(0.00)	(2.10)	(5.39)	(9.35)	(10.21)	(11.87)	(7.42)
pseudo R ²	0.011	0.006	0.000	0.012	0.041	0.073	0.102	0.146	0.222
impact of the share of R&D employment on average employment growth from 2004–2006; # of obs.: 809									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.001	-0.003	0.000	-0.007 [*]	-0.012 ^{***}	-0.015 ^{***}	-0.020 ^{***}	-0.025 ^{***}	-0.039 ^{***}
	(-0.08)	(-1.21)	(-0.37)	(-1.74)	(-4.23)	(-5.43)	(-5.53)	(-4.74)	(-4.72)
log ratio of R&D employment to total employment (t-2)	-0.002	-0.001	0.000	0.004	0.006 ^{**}	0.010 ^{***}	0.015 ^{***}	0.016 ^{***}	0.028 ^{***}
	(-0.14)	(-0.38)	(0.00)	(1.30)	(2.22)	(4.07)	(4.36)	(3.34)	(3.28)
newly founded (t-2,t-5)	0.048 ^{**}	0.007	0.008	0.068 ^{**}	0.066 ^{***}	0.090 ^{***}	0.138 ^{***}	0.317 ^{***}	0.335 ^{***}
	(2.14)	(0.75)	(0.36)	(2.55)	(3.02)	(3.31)	(2.89)	(3.48)	(3.28)
Constant	-0.065 ^{***}	-0.004	0.001	0.060 ^{**}	0.113 ^{***}	0.154 ^{***}	0.220 ^{***}	0.282 ^{***}	0.460 ^{***}
	(-2.79)	(-0.36)	(0.23)	(2.56)	(5.90)	(9.00)	(11.16)	(12.44)	(7.85)
Pseudo R ²	0.010	0.007	0.000	0.019	0.051	0.083	0.112	0.160	0.243
impact of R&D intensity on average growth rate of sales from 2004–2006; #of obs.: 830									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	0.011	0.008 ^{**}	0.002	-0.002	-0.007	-0.012 ^{***}	-0.020 ^{***}	-0.035 ^{***}	-0.050 ^{***}
	(1.05)	(2.07)	(0.58)	(-0.42)	(-1.45)	(-2.97)	(-3.41)	(-4.38)	(-6.20)
log ratio of R&D to sales (t-2)	-0.010	-0.001	0.003	0.008 [*]	0.014 ^{***}	0.023 ^{***}	0.028 ^{***}	0.038 ^{***}	0.039 ^{***}
	(-1.24)	(-0.24)	(0.79)	(1.89)	(2.95)	(4.69)	(5.86)	(5.35)	(2.79)
newly founded (t-2,t-5)	0.014	0.039	0.047 ^{**}	0.067 ^{**}	0.087 ^{**}	0.121 ^{***}	0.213 ^{***}	0.464 [*]	1.406 ^{***}
	(0.33)	(1.63)	(2.24)	(2.41)	(2.58)	(2.81)	(2.90)	(1.84)	(4.16)
constant	-0.141 ^{***}	-0.043 [*]	0.036 [*]	0.101 ^{***}	0.178 ^{***}	0.276 ^{***}	0.368 ^{***}	0.531 ^{***}	0.713 ^{***}
	(-3.81)	(-1.74)	(1.91)	(4.14)	(6.05)	(10.14)	(12.17)	(8.49)	(10.68)
Pseudo R ²	0.009	0.004	0.005	0.011	0.022	0.043	0.065	0.101	0.209

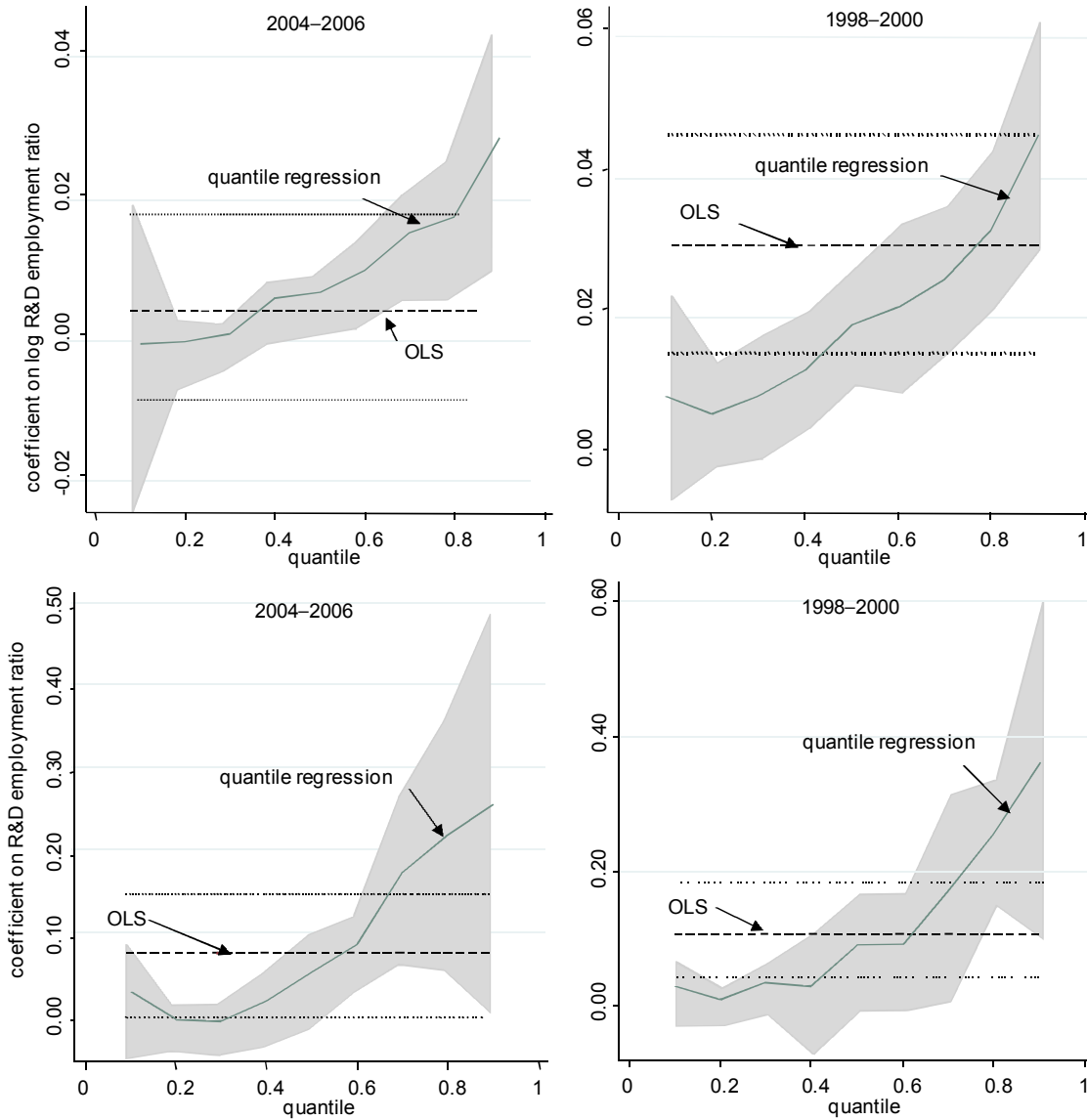
Note: ^{***}, ^{**} and ^{*} denote significance at the 1, 5 and 10 percent levels, respectively. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications.

Table 12: Quantile regression estimates of the determinants of employment and sales growth from 1998–2000

impact of the ratio of R&D to sales on employment growth from 1998–2000; #of obs.: 700									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.008 [*]	-0.005 ^{**}	-0.003	-0.008 ^{**}	-0.014 ^{***}	-0.020 ^{***}	-0.031 ^{***}	-0.044 ^{***}	-0.078 ^{***}
	(-1.84)	(-2.50)	(-1.14)	(-2.03)	(-4.06)	(-4.30)	(-6.31)	(-7.21)	(-8.17)
log ratio of R&D to sales (t-2)	0.008	0.003	0.004	0.015 ^{***}	0.015 ^{***}	0.021 ^{***}	0.026 ^{***}	0.024 ^{***}	0.033 ^{***}
	(1.42)	(1.26)	(1.05)	(3.11)	(4.01)	(5.52)	(6.89)	(3.79)	(4.92)
newly founded (t-2,t-5)	-0.010	0.004	0.012	0.035	0.064 ^{**}	0.081 ^{**}	0.094	0.207 ^{***}	0.169 ^{**}
	(-0.35)	(0.51)	(0.54)	(1.59)	(2.30)	(2.56)	(1.58)	(3.87)	(2.17)
Constant	0.007	0.008 ^{**}	0.023	0.111 ^{***}	0.164 ^{***}	0.241 ^{***}	0.340 ^{***}	0.431 ^{***}	0.738 ^{***}
	(0.34)	(2.09)	(1.12)	(3.87)	(7.11)	(7.81)	(10.55)	(10.17)	(10.72)
pseudo R ²	0.016	0.018	0.004	0.028	0.057	0.094	0.140	0.195	0.261
impact of the share of R&D employment on average employment growth from 1998–2000; # of obs.: 608									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	-0.009 [*]	-0.004	-0.003	-0.011 ^{**}	-0.014 ^{***}	-0.021 ^{***}	-0.031 ^{***}	-0.040 ^{***}	-0.053 ^{***}
	(-1.75)	(-1.43)	(-0.85)	(-2.46)	(-3.23)	(-4.24)	(-5.47)	(-6.23)	(-5.10)
log ratio of R&D employment to total employment (t-2)	0.008	0.005	0.008 [*]	0.011 ^{***}	0.018 ^{***}	0.020 ^{***}	0.024 ^{***}	0.032 ^{***}	0.046 ^{***}
	(1.10)	(1.44)	(1.76)	(2.63)	(4.00)	(3.63)	(5.60)	(5.55)	(6.14)
newly founded (t-2,t-5)	0.000	0.007	0.025	0.053 [*]	0.082 ^{**}	0.108 ^{***}	0.147 ^{***}	0.217 ^{***}	0.240 ^{**}
	(0.01)	(0.58)	(1.06)	(1.83)	(2.16)	(2.71)	(2.66)	(4.21)	(2.48)
constant	0.000	0.007	0.031	0.098 ^{***}	0.153 ^{***}	0.224 ^{***}	0.314 ^{***}	0.414 ^{***}	0.586 ^{***}
	(0.00)	(1.22)	(1.28)	(3.83)	(5.95)	(7.29)	(8.55)	(9.36)	(8.79)
pseudo R ²	0.015	0.018	0.010	0.037	0.069	0.111	0.167	0.229	0.282
impact of R&D intensity on average growth rate of sales from 1998–2000; #of obs.:703									
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employment (t-2)	0.021 ^{***}	0.014 ^{***}	0.010 ^{**}	0.003	-0.005	-0.012 ^{***}	-0.013 ^{**}	-0.023 ^{***}	-0.049 ^{***}
	(2.91)	(3.88)	(2.34)	(0.75)	(-1.26)	(-2.77)	(-2.32)	(-3.51)	(-4.27)
log ratio of R&D to sales (t-2)	0.003	0.009 ^{**}	0.014 ^{***}	0.020 ^{***}	0.030 ^{***}	0.038 ^{***}	0.045 ^{***}	0.055 ^{***}	0.071 ^{***}
	(0.27)	(2.16)	(2.70)	(3.81)	(5.05)	(6.56)	(5.94)	(6.50)	(3.73)
newly founded (t-2,t-5)	-0.029	0.029	0.077 ^{***}	0.100 ^{***}	0.121 ^{***}	0.181 ^{***}	0.256 ^{***}	0.388 ^{***}	0.611 ^{***}
	(-0.66)	(0.63)	(2.74)	(3.23)	(3.42)	(3.20)	(3.49)	(4.44)	(2.66)
constant	-0.147 ^{***}	-0.042 [*]	0.019	0.111 ^{***}	0.223 ^{***}	0.317 ^{***}	0.383 ^{***}	0.526 ^{***}	0.813 ^{***}
	(-3.03)	(-1.97)	(0.67)	(3.34)	(6.16)	(11.61)	(10.22)	(10.33)	(8.49)
pseudo R ²	0.025	0.012	0.013	0.023	0.044	0.076	0.112	0.165	0.230

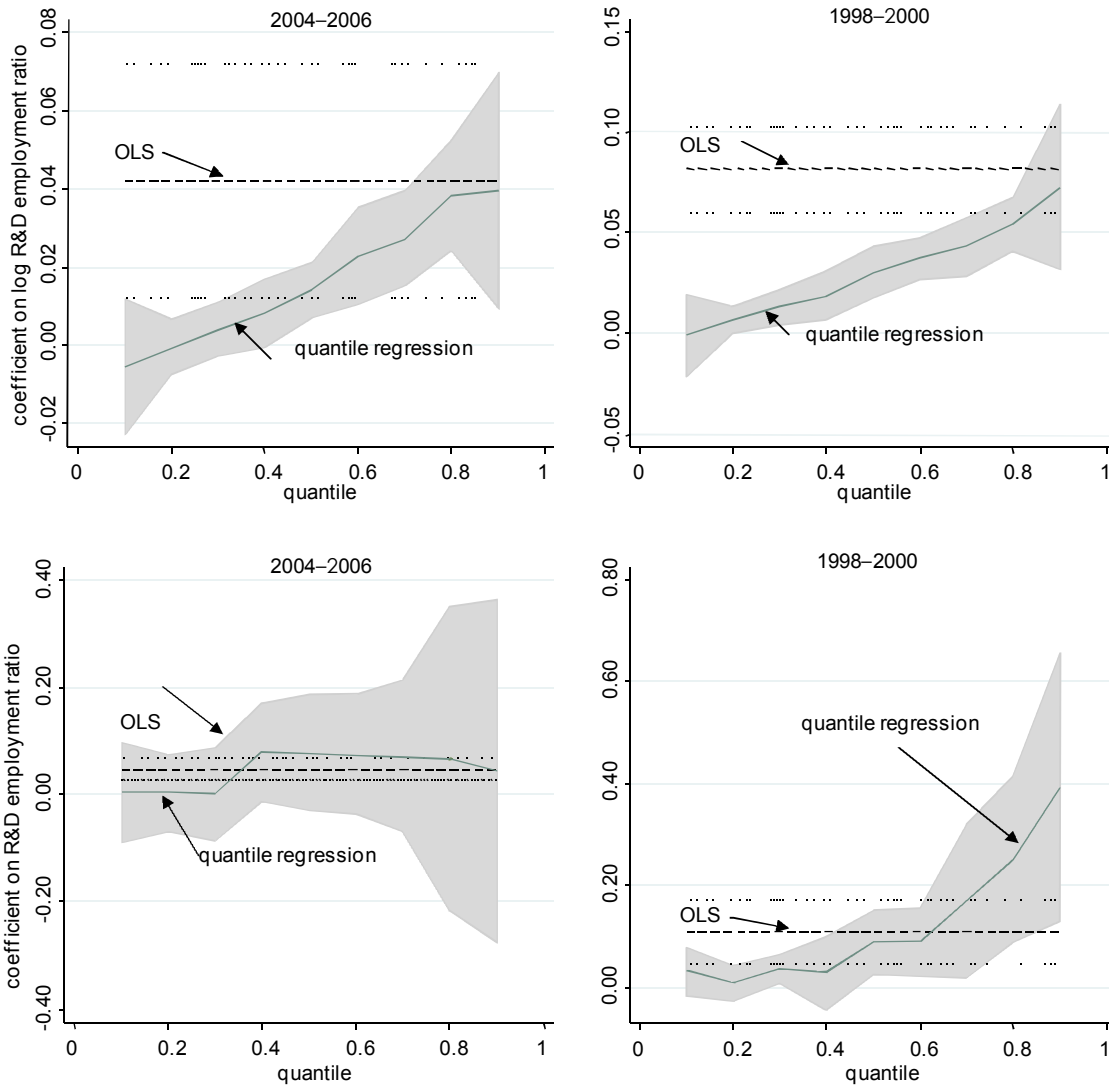
Note: ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively. t-values in parentheses are based on standard errors that are bootstrapped with 1000 replications.

Graph 2: Impact of R&D intensity on employment growth: Quantile regression and OLS estimates



Note: The R&D employment ratio refers to the year 2004 (graphs on the left hand side) and 1998 (graphs on the right hand side).

Graph 3: Impact of R&D intensity on growth of sales



Note: The R&D employment ratio refers to the year 2004 (graphs on the left hand side) and 1998 (graphs on the right hand side).