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

Martin Falk

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Abstract This paper investigates the relationship between initial research and development (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 least absolute deviation (LAD) estimator show that initial R&D intensity has a positive and significant impact on both employment and sales growth in the subsequent 2 years. Quantile regressions for each cross-section reveal that the impact of R&D intensity is 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 growth. Finally, we find that the impact of R&D decreases significantly over time.

Keywords R&D activities · Firm growth · Quantile regressions

JEL Classifications L25 · O33 · C21 · L26

M. Falk (✉)
Austrian Institute of Economic Research (WIFO), Vienna, Austria
e-mail: martin.falk@wifo.ac.at

1 Introduction

The impact of R&D and/or innovation activities on firm performance has been of considerable interest to scholars for a long time. Knowledge of the strength of the relation between R&D and firm performance is important because a positive and significant association helps us to justify R&D subsidy policies for the enterprise sector. One strand of the literature focuses on the employment effects of R&D and the other on impact of R&D on productivity (for surveys of the empirical literature see Pianta 2005 and Hall et al. 2009, respectively).[1] An additional strand of the literature focuses on the impact of R&D and/or innovation activities on firm growth.

In recent years, quantile regressions have increasingly been used in empirical studies on firm growth and the effects of innovation and/or R&D activities (see Coad and Rao 2006, 2008; Goedhuys and Sleuwaegen 2009; Hölzl 2009; Kaiser 2009; Zimmermann 2009). These studies show that the impact of innovation activities (measured 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. Furthermore, the majority of these studies show that the impact of innovation activities is only significant for a small

[1] For a survey on the various channels through which innovation affects employment see Spiezia and Vivarelli (2000) and Petit (1995).

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proportion of firms at the top part of the distribution, while the average effect is quite small and often insignificant. 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.

This paper concentrates on the relationship between initial R&D intensity and firm performance in subsequent years. The study uses simultaneous quantile regression to explore the parameter heterogeneity in the relationship between R&D and firm growth across the conditional growth distribution. The model is estimated using 3,700 Austrian firm observations for the period 1996–2006.

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). Some studies find that R&D activities do not lead to higher firm growth. For instance, Brouwer et al. (1993) find that 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. Others scholars use a broader measure of innovation activity such as innovation expenditures or innovation output measures. Based on Italian firm-level data, Piva and Vivarelli (2004, 2005) find that innovative investment has a small but significant effect on employment growth. In addition, a large number of studies investigate the impact of product and process innovations on employment growth (see, amongst others, Harrison et al. 2008; Hall et al. 2008; Van Reenen 1997). These studies find a positive relationship between product innovation and employment at the firm level. However, the effect of process innovations on employment is not clear cut (see Pianta 2005 for a literature survey).

With respect to the effects of R&D on productivity and/or output, the literature agrees that the effect of R&D on productivity is positive (Hall et al. 2009; Parisi et al. 2006). Klette and Kortum (2004) suggest that there are constant returns to R&D across firms, while there are diminishing returns to R&D in the longitudinal dimension. Diminishing returns to R&D may appear as more and more researchers are engaged in duplication activities (Aghion and Howitt 1998). In contrast, Henderson and Cockburn (1996) suggest that, for R&D-intensive firms, past success can increase the firm's R&D capability so that additional R&D investments are more productive. Empirical studies of whether there are increasing or decreasing returns to R&D have produced mixed results (Madsen 2007; Kortum 1993).

In addition, there is considerable heterogeneity in the effects of R&D across different types of firms. In particular, the effects of R&D are higher in science-based (R&D-intensive or/and high-tech) firms (Hall et al. 2009; Ortega-Argilés et al. 2010). However, Wakelin (2001) shows that the productivity effect of R&D is higher among firms belonging to the "net users of innovations." Similarly, using Italian data, Del Monte and Papagni (2003) find that the effect of R&D on firm growth is greater in firms in the traditional sectors than for those in sectors with high R&D intensity. Other studies investigate whether the effects of R&D are nonlinear, in particular whether there are diminishing or increasing returns to R&D. Finally, a number of studies have addressed the heterogeneity in the impact of R&D by using quantile regressions (see Coad and Rao 2008; Hölzl 2009; Stam and Wennberg 2009).

This paper also focuses on the link between initial R&D intensity and firm growth in the future. To the best of my knowledge no empirical study at the firm level in this area is available for Austria. Previous studies on determinants of firm growth typically do not employ a measure of R&D activities. This paper contributes to the literature in a number of aspects. Firstly, the database of the paper is more comprehensive than those used in most of the previous studies for other countries, in that it takes into account very small firms and service firms. Note that one-quarter of the firms have ten or fewer employees. Secondly, it provides elasticities of employment (sales) growth with respect to R&D intensity across the conditional quantile distribution. Thirdly, the stability of the parameter over time will be investigated. A detailed look into the literature shows that 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 relevant 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]

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

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, we model firm growth as a function of size and age and a measure of R&D activity (Evans 1987a, b; Hall 1987):

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

where i and t are indices of the firm and the year, with $\tau = 2$, 3, and 4, α_0 is the constant and u is the error term. The dependent variable is either the average employment growth rate or the average growth rate of sales in nominal prices calculated for several 2-year periods over the period 1996–2006.[3] In particular, the growth rate is calculated as the geometric growth rate over a 2-year period: $gr_{it} = (L_{it}/L_{it-2})^{1/(t-(t-2))} - 1$. L is employment, R&D/Y is the ratio of R&D expenditures to sales, and $d$young is a dummy variable for young firms that equals 1 if the firm was founded between $t-2$ and $t-5$, and 0 otherwise.[4]

Alternatively, one can employ the ratio of R&D employment to total employment. Since R&D intensity is highly skewed, one can employ log R&D intensity. It is often found that R&D and/or innovation activities will affect firm performance only with a certain time lag (Ravenscraft and Scherer 1982; Pakes 1985; Lachenmaier and Rottmann 2007). Piva and Vivarelli (2005), however, find that the impact of lagged value of innovation activities on employment is not significant. In this paper, we consider a 1-year ($t-3$) and 2-year time lag ($t-4$) for the impact of R&D intensity on firm growth besides initial R&D intensity ($t-2$).[5] 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. The inclusion of initial employment allows us to test Gibrat's law (for a recent empirical investigation see Lotti et al. 2009 and the survey by Coad 2009).

The firm growth equation can be estimated by ordinary least squares (OLS). Note that a selection bias may arise from using the sample of firms conducting R&D activities. However, very few firms are available with no R&D expenditures. Furthermore, nothing is known about firms with no R&D activities except for their geographical location. Therefore, empirical techniques to correct for sample selection bias are difficult to use. The main hypothesis is that R&D intensity has a positive and significant impact on firm growth. An important limitation of the model here is that investment is not included. It is well known that excluding relevant variables leads to omitted variables bias in the estimated coefficients. In particular, this may lead to overestimation of the positive impact of R&D intensity on firm growth. This limitation should be considered when interpreting the results of this study.

It is well known that OLS only allows estimation of mean effects. It is likely that the impact of R&D intensity on firm growth differs between low- and

[2] R&D intensity in the business sector [measured as the ratio of R&D expenditures in the business sector to gross domestic product (GDP)] doubled since the beginning of the 1990s (from 0.9% in 1993 to 1.7% in 2009).

[3] Ideally sales should be deflated by an industry price index. However, the use of growth rates of sales in nominal prices is probably unlikely to produce a bias, since producer price inflation is quite small during the period and does not vary much across industries during the period. Unreported results show that the R&D coefficients do not change when sales in current prices are replaced by sales deflated by an overall price index.

[4] It is well known that growth of R&D capital stock is a better measure than R&D intensity (Mairesse and Hall 1996). However, the available time series are too short for calculating

Footnote 4 continued
the R&D capital stock. Therefore, the firm growth equation contains R&D intensity as a proxy for the stock of R&D capital.

[5] We use a 2-year lag of R&D intensity since employment and sales growth rate are calculated over a 2-year period and to avoid a simultaneous bias. Foray et al. (2007) also use the R&D-to-sales ratio lagged by 2 years.

high-growth firms. Indeed, previous studies have shown considerable heterogeneity of the impact of R&D and/or innovation activities at different points of the conditional firm growth distribution. In particular, the average effect of R&D and/or innovation activity for the average firm turns out to be very small and not significant (Coad and Rao 2008; Hölzl 2009; Stam and Wennberg 2009).

The quantile regression method allows one to focus on specific parts of the distribution of conditional growth rates and is suitable for detecting differences in the effects of R&D intensity at various quantiles (Koenker and Bassett 1978; Koenker and Hallock 2001; Koenker 2005). For a given cross-section, the quantile regression model can be written as:

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

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. $Q_{\theta}(gr_{it}|Z_{it})$ is the θth 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 nonnormally distributed. The latter is important in our case, since the 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 nine different quantiles ranging from 0.1 to 0.9. We provide estimations for several subperiods as well as for the pooled sample.[6]

[6] Note that the panel quantile regression technique accounting for unobserved individual effects is only available when T is large. For a short time span, quantile regression techniques for panel data are not available.

In the empirical section of this paper, we investigate the following research questions: (1) What is the impact of 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? (2) Are there differences in the performance effect of R&D between fast- and slow-growing companies? (3) 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 (4) 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 labor 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. A special feature of the data is that very small firms are covered by the data. Approximately 25% of the firms have fewer than ten employees. Another special characteristic of the data is that service firms are included. Firms applying for an R&D project are requested to give information on: (1) total sales (in thousand €), (2) the share of exports in sales, (3) number of employees (full-time equivalents), (4) number of R&D employees (full-time equivalents), (5) expenses for research and development (in thousand €), and (6) cash flow (in thousand €). In addition, there is information on the legal form and geographic location of the firm.[7] These data have to be provided for the last 3 years prior to the application for a R&D project. Note that all firms are required to provide complete and correct information on R&D expenditures and R&D employment, even those that have previously successfully applied for and obtained R&D funding from the funding agency. About 30% of applications for

[7] 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	Dependent variables			Explanatory variables				
	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 3 years (percentages)	No. 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

funding are rejected on average. Therefore the sample includes firms that do not receive R&D subsidies. The database includes all firms. However, sole proprietors (with no employees) are excluded. The database is one of the most detailed in terms of coverage and data quality among most studies conducted so far. Its 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.[8]

The initial sample contains information for between 1,500 and 1,780 firms. For instance, for the year 2006, information on 1,748 firms is available (excluding public research organizations, universities, and technical colleges). Excluding firms with no information on firm age and sales leads to a slight reduction by 50 observations per year. Furthermore, missing observations for R&D expenditures reduce the sample by approximately 300 firms per year. When the 2006 wave and the two previous waves are combined, only 830 firms are left. Since the reduction in sample size is quite large, it is important to know whether firms that do not know their exact amount of R&D expenditures display some systematic pattern. To check whether a selection bias is introduced, we estimated a probit equation explaining the probability of firms refusing to answer questions on R&D expenditures. The right-hand variables are firm size, region dummy variables, and cash flow. The probit estimates show that there are few systematic factors which increase the probability of item nonresponse on R&D expenditures. In particular, the probability of item nonresponse is similar for small and large firms. We conclude that selection bias is not a serious problem. The resulting sample size ranges between 620 and 830 for each 2-year period. It can be considered as approximately representative of all firms doing R&D given the number of 2,190 firms doing R&D in Austria in the private sector (NACE 10–72 and 74) for the year 2006 according to Statistics Austria.

Table 1 reports the median of the key variables. The median employment growth rate for each 2-year interval varies between 2.3% and 4.6% per year, whereas the median of the average annual growth rate of sales in current prices varies between 6.5% and 10.6%. The median ratio of R&D expenditures to sales ranges between 4.0% and 5.2%. 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. The share of young firms in the last 3 years before the initial year is 18%.

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

[8] The funding agency plans to collect industry affiliation data from Statistics Austria, which will allow us to categorize the sample firms into different industries.

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
No. of obs.	3,695	3,673	3,695	3,695	3,695

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

Source: FFG, own calculations

Table 3 Median of the average employment growth rates in the next 2 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 subperiods 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

ranges between 4.1% for firms with an R&D intensity between 10% and 20% and −0.2 for firms with an R&D intensity of 1.5% or less.

4 Empirical results

4.1 Median regression results for each subperiod

Tables 4 and 5 present 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 Tables 4 and 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.[9] In each table, one can find separate estimation results for five different periods and different lags of the R&D intensity (i.e., initial R&D intensity and two different lags). Standard errors are based on the bootstrap method with 1,000 replications.

[9] 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

Subperiod for the dep. var.	Log employment $(t-2)$	Log R&D intensity $(t-2)$	Newly founded $(t-2, t-5)$	Constant	No. of obs.
R&D intensity measured in the initial year $(t-2)$					
2004–2006 $((t-2)-(t))$	−0.012***	0.003	0.069***	0.103***	822
	(−4.20)	(1.37)	(3.15)	(5.38)	
2002–2004 $((t-2)-(t))$	−0.011***	0.003	0.037**	0.083***	830
	(−3.42)	(1.32)	(2.28)	(4.79)	
2000–2002 $((t-2)-(t))$	−0.019***	0.012***	0.067***	0.160***	704
	(−5.15)	(2.83)	(3.31)	(6.46)	
1998–2000 $((t-2)-(t))$	−0.014***	0.015***	0.067**	0.164***	698
	(−4.26)	(3.97)	(2.45)	(7.16)	
1996–1998 $((t-2)-(t))$	−0.019***	0.014***	0.013	0.17***	619
	(−5.15)	(4.06)	(0.54)	(8.21)	
	Log employment $(t-2)$	Log R&D intensity $(t-3)$	Newly founded $(t-2, t-5)$	Constant	No. of obs
R&D intensity measured lagged minus one $(t-3)$					
2004–2006 $((t-2)-(t))$	−0.01***	0.006**	0.043	0.110***	580
	(−3.58)	(2.14)	(1.48)	(5.22)	
2002–2004 $((t-2)-(t))$	−0.010***	0.004	0.014	0.085***	561
	(−2.62)	(1.56)	(0.82)	(4.03)	
2000–2002 $((t-2)-(t))$	−0.016***	0.013***	0.084***	0.149***	483
	(−3.90)	(2.91)	(2.92)	(5.19)	
1998–2000 $((t-2)-(t))$	−0.017***	0.018***	0.030	0.197***	461
	(−3.86)	(4.23)	(0.91)	(6.57)	
1996–1998 $((t-2)-(t))$	−0.022***	0.018***	−0.012	0.213***	397
	(−5.03)	(3.89)	(−0.45)	(8.62)	
	Log employment $(t-2)$	Log R&D intensity $(t-4)$	Newly founded $(t-2, t-5)$	Constant	No. of obs.
R&D intensity measured lagged minus one $(t-4)$					
2004–2006 $((t-2)-(t))$	−0.013***	0.008***	0.021	0.129***	470
	(−3.67)	(2.33)	(0.63)	(5.59)	
2002–2004 $((t-2)-(t))$	−0.012***	0.004	0.033	0.093***	451
	(−2.80)	(1.61)	(1.41)	(3.83)	
2000–2002 $((t-2)-(t))$	−0.013***	0.007	0.082***	0.113***	396
	(−2.94)	(1.63)	(3.09)	(3.66)	
1998–2000 $((t-2)-(t))$	−0.013***	0.013***	0.028	0.157***	367
	(−2.79)	(2.23)	(0.62)	(4.70)	

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Dependent variable is the geometric annual change in employment over each 2-year period. *t* Values in *parentheses* are based on standard errors that are bootstrapped with 1,000 replications

The result obtained from the median regressions show 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 2 years in almost all cases. This means that sales and employment growth in the subsequent 2 years

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

Subperiod for the dep. var.	Log employment ($t-2$)	Log R&D employment ratio ($t-2$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured in the initial year ($t-2$)					
2004–2006 (($t-2$) − (t))	−0.012***	0.006***	0.063***	0.112***	780
	(−4.49)	(2.21)	(2.80)	(5.93)	
2002–2004 (($t-2$) − (t))	−0.009***	0.006***	0.032**	0.081***	778
	(−3.12)	(2.40)	(2.08)	(5.20)	
2000–2002 (($t-2$) − (t))	−0.019***	0.010***	0.087***	0.148***	653
	(−5.23)	(2.13)	(4.33)	(6.52)	
1998–2000 (($t-2$) − (t))	−0.014***	0.018***	0.082**	0.153***	602
	(−3.19)	(3.91)	(2.13)	(5.81)	
1996–1998 (($t-2$) − (t))	−0.018***	0.017***	0.016	0.165***	500
	(−4.63)	(4.02)	(0.65)	(7.44)	
	Log employment ($t-2$)	Log R&D employment ratio ($t-3$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured lagged minus one ($t-3$)					
2004–2006 (($t-2$) − (t))	−0.011***	0.006*	0.055*	0.109***	563
	(−3.62)	(1.85)	(1.74)	(5.06)	
2002–2004 (($t-2$) − (t))	−0.009**	0.006*	0.021	0.078***	544
	(−2.50)	(1.95)	(1.17)	(4.06)	
2000–2002 (($t-2$) − (t))	−0.013***	0.010**	0.080***	0.112***	441
	(−3.27)	(2.38)	(3.25)	(4.61)	
1998–2000 (($t-2$) − (t))	−0.014**	0.020***	0.071	0.163***	410
	(−2.59)	(3.72)	(1.43)	(5.02)	
1996–1998 (($t-2$) − (t))	−0.018***	0.020***	−0.004	0.173***	359
	(−4.30)	(3.35)	(−0.20)	(7.54)	
	Log employment ($t-2$)	Log R&D employment ratio ($t-4$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured lagged minus two ($t-4$)					
2004–2006 (($t-2$) − (t))	−0.010***	0.005	−0.006	0.102***	457
	(−3.16)	(1.41)	(−0.16)	(4.46)	
2002–2004 (($t-2$) − (t))	−0.008**	0.006**	0.014	0.073***	436
	(−2.07)	(2.12)	(0.54)	(3.66)	
2000–2002 (($t-2$) − (t))	−0.009*	0.006	0.084***	0.080***	363
	(−1.91)	(1.49)	(2.61)	(3.05)	
1998–2000 (($t-2$) − (t))	−0.012**	0.016**	0.084	0.139***	323
	(−2.04)	(2.06)	(1.41)	(4.10)	

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Dependent variable is the geometric annual change in employment over each 2-year period. t Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications

is higher, when the firm's expenditures in R&D increases, given total sales. The results for the growth equation, where the dependent variable is the average annual employment growth rate, show that the two measures of log R&D intensity are significant at the 5% level in 19 out of 28 cases

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

Subperiod for the dep. var.	Log employment ($t-2$)	Log R&D intensity ($t-2$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured in the initial year ($t-2$)					
2004–2006 (($t-2$) − (t))	−0.006	0.014***	0.084**	0.174***	822
	(−1.20)	(3.04)	(2.57)	(5.87)	
2002–2004 (($t-2$) − (t))	−0.004	0.011***	0.095***	0.127***	830
	(−1.36)	(3.53)	(3.73)	(6.53)	
2000–2002 (($t-2$) − (t))	−0.010*	0.025***	0.119***	0.183***	704
	(−1.93)	(4.56)	(4.24)	(6.04)	
1998–2000 (($t-2$) − (t))	−0.005	0.031***	0.116***	0.229***	698
	(−1.45)	(5.03)	(3.05)	(6.34)	
1996–1998 (($t-2$) − (t))	−0.010**	0.030***	0.102***	0.235***	619
	(−2.41)	(4.20)	(4.23)	(6.29)	
	Log employment ($t-2$)	Log R&D intensity ($t-3$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured in the initial year ($t-3$)					
2004–2006 (($t-2$) − (t))	−0.002	0.010*	0.034	0.143***	580
	(−0.37)	(1.85)	(1.05)	(4.65)	
2002–2004 (($t-2$) − (t))	−0.002	0.014***	0.038	0.120***	561
	(−0.54)	(3.06)	(1.55)	(4.96)	
2000–2002 (($t-2$) − (t))	−0.011	0.014***	0.099***	0.145***	483
	(−1.82)	(2.93)	(3.26)	(4.69)	
1998–2000 (($t-2$) − (t))	−0.002	0.018***	0.116***	0.161***	461
	(−0.36)	(2.44)	(2.02)	(3.86)	
1996–1998 (($t-2$) − (t))	−0.008	0.024***	0.060	0.205***	397
	(−1.32)	(3.35)	(1.31)	(5.43)	
	Log employment ($t-2$)	Log R&D intensity ($t-4$)	Newly founded ($t-2$, $t-5$)	Constant	No. of obs.
R&D intensity measured lagged minus two ($t-4$)					
2004–2006 (($t-2$) − (t))	−0.003	0.012**	0.046	0.160***	470
	(−0.52)	(2.08)	(1.01)	(4.39)	
2002–2004 (($t-2$) − (t))	0.002	0.009*	0.049	0.093***	451
	(0.33)	(1.85)	(1.44)	(3.31)	
2000–2002 (($t-2$) − (t))	−0.013**	0.015***	0.120***	0.164***	396
	(−2.30)	(2.65)	(4.40)	(5.33)	
1998–2000 (($t-2$) − (t))	−0.002	0.020**	0.085	0.167***	367
	(−0.33)	(2.54)	(0.87)	(3.61)	

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Dependent variable is the geometric annual change in sales over each 2-year period. t Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications

(Tables 4, 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% level in 12 out of 14 cases and significant at the 10% level in the remaining 2 cases, with coefficients ranging between 0.009 and 0.031 (Table 6). Accordingly, a rise in R&D intensity of 10% (e.g., from 5% to 5.5%)

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 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 with 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 (Table 5).

The decline in the impact of R&D is consistent with the stylized effects reported by Klette and Kortum (2004). Hall (1993) also finds strong evidence in favor of a declining rate of return to R&D from 1979–1983 and 1986–1991 based on US firm-level 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 3 years) from 23% in 2001 to 18% in 2006. To quantify this effect, we reestimated 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. Another explanation for the decline in the effect of R&D is diminishing returns to R&D. Kortum (1993) suggests that, as economywide R&D investment devoted to product innovation increases, more and more researchers could be engaged in duplicate research activities and thus there are decreasing returns to R&D. We thus conclude that the decline in effect of R&D mainly reflects diminishing returns to R&D.

In the next step the robustness of the results for the hypothesis of decreasing returns to R&D across firms rather than across time is tested. Decreasing returns to R&D across firms occurs when the productivity of R&D activity decreases as R&D increases beyond a certain critical point. This possible nonlinearity can be tested by including the squared R&D intensity. Unreported results based on a quadratic specification show that (non-log) R&D intensity is positive and its squared term is negative. This indicates a positive relationship between firm growth and R&D intensity to a certain level of R&D intensity, but a decreasingly less positive relationship beyond this level. However, the positive relationship is prevalent for almost the total sample, since the coefficient on the square term is very small in absolute terms. Moreover, the turning point of the quadratic specification in all three regressions falls far beyond the data range of R&D intensity (with R&D intensity of more than 100%). Overall, this indicates that there are diminishing returns to R&D over time but not across firms for a given point of 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 equations at various quantiles using pooled data covering five cross-sections for the period 1996–2006.[10] Again, the growth rates are measured as the annual geometric growth rate based on a 2-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 1,000 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.

[10] Estimation is performed using the SQREG command in STATA 10.0.

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

	q10	q20	q30	q40	q50	q60	q70	q80	q90
Specification with log R&D intensity measured in the *initial year* ($t-2$); no. of obs. 3,695									
Log employment ($t-2$)	−0.005	−0.006***	−0.003***	−0.008***	−0.015***	−0.021***	−0.029***	−0.037***	−0.056***
	(−1.56)	(−10.02)	(−4.16)	(−5.04)	(−9.80)	(−14.22)	(−16.48)	(−14.53)	(−14.77)
Log R&D intensity ($t-2$)	−0.005	0.000	0.001	0.005***	0.008***	0.010***	0.015***	0.019***	0.027***
	(−1.64)	(0.41)	(1.16)	(3.33)	(5.40)	(9.22)	(9.11)	(9.09)	(7.06)
Newly founded ($t-2$, $t-5$)	0.011	0.001	0.006	0.036***	0.047***	0.062***	0.092***	0.135***	0.239***
	(0.60)	(0.26)	(0.68)	(4.52)	(5.20)	(7.18)	(5.60)	(5.55)	(7.20)
Constant	−0.060***	0.005*	0.007***	0.065***	0.131***	0.191***	0.270***	0.365***	0.555***
	(−3.16)	(1.90)	(2.65)	(6.71)	(12.73)	(20.77)	(22.92)	(22.82)	(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 log R&D intensity measured *lagged minus one* ($t-3$); no. of obs. 2,501									
Log employment ($t-2$)	−0.005	−0.006***	−0.003***	−0.009***	−0.015***	−0.021***	−0.027***	−0.036***	−0.050***
	(−1.63)	(−7.98)	(−3.22)	(−6.08)	(−9.72)	(−12.11)	(−13.85)	(−12.84)	(−12.61)
Log R&D intensity ($t-3$)	−0.003	0.002	0.003**	0.007***	0.011***	0.013***	0.016***	0.020***	0.028***
	(−1.00)	(1.64)	(2.02)	(5.08)	(6.66)	(7.53)	(7.95)	(8.03)	(6.95)
Newly founded ($t-2$, $t-5$)	−0.005	0.000	0.006	0.023**	0.027**	0.044***	0.056***	0.082***	0.142***
	(−0.22)	(0.08)	(0.72)	(2.18)	(2.42)	(4.15)	(3.50)	(3.87)	(3.07)
Constant	−0.051***	0.010***	0.017	0.082***	0.144***	0.198***	0.269***	0.362***	0.529***
	(−2.60)	(3.44)	(2.21)	(8.54)	(12.54)	(17.45)	(19.81)	(20.51)	(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 log R&D intensity measured *lagged minus two* ($t-4$); no. of obs. 1,700									
Log employment ($t-2$)	0.000	−0.006***	−0.002**	−0.007***	−0.012***	−0.016***	−0.020***	−0.028***	−0.045***
	(0.00)	(−4.61)	(−2.51)	(−3.66)	(−5.88)	(−8.98)	(−7.17)	(−9.84)	(−9.23)
Log R&D intensity ($t-4$)	−0.006*	0.000	0.001	0.005***	0.008***	0.011***	0.015***	0.018***	0.016**
	(−1.70)	(0.08)	(0.95)	(3.15)	(4.34)	(6.81)	(8.01)	(5.75)	(2.48)
Newly founded ($t-2$, $t-5$)	0.014	0.005	0.003	0.016	0.033**	0.044***	0.041**	0.058***	0.041
	(0.39)	(0.78)	(0.39)	(1.03)	(2.13)	(3.79)	(2.29)	(2.78)	(1.03)
Constant	−0.092***	0.004	0.007	0.063***	0.120***	0.169***	0.226***	0.312***	0.461
	(−3.25)	(0.62)	(1.77)	(5.00)	(7.73)	(14.24)	(12.93)	(19.85)	(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% levels, respectively. t Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications. Pooled estimates for the subperiods 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*)

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 (Coad and Rao 2008; Hölzl 2009; Stam and Wennberg 2009). In particular, R&D intensity is positive and statistically significant at the 5% level only at the middle and upper quantiles, i.e., between $q = 0.4$ and the highest quantile (0.9) (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 significant positive effect on the ratio of profits to sales for the 50%, 25%, and 10% most profitable firms but a negative impact on the 10% least profitable firms.

Turning to the magnitude of the effects, we observe that the coefficient continuously increases from the

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

	q10	q20	q30	q40	q50	q60	q70	q80	q90
Specification with log R&D intensity in the *initial year* ($t-2$); no. of obs. 3,710									
Log employment ($t-2$)	0.018***	0.010***	0.005***	0.000	−0.007***	−0.012***	−0.017***	−0.026***	−0.042***
	(5.90)	(4.76)	(2.84)	(−0.12)	(−4.01)	(−5.22)	(−6.98)	(−8.06)	(−8.66)
Log R&D intensity ($t-2$)	0.000	0.004*	0.010***	0.013***	0.019***	0.027***	0.035***	0.046***	0.065***
	(0.06)	(1.98)	(5.08)	(6.34)	(9.55)	(9.08)	(11.63)	(13.02)	(11.27)
Newly founded firms ($t-2$, $t-5$)	0.005	0.037***	0.057***	0.082***	0.099***	0.138***	0.226***	0.331***	0.736***
	(0.29)	(3.10)	(5.78)	(6.90)	(8.40)	(6.86)	(7.32)	(8.63)	(7.32)
Constant	−0.171***	−0.050***	0.024***	0.091***	0.175***	0.265***	0.354***	0.495***	0.742***
	(−9.33)	(−4.16)	(2.40)	(7.92)	(15.16)	(18.14)	(24.66)	(21.52)	(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 log R&D intensity *lagged minus one* ($t-3$); no. of obs. 2,510									
Log employment ($t-2$)	0.014***	0.009***	0.005***	0.000	−0.004	−0.010***	−0.014***	−0.021***	−0.032***
	(2.99)	(3.53)	(2.29)	(0.21)	(−1.54)	(−3.88)	(−5.43)	(−5.07)	(−7.09)
Log R&D intensity ($t-3$)	−0.009***	−0.003***	0.006***	0.011***	0.015***	0.021***	0.030***	0.042***	0.059***
	(−2.12)	(−0.91)	(2.32)	(4.50)	(6.38)	(6.47)	(9.46)	(8.75)	(13.12)
Newly founded ($t-2$, $t-5$)	0.007	0.013	0.036***	0.042***	0.060***	0.074***	0.107***	0.180***	0.201***
	(0.31)	(0.65)	(2.59)	(3.08)	(4.36)	(4.10)	(4.54)	(5.18)	(3.22)
Constant	−0.184***	−0.072***	0.011	0.080***	0.144***	0.228***	0.323***	0.456***	0.654***
	(−8.28)	(−5.55)	(0.73)	(6.63)	(10.5)	(13.46)	(20.62)	(14.67)	(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 log R&D intensity *lagged minus two* ($t-4$); no. of obs. 1,705									
Log employment ($t-2$)	0.012***	0.010***	0.008***	0.001	−0.003	−0.010***	−0.015***	−0.020***	−0.034***
	(1.83)	(3.49)	(3.03)	(0.49)	(−0.84)	(−2.87)	(−4.46)	(−4.21)	(−6.31)
Log R&D intensity ($t-4$)	−0.012***	−0.003	0.004***	0.009***	0.014***	0.017***	0.028***	0.030***	0.048***
	(−2.19)	(−1.02)	(1.71)	(2.97)	(5.51)	(4.66)	(6.21)	(5.40)	(8.08)
Newly founded ($t-2$, $t-5$)	−0.014	0.010	0.046***	0.045***	0.073***	0.065***	0.084***	0.162***	0.200***
	(−0.38)	(0.33)	(2.94)	(2.19)	(4.33)	(3.92)	(3.01)	(2.84)	(2.22)
Constant	−0.186***	−0.076***	−0.009	0.073***	0.138***	0.215***	0.321***	0.396***	0.627***
	(−7.21)	(−4.96)	(−0.64)	(4.27)	(7.56)	(9.04)	(15.43)	(10.85)	(15.53)
Pseudo R^2	0.016	0.007	0.006	0.007	0.016	0.027	0.046	0.070	0.122

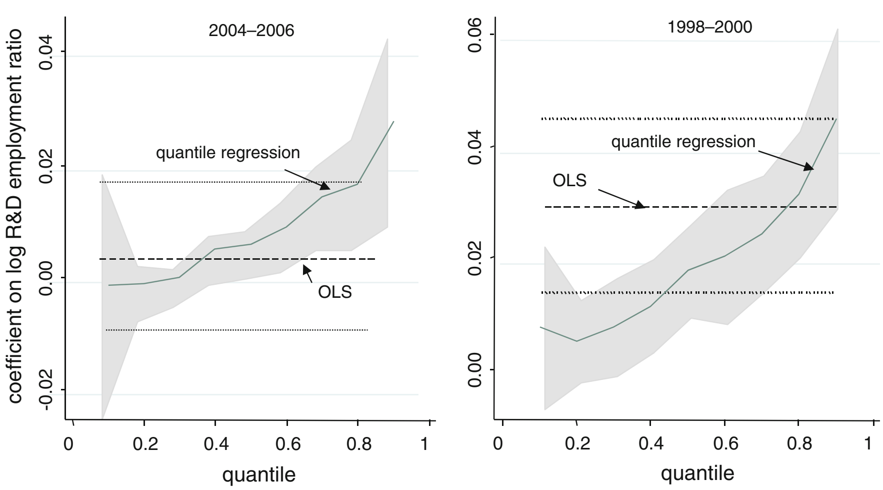
Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *t* Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications. For further notes see Table 7 lower to upper quantile of the employment growth distribution. For example, a 1% increase 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 (Table 7). 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 year at the 0.4 quantile. For further insights into the magnitude of the effect, one can calculate the elasticity of firm growth with respect to R&D intensity. This is done by dividing the coefficients by the value of the corresponding quantile of the employment growth distribution. Table 7 shows that the elasticity of employment growth with respect to R&D intensity is highest for $q = 0.4$, followed by the median.

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 (Table 8). For instance, at the 10% conditional quantile of the sales growth distribution, 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 with the value of the growth rate of the 0.8 and 0.9 quantiles of the distribution of the sales growth rate. The upper panel in Table 8 shows that the growth R&D elasticity is highest at the 0.4 and 0.5 quantiles, and then continuously decreases with rising quantiles.

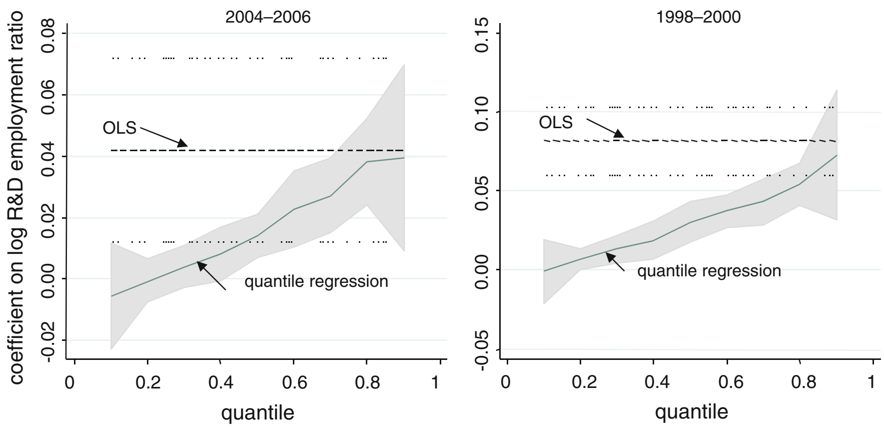
The dummy variable for young firms is significant in the employment growth equation from the 0.4 and upper quantiles, suggesting that young firms tend to have higher growth rates but only for firms with positive conditional growth rates. Furthermore, the coefficient of the dummy variable increases as 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.

Graphs 1 and 2 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 equations for two selected cross-section periods, namely 2004–2006 and 1998–2000, respectively. Here R&D intensity shows a significant effect only at the 0.50 quantile or at higher quantiles, suggesting that only firms at and above median growth rates benefit from R&D investment.



Graph 1 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 2 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*)

To sum up, we can conclude that the results of this study are considerably more optimistic than previous estimates of the impact of R&D on firm growth using quantile regression. However, it is difficult to generalize previous findings since studies differ widely in the dimensions, being based on different sample periods and countries, coverage of very small firms and service firms, as well as different model specifications. Coad and Rao (2008) also use the quantile regression technique to analyze the impact of a composite innovativeness index on the growth rate of sales, where the index is composed of R&D and patent intensity as well as the corresponding stock values. Using US firm-level data, the authors show 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 European Union (EU) countries for the period 1998–2000, Hölzl (2009) finds that R&D activities are more important for the growth of fast-growing, small and medium-sized enterprises (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 labor spent on R&D activities) on employment growth based on a Dutch startup survey. The authors find that initial R&D intensity has no impact on firm growth using OLS. However, initial R&D intensity is highly significant for the 10% fastest-growing firms.

5 Conclusions

The main objective of this paper is 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 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., the ratio of R&D employment to total employment and the 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 with the more recent time periods of 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 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. Overall, the results are considerably more optimistic than previous estimates of the impact of R&D on firm growth using quantile regression.

The findings have some important implications for innovation policy. Since the majority of firms with R&D activities benefit from R&D activities, so 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 range of the 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 part of the distribution 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 interventions at this particular group.

Explanations for 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 have 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 lack of 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.

Appendix

See Tables 9, 10, 11, and 12

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

	2004–2006	2002–2004	2000–2002	1998–2000	1996–1998
Impact of initial/lag R&D intensity on employment growth ($t-2$, t)					
Measure of R&D intensity: R&D expenditures in % of sales					
R&D sales ratio ($t-2$)	0.004	−0.003	0.015***	0.023***	0.019***
	(0.79)	(−0.46)	(2.80)	(3.22)	(2.88)
R&D sales ratio ($t-3$)	0.001	−0.001	0.023***	0.020***	0.026***
	(0.19)	(−0.23)	(3.52)	(3.01)	(2.86)
R&D sales ratio ($t-4$)	0.004	0.000	0.018**	0.018**	
	(0.65)	(0.05)	(2.50)	(2.13)	
Measure of R&D intensity: R&D employment in % of total employment					
R&D employment ratio ($t-2$)	0.004	0.004	0.019***	0.030***	0.022***
	(0.73)	(0.96)	(3.44)	(4.06)	(3.29)
R&D employment ratio ($t-3$)	0.005	0.010*	0.012**	0.027***	0.021***
	(0.99)	(1.92)	(2.11)	(3.73)	(2.74)
R&D employment ratio ($t-4$)	0.002	0.006	0.010*	0.022***	
	(0.41)	(1.15)	(1.73)	(2.71)	
Impact of initial/lag R&D intensity on sales growth ($t-2$, t)					
Measure of R&D intensity: R&D expenditures in % of sales					
R&D sales ratio ($t-2$)	0.042***	0.049***	0.096***	0.081***	0.075***
	(3.28)	(3.72)	(4.40)	(3.66)	(3.67)

Table 9 continued

	2004–2006	2002–2004	2000–2002	1998–2000	1996–1998
R&D sales ratio ($t-3$)	0.023**	0.041***	0.034***	0.047***	0.061***
	(2.40)	(3.02)	(3.68)	(3.18)	(2.84)
R&D sales ratio ($t-4$)	0.016**	0.018*	0.043***	0.050***	
	(1.73)	(1.78)	(4.36)	(2.89)	
Measure of R&D intensity: R&D employment in % of total employment					
R&D employ. ratio ($t-2$)	−0.013	0.032**	0.048***	0.057***	0.038***
	(−0.65)	(2.14)	(3.41)	(3.79)	(3.47)
R&D employ. ratio ($t-3$)	0.033*	0.027**	0.023**	0.053***	0.048***
	(1.79)	(2.30)	(2.37)	(3.82)	(3.74)
R&D employ. ratio ($t-4$)	0.002	0.023*	0.020*	0.054***	
	(0.22)	(1.82)	(1.98)	(4.26)	

Note: ***, **, and * denote significance at the 1%, 5%, and 10% 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)

	q10	q20	q30	q40	q50	q60	q70	q80	q90
Specification with log R&D employment ratio measured in the initial year ($t-2$); no. of obs. 3,396									
Log employment ($t-2$)	−0.002	−0.005***	−0.002***	−0.008***	−0.014***	−0.020***	−0.026***	−0.033***	−0.045***
	(−0.53)	(−4.61)	(−2.15)	(−5.65)	(−9.44)	(−12.11)	(−14.37)	(−15.11)	(−10.75)
Log ratio of R&D employment to total employment ($t-2$)	−0.001	0.002	0.003***	0.007***	0.010***	0.013***	0.019***	0.023***	0.036***
	(−0.36)	(1.36)	(2.12)	(4.29)	(6.33)	(9.63)	(9.56)	(10.86)	(7.63)
Newly founded ($t-2$, $t-5$)	0.000	0.003	0.016	0.038***	0.050***	0.068***	0.107***	0.141***	0.248***
	(0.00)	(1.03)	(1.66)	(4.14)	(5.79)	(6.60)	(5.68)	(5.80)	(7.64)
Constant	−0.063***	0.004	0.008***	0.071***	0.128***	0.187***	0.255***	0.337***	0.497***
	(−3.69)	(1.42)	(2.81)	(8.37)	(13.5)	(18.38)	(23.31)	(24.65)	(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 log R&D employment ratio measured lagged minus one ($t-3$); no. of obs. 2,356									
Log employment ($t-2$)	−0.002	−0.005***	−0.002***	−0.007***	−0.013***	−0.017***	−0.024***	−0.029***	−0.041***
	(−0.48)	(−3.78)	(−1.84)	(−4.24)	(−7.85)	(−10.41)	(−12.07)	(−12.42)	(−10.37)
Log ratio of R&D employment to total employment ($t-3$)	−0.002	0.003	0.003***	0.007***	0.010***	0.014***	0.017***	0.023***	0.035***
	(−0.54)	(1.27)	(2.12)	(4.89)	(5.39)	(6.42)	(8.06)	(10.15)	(7.62)
Newly founded ($t-2$, $t-5$)	−0.005	0.000	0.005	0.023***	0.034***	0.039***	0.054***	0.078***	0.094***
	(−0.24)	(0.05)	(0.68)	(1.86)	(3.66)	(3.33)	(3.21)	(3.78)	(3.03)
Constant	−0.064***	0.005	0.007***	0.064***	0.122***	0.172***	0.241***	0.316***	0.476***
	(−3.13)	(1.63)	(2.00)	(6.45)	(9.93)	(16.65)	(19.91)	(24.48)	(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 log R&D employment ratio measured lagged minus two ($t-4$); no. of obs. 1,604									
Log employment ($t-2$)	0.001	−0.006***	−0.002	−0.006***	−0.010***	−0.015***	−0.019***	−0.025***	−0.035***
	(0.15)	(−4.28)	(−1.50)	(−2.65)	(−4.89)	(−7.77)	(−7.07)	(−7.13)	(−6.15)
Log ratio of R&D employment to total employment ($t-4$)	−0.008	−0.001	0.001	0.005***	0.007***	0.010***	0.016***	0.021***	0.029***
	(−1.68)	(−0.25)	(0.82)	(2.92)	(3.04)	(4.78)	(5.41)	(6.59)	(5.44)

Table 10 continued

	q10	q20	q30	q40	q50	q60	q70	q80	q90
Newly founded ($t-2$, $t-5$)	0.018	0.002	0.002	0.006	0.036***	0.041***	0.052***	0.063***	0.093***
	(0.57)	(0.38)	(0.28)	(0.43)	(1.99)	(3.33)	(2.70)	(2.65)	(2.14)
Constant	−0.094***	0.004	0.004	0.054***	0.098***	0.147***	0.210***	0.293***	0.424***
	(−3.73)	(0.69)	(1.37)	(4.21)	(8.05)	(12.88)	(12.79)	(15.67)	(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% levels, respectively. *t* Values in *parentheses*. Pooled estimates for the subperiods 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 to 2006

	q10	q20	q30	q40	q50	q60	q70	q80	q90
Impact of R&D to sales ratio on average employment growth from 2004 to 2006; no. of obs. 831									
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 to 2006; no. of obs. 809									
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 to 2006; No. of obs. 830									
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% levels, respectively. *t* Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications

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

	q10	q20	q30	q40	q50	q60	q70	q80	q90
	Impact of the ratio of R&D to sales on employment growth from 1998 to 2000; No. of obs. 700								
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 to 2000; No. of obs. 608									
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 to 2000; No. of obs. 703									
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% levels, respectively. *t* Values in parentheses are based on standard errors that are bootstrapped with 1,000 replications

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