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 between 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 turnover 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. However, 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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1 Introduction

The impact of R&D activities on firm performance has been of considerable interest to scholars, for a long time. The literature largely agrees that firm performance of R&D doing firms is better than that of non-R&D doing firms, and that the initial R&D intensity is significantly positively related to firm performance in the future period. Studies include Foray, Hall and Mairesse (2007) for large publicly listed U.S firms; Hall (1987) for U.S. industrial firms; Del Monte and Papagni (2003) for Italy; Nurmi (2004) for Finland; Yang and Huang (2005) for Taiwan and Yasuda (2005) for Japan.

Austria is an interesting country case, since it is one of the few industrialized countries that experienced a rapid increase in R&D expenditures in the last 15 years. 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). Given the increase in R&D expenditures in the last 15 years, it is natural to ask whether the magnitude of the impact of R&D activities on firm growth has changed over time. Given this background, it is surprising that there has been little reliable economic research at the firm level for Austria, given the large academic and public interest on this topic.

The aim of this paper is to re-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. Quantile regressions are often used in empirical studies on firm growth, and on the effects of innovation activities (see amongst others Kaiser, 2009; Coad and Rao, 2008 and Hölzl, 2009). 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 is rising or falling over time. The dependent variable is either the average employment growth rate or the average growth rate of turnover calculated for several two-year periods, over the period 1996-2006. Another aim of the 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). In addition, we use two different measures of R&D intensity (i.e. the ratio of R&D expenditures to turnover and the ratio of R&D employment to total employment). To answer these research questions this study draws on a unique database of R&D doing firms provided by the Austrian Research Promotion Agency (FFG). With an estimation sample between 600 and 800 observations for each cross-section (excluding

universities and public research institutions), it is a representative source of data for firms with R&D activities in Austria. The relationship between R&D activities and company growth is estimated using the OLS, median and quantile regression method. This study will lead to a better understanding of the importance of R&D to firm growth in one of the EU countries with a high level of R&D spending in the business sector relative to GDP.

In literature, there are a number of empirical studies on the impact of R&D activities on firm growth. Using data for U.S. manufacturing firms, Hall (1987) finds that the employment growth rate is significantly higher for R&D doing firms than that of non R&D doing firms. In addition, the author finds that R&D spending in the initial year has a significant impact on employment growth in subsequent years. Using data for 500 industrial firms in Italy, Del Monte and Papagni (2003) find that R&D activities are an important factor for firm growth, both in the high-tech sector as well as in the non-high tech sector. Yasuda (2005) finds that R&D intensity (measured as the R&D to turnover ratio as well as the ratio of R&D expenditure to total employment) has a significant and positive impact on firm growth using data for 14 000 Japanese companies in manufacturing, wholesale, and retail trade. The author suggests that an increase in R&D intensity by 10 per cent leads to an increase in firm growth between 1 and 3.5 percentage points per year. Using panel data for 3 459 industrial firms for Taiwan for the period 1992-1998, Yang and Huang (2005) show that R&D intensity is an important driver for the company's growth. For Finnish companies during the period 1981-1994, Nurmi (2004) shows that R&D intensity has a significant impact on firm growth. Unlike the other studies mentioned above, however, no company-specific information on R&D expenditure is used because of data availability. Based on 88 technology based German firms for the period 1997-2002, Wöhrl et al. (2009) find a positive and significant relationship between R&D intensity and sales growth, while the impact of R&D intensity follows a u-shaped pattern. Some studies find that R&D activities do lead to higher firm growth. 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. Other studies only employ a dummy variable whether or not firms untertake R&D (see e.g. Liu et al., 1999).

In recent years, quantile estimators are increasingly used to study the impact of R&D activities on firm growth. 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 Coad and Rao (2008) for US manufacturing firms. The authors also use the quantile 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 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. Stam and Wennberg (2009) investigate 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 less 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 address 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). Instead, most studies in this area still employ standard OLS or GMM techniques that give the results of the conditional mean function of the firm growth rates. 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 R&D expenditures increased considerably during the last 15 years. 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). Further, related literature investigates the impact of R&D capital on productivity at the firm level (see e.g. Hall and Mairesse, 1995). 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). Due to data availability, 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 help us in justifying R&D subsidies

to R&D doing firms. 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 as well as service firms. In addition, the sample size is quite large compared to the total number of R&D doing firms.

The main finding of the study is that there is a sizable variation in the semi-elasticities of firm growth with respect to R&D intensity across the conditional distribution of growth rates. In particular, we find a general rise in the semi-elasticity as one move from the 0.3 quantile to the highest quantile. In contrast, R&D intensity is not significant at the lower quantiles. More importantly, the elasticity of firm growth with respect to R&D intensity is largest for firms at or slightly below the median of conditional distribution of growth rates. Finally, an interesting result is that the impact of R&D intensity on firm growth shows considerable variation over time with a decreasing trend.

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 is presented; and in section 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. However, some R&D doing firms do not benefit from innovations which implies that the impact of R&D (e.g. returns to R&D) are heterogeneous across firms (see Teece, 1986). In order to investigate the average effect of R&D one model 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 τ 2, 3 and 4. 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 is employment and R&D/Y is the ratio of R&D expenditures to turnover. 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* , that equals 1 if the firm has been founded between t-2 and t-5. 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). The growth equation can be estimated by OLS. Note that a selection bias may arise from using the sample of R&D doing firms. However, since nothing is known about non-R&D doing firms 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 to estimate the mean effects. There might be a large heterogeneity in the effects of R&D as mentioned by Teece (1986). For instance, one might expect 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. For a given cross-section, the quantile regression model can be written as:

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

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. $Q\left(gr_{it} | Z_{it}\right)$ 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 Shapiro-Wilk test rejects the null hypothesis that the growth rates of turnover and employment are normally distributed. In this study we consider regression estimates at 9

different quantiles ranging from the 0.1 to 0.9 quantile. We provide estimations for several sub-periods as well as for the pooled sample.

In the empirical section of the paper we investigate the following research questions: (i) What is the impact of the initial R&D intensity on the change in turnover 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? (iv) What is the impact of firm age and size on firm growth of R&D-doing firms?

3 Data and descriptive results

The data used in this study is 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 turnover (in thousand €), (ii) the share of exports in turnover, (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 thousands €). In addition, there is information on the legal form and information on the geographic location of the firm.[1] These data have to be provided for the last three years of the year of 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 2 190 R&D doing firms 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.

[1] Regional dummy variables are never significant and are therefore not included in the final specification.

Table 1 and Table 2 report the median of the key variables. The median employment growth rate for each two-year interval varies between 1.1 and 4.6 per cent per year, whereas the median of the average annual growth rate of turnover in current prices varies between 5.3 and 10.6 per cent. The median ratio of R&D expenditures is about 5 per cent. Table 2 shows that 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.

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

	average growth rates of employment (median)	average growth rates of turnover (median)	# of obs.
1995-1997	1.1	6.5	546
1996-1998	3.4	8.4	619
1997-1999	3.5	8.2	633
1998-2000	4.6	9.5	698
1999-2001	4.2	8.8	727
2000-2002	3.2	6.5	704
2001-2003	2.5	5.3	737
2002-2004	2.3	8.0	830
2003-2005	3.5	8.3	853
2004-2006	4.0	10.6	822

Source: FFG, own calculations.

Table 2: Descriptive statistics for the two measures of R&D intensity and initial employment and the percentage of newly founded firms

	initial employment (median)	percentage of young firms founded in the last three years	ratio of R&D employment to total employment (median)	ratio of R&D expenditures to turnover (median)
1995	70	18	7.8	4.0
1996	67	17	7.9	4.1
1997	64	16	8.3	4.2
1998	57	18	8.3	4.0
1999	55	20	8.2	4.5
2000	54	22	8.0	4.7
2001	48	23	9.1	5.0
2002	49	23	9.3	5.0
2003	53	21	9.5	4.8
2004	49	18	10.5	5.2

Source: FFG, own calculations.

Table 3 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 turnover while at the 0.4 quantile and above we can observe positive growth rates.

Table 3: Descriptive statistics at various quantiles

	average growth rates of employment (t,t-2)	average growth of turnover (t-2/t)	initial employment (t-2)	ratio of R&D expenditures to turnover (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 period 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 4 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 a R&D intensity, between 10 and 20 per cent and -0.2 for firms with a R&D intensity of 1.5 per cent or less. Table 5 shows that the positive relationship between R&D intensity and the employment growth rate in the two subsequent years holds for both young and established firms. Figure 1 in the appendix shows that the distribution of both turnover 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 4: Median of the average employment growth rates in the next two years by initial firm size and initial R&D turnover ratio

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

Notes: See Table 3. 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 R&D intensity is measured in the initial year.

Table 5: Average (median) employment growth rates in the subsequent two years by R&D intensity and by age between 1996 and 2006

	established firms	young firms
ratio of R&D expenditures to turnover:	3.4	10.7
1.5% or less	2.4	11.8
1.5% - under 4%	6.9	15.5
4% -under 10%	6.9	22.5
10% - under 20%	7.3	22.5

Notes: see Table 3. Source: FFG, own calculations.

4 Empirical results

4.1 Median regression results for each sub-period

Table 6 and Table 7 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 6 and Table 7 is that R&D intensity is either defined as the ratio of R&D expenditures to turnover or the ratio of R&D employment to total employment. Table 8 shows the corresponding results for turnover growth as the dependent variable. 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 turnover and employment growth in the subsequent two years in almost all

cases. This means that the turnover and employment growth in the subsequent two years is higher, when the firm's expenditures in R&D increase, given total turnover. 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 6 and 7). The corresponding coefficients range between 0.003 and 0.02.

For the turnover 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 8). 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 turnover 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 period 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 7). In a related literature, Hall (1993) found strong evidence in favor of a declining rate of return to R&D between 1979-1983 and 1986-1991 based on US data.

Having found that the impact of R&D intensity on firm growth is decreasing 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. As Table 1 indicates 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-estimate 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.

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.

Table 6: Median estimates for the impact of the ratio of R&D expenditures to turnover on employment growth

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

Notes: Dependent variable is the geometric annual change in employment over each two-year period. t-values in parenthesis are based on standard errors that are bootstrapped with 1000 replications.

Table 7: Median estimates for the impact of the share of R&D employment on employment growth

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

Notes: Dependent variable is the geometric annual change in employment over each two-year period. t-values in parenthesis are based on standard errors that are bootstrapped with 1000 replications.

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

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

Notes: Dependent variable is the geometric annual change in turnover over each two-year period. t-values in parenthesis are based on standard errors that are bootstrapped with 1000 replications.

4.2 Quantile regression results for the pooled sample

Table 9 and Table 10 show the results of the simultaneous quantile regressions for the employment and turnover growth equation at various quantiles using pooled data covering five cross-sections for the period 1996-2006.[2] 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 specification includes 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 12 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 turnover 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 9). At the 0.1, 0.2, and 0.3 quantile, R&D intensity is not significantly different from zero. This indicates that R&D intensity does matter only when a certain level of firm growth is achieved. In other words, R&D activities are not effective in shrinking firms. 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.

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

Table 9: Quantile estimations for the impact of R&D to turnover 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	-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 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	-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 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	-0.006	-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: t-values in parenthesis 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. 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 10: Quantile estimations for the impact of R&D intensity on average growth rate of turnover 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 employ-	0.018	0.010	0.005	0.000	-0.007	-0.012	-0.017	-0.026	-0.042
ment (t-2)	(5.90)	(4.76)	(2.84)	(-0.12)	(-4.01)	(-5.22)	(-6.98)	(-8.06)	-8.66)
log R&D in-	0.000	0.004	0.010	0.013	0.019	0.027	0.035	0.046	0.065
tensity (t-2)	(0.06)	(1.98)	(5.08)	(6.34)	(9.55)	(9.08)	(11.63)	(13.02)	11.27)
newly founded	0.005	0.037	0.057	0.082	0.099	0.138	0.226	0.331	0.736
(t-2,t-5)	(0.29)	(3.10)	(5.78)	(6.90)	(8.40)	(6.86)	(7.32)	(8.63)	(7.32)
	-0.171	-0.050	0.024	0.091	0.175	0.265	0.354	0.495	0.742
constant	(-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 R&D intensity **lagged minus one** (t-3); # of obs : 2510								
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employ-	0.014	0.009	0.005	0.000	-0.004	-0.010	-0.014	-0.021	-0.032
ment (t-2)	(2.99)	(3.53)	(2.29)	(0.21)	(-1.54)	(-3.88)	(-5.43)	(-5.07)	(-7.09)
log R&D in-	-0.009	-0.003	0.006	0.011	0.015	0.021	0.030	0.042	0.059
tensity (t-3)	(-2.12)	(-0.91)	(2.32)	(4.50)	(6.38)	(6.47)	(9.46)	(8.75)	(13.12)
newly founded	0.007	0.013	0.036	0.042	0.060	0.074	0.107	0.180	0.201
(t-2,t-5)	(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 R&D intensity **lagged minus two** (t-4); # of obs : 1705								
	q10	q20	q30	q40	q50	q60	q70	q80	q90
log employ-	0.012	0.010	0.008	0.001	-0.003	-0.010	-0.015	-0.020	-0.034
ment (t-2)	(1.83)	(3.49)	(3.03)	(0.49)	(-0.84)	(-2.87)	(-4.46)	(-4.21)	(-6.31)
log R&D in-	-0.012	-0.003	0.004	0.009	0.014	0.017	0.028	0.030	0.048
tensity (t-4)	(-2.19)	(-1.02)	(1.71)	(2.97)	(5.51)	(4.66)	(6.21)	(5.40)	(8.08)
newly founded	-0.014	0.010	0.046	0.045	0.073	0.065	0.084	0.162	0.200
(t-2,t-5)	(-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: t-values in parenthesis 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. The explanatory variables are measured in the initial year, and for R&D intensity also for lagged minus one and lagged minus two years.

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, one can calculate the elasticity of firm growth with respect to the R&D intensity. This can be calculated by dividing the coefficients by the value of the corresponding quantile of the employment growth distribution. Table 9 shows that the elasticity of employment growth with respect to R&D intensity is highest for q=0.4 respectively, followed by the median.

For the turnover 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^{th} conditional quantile of the turnover growth distribution, the R&D intensity is not significant. From the 30^{th} to 90^{th} conditional quantile, both the coefficient and its significance increase considerably along the conditional growth distribution. However, at the 80^{th} and 90^{th} quantiles, the reported coefficients are quite low when compared to the value of the 0.8 and 0.9 quantile of the distribution of the turnover growth rate. The upper panel in Table 10 shows that the growth-R&D elasticity is highest at the 0.3 and 0.4 quantile, and is then continuously decreasing 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 quantile. For example, in the upper panel of Table 9 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, and 20, and 80, and 90 percentile, the coefficient for the R&D intensity is outside the 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 confidence interval of the OLS estimate.

Table 13 and Table 14 in the appendix show the estimation results of both the employment growth and turnover 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 the conditional median distribution or at higher quantiles, suggesting that firms with and above median growth rates benefit only from R&D investment.

5 Conclusions

The main objective of this paper was to re-examine the relationship between R&D intensity and firm growth and using a large and unique data set for Austrian firms for the period 1995-2006. In particular, the quantile regression methodology is used in order to explore whether the impact of R&D activities differ 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 turnover 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 turnover), 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 quartile (e.g fast growing firms) can be as large as 0.04, while the effect in the lower quartiles (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 greater 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 R&D doing firms benefit from R&D activities then increasing R&D subsidies is as 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. One implication is that R&D funding agencies should be cautious about providing R&D subsidies to shrinking firms. In order to enhance firm growth, one priority of the R&D funding agency is 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 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 is the use of other performance measures such as the profit to turnover ratio.

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Appendix:

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

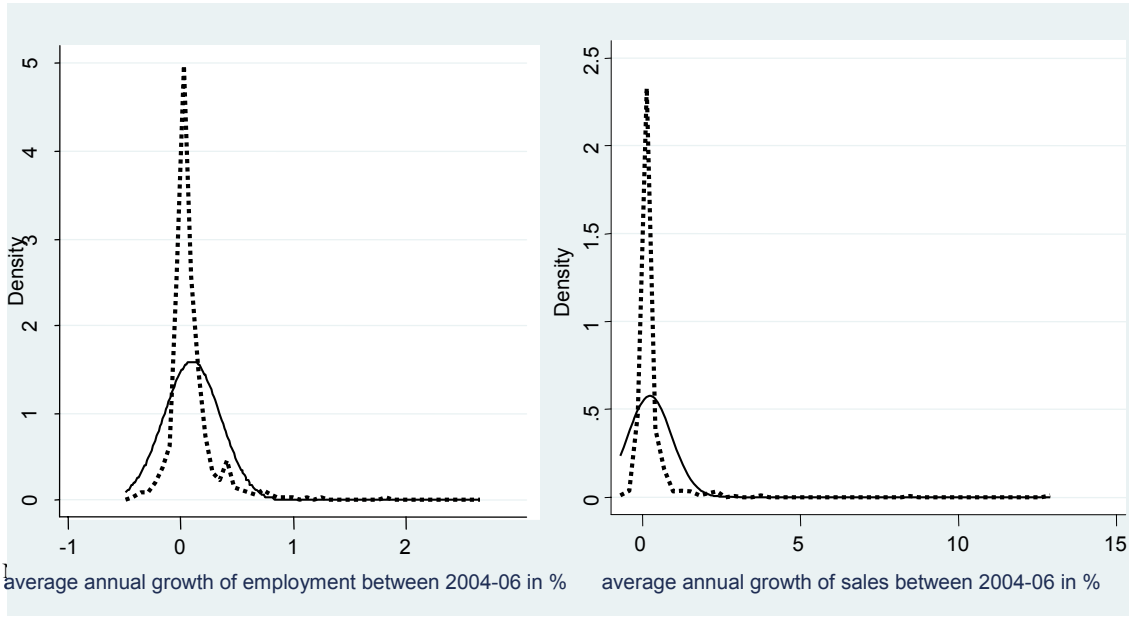


Table 11: OLS results of the impact of R&D intensity on firm performance

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

Note: All equations include initial employment and a dummy variable for young firms. T-statistics are based on heteroscedasticity-consistent standard errors.

Table 12: Quantile estimations for the impact of the ratio of R&D employment to total 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	-0.005	-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 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	-0.005	-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 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	-0.006	-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)
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: t-values in parenthesis. 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 13: Quantile estimations of the determinants of employment and turnover growth between 2004-2006

	impact of R&D to turnover ratio on average employment growth between 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 turnover (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 between 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 turnover between 2004-2006 between 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 turnover (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

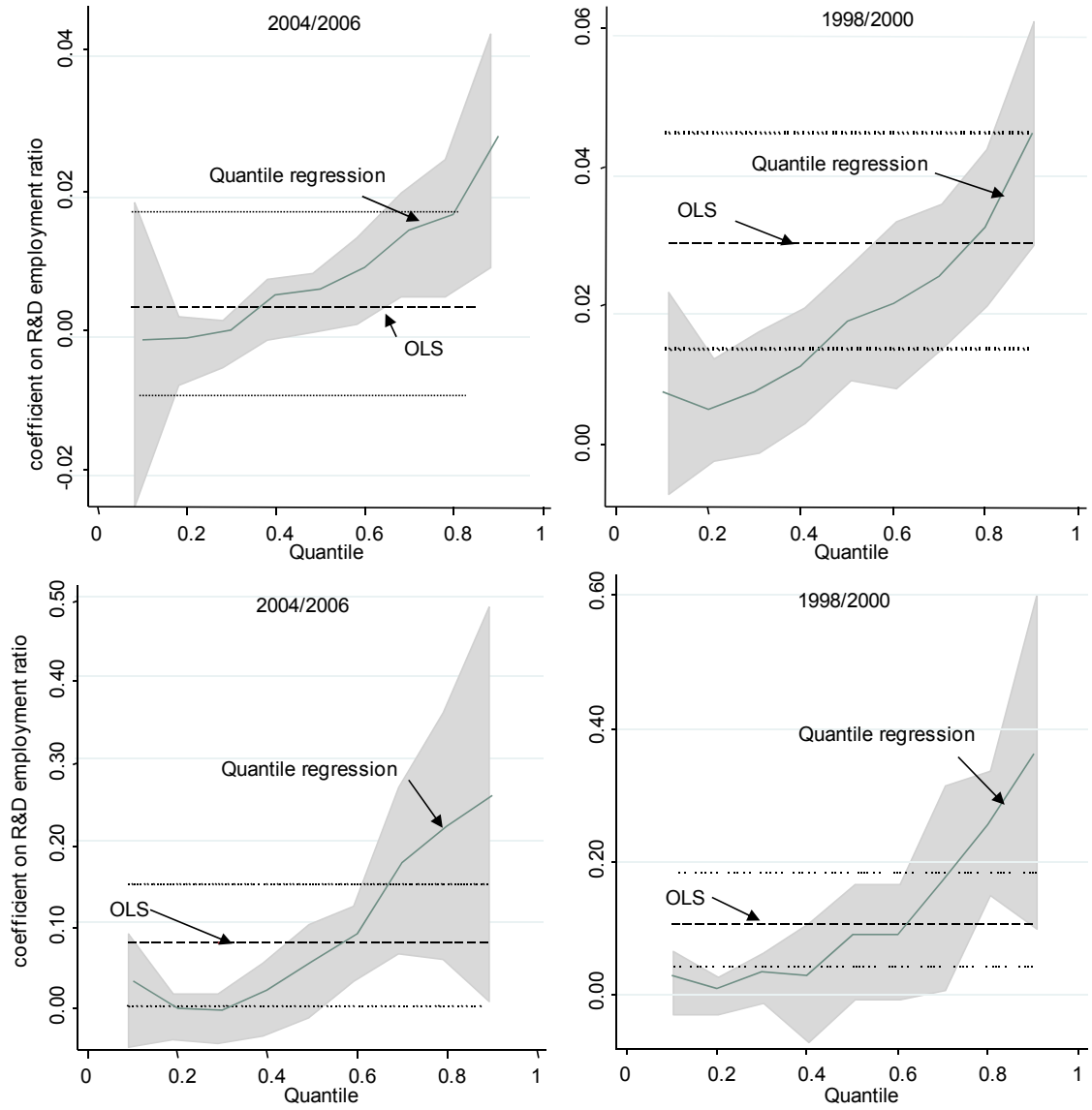
Note: t-values in parenthesis are based on standard errors that are bootstrapped with 1000 replications.

Table 14: Quantile estimations of the determinants of employment and turnover growth between 1998-2000

	impact of the ratio of R&D to turnover on employment growth between 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 turnover (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 between 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 turnover between 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 turnover (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)
	-0.147	-0.042	0.019	0.111	0.223	0.317	0.383	0.526	0.813
constant	(-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: t-values in parenthesis are based on standard errors that are bootstrapped with 1000 replications.

Graph 2: Impact of R&D intensity on employment growth



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