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## Firm growth and R&D expenditure

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# PAPERS on Economics & Evolution



MAX-PLANCK-GESELLSCHAFT

# 0710

## **Firm Growth and R&D Expenditure**

**by**

**Alexander Coad  
Rekha Rao**

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## FIRM GROWTH AND R&amp;D EXPENDITURE\*

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November 9, 2007

**Abstract**

We apply a panel vector autoregression model to a firm-level longitudinal database to observe the co-evolution of sales growth, employment growth, profits growth and growth of R&D expenditure. Contrary to expectations, profit growth seems to have little detectable effect on R&D investment. Instead, firms appear to increase their total R&D expenditure following growth in sales and growth of employment. In a sense, firms behave ‘as if’ they aim for a roughly constant ratio of R&D to employment (or sales). We observe heterogeneous effects for growing or shrinking firms however, suggesting that firms are less willing to reduce their R&D levels following a negative growth shock than they are willing to increase R&D after a positive shock.

**JEL codes:** L20, L10, O32**Keywords:** Firm Growth, Panel VAR, R&D expenditure, Industrial Dynamics

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# 1 Introduction

Modern business firms make strategic choices about investment in research and development (R&D) in the hope of enjoying competitive advantage in subsequent periods. Their choice of R&D expenditure levels may depend upon many factors, and the choice of R&D investment levels is the outcome of lengthy negotiations within firms. Since the returns to R&D cannot be known *ex ante* (by definition), considerable leeway exists for behavioural factors and business intuition as opposed to any kind of serious ‘cost-benefit analysis’ – R&D investment is very much an ‘art’ rather than a science.

R&D expenditure is usually split roughly evenly between the wages and salaries of scientific personnel, on the one hand, and some kind of research materials and equipment on the other (Hall and Van Reenen, 2000, p. 459). In addition, the knowledge obtained from research activities is largely tacit in nature, even when information describing the obtained knowledge can be conveyed in scientific publications or patent documents (for discussions, see e.g. Zellner (2002) and Witt and Zellner (2005)). Much of the value of an R&D investment is therefore embodied in the minds of the scientists. These scientists gradually gain experience, accumulating research capabilities and tacit understanding of their scientific domain with the passing of time. As a result, investment in R&D is most effective when the research programme is followed for a long period, where the R&D personnel learn to work together and proceed with minimal interruptions or fluctuations in resources. Investment in R&D therefore tends to be rather smoothed over time. However, it should also be noted that firms have no guarantee that their R&D efforts will eventually result in superior performance. Given these characteristics of R&D investment (i.e. uncertainty and the need for constant commitment), it is reasonable to expect that firms will find it useful to have ‘rules of thumb’ such as devoting a certain percentage of total sales to R&D.<sup>1</sup>

The literature on R&D investment has long been interested in observing how R&D expenditure varies with firm size.<sup>2</sup> This literature has typically found that, above a certain threshold level, R&D expenditure increases more or less proportionally with firm size (see the survey in Symeonidis (1996)). This is consistent with the hypothesis that firms keep their R&D intensities (i.e., R&D/Sales) at roughly constant ratios.

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<sup>1</sup>We are distancing ourselves here from some (rather ridiculous) ideas originating in neoclassical economic theory, which consider R&D investment levels to be chosen by rational agents optimizing future revenue streams on an infinite horizon.

<sup>2</sup>Another strand of the literature has investigated how government initiatives can induce private R&D expenditure. Some authors have analysed the sensitivity of firms R&D expenditure to subsidies and fiscal incentives (see for example Gorg and Strobl (2007) and the survey in Hall and Van Reenen (2000)). Others have focused on the influence of public R&D on firms’ R&D expenditure – see Guellec and van Pottelsberghe (2003) and also the survey in David et al. (2000). Still others have focused on the influence of institutional factors on firm-level R&D investment levels, including such factors as patent protection, human capital and international openness (Falk (2006)).

Most firms do not stay the same size, however. How does a growing firm adjust its R&D levels? What are the processes of R&D investment? This question does not seem to have been addressed in the previous literature, and is the focus of this paper. By observing how R&D expenditure changes in growing firms, we stand to learn a lot about firms' R&D investment behavior. For example, how are R&D programmes dependent upon internal sources of finance? Are profits reinvested into R&D growth? How does the growth of sales and employment affect growth of R&D? What are the relevant time horizons? Bearing in mind the preceding discussion, we can tentatively suggest two hypotheses here. First, it is reasonable to suppose that growing firms increase their R&D expenditures, although the magnitude of this elasticity is likely to be less than proportional in the short run (especially if there exists uncertainty about future market conditions). Second, there may be asymmetries of R&D investment if the consequences of reducing R&D expenditure are costly. As a result, we expect that R&D expenditure is sensitive to growth in growing firms whilst it is more constant in the case of declining firms.

In order to investigate the co-evolution of firm growth and R&D expenditure, we apply the reduced-form panel vector autoregression (VAR) model introduced by Coad (2007a). This model allows us to observe the lead-lag relationships and the complex interactions between our R&D growth variable and the firm growth variables (i.e. growth of employment, sales and operating income).

**Structure of the paper** In Section 2 we present the database along with some summary statistics. In Section 3 we discuss our regression methodology. In Section 4 we present our main results. The robustness of these results is explored in Section 5. In Section 6 we discuss these results, and conclude in Section 7.

## 2 Database and summary statistics

### 2.1 Data

We base our analysis on the well-known Compustat database and restrict ourselves to US manufacturing firms (SIC classes 2000-3999). We start our analysis from 1973 only because the disclosure of R&D expenditure was made compulsory for US firms in 1972 (see (Hall and Oriani, 2006, Table 1)).<sup>3</sup>

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<sup>3</sup>Although we do actually have some observations for R&D expenditure for firms before 1972, due to the voluntary nature of disclosure of R&D expenditure during this period these observations are prone to sample selection bias (i.e. self-selection bias). Furthermore, we have relatively few observations before the 1970s which discourages analysis of these earlier years.

The variables of interest are Total Sales, Employees, Operating Income (sometimes referred to as ‘profits’) and R&D expenditure.<sup>4</sup> We replace operating income and R&D with 0 if the company has declared the relevant amount to be “insignificant”. In order to avoid misleading values and the generation of NaNs<sup>5</sup> whilst taking logarithms and ratios, we now retain only those firms with strictly positive values for operating income,<sup>6</sup> R&D expenditure, and employees in each year. This creates some missing values, especially for our growth of operating income variable.

In keeping with previous studies, our measure of growth rates is calculated by taking the differences of the logarithms of size:

$$GROWTH_{it} = \log(X_{it}) - \log(X_{i,t-1}) \quad (1)$$

where, to begin with,  $X$  is measured in terms of employment, sales, R&D expenditure or operating income for firm  $i$  at time  $t$ .

In keeping with previous work (e.g. Bottazzi et al. (2005)) the growth rate distributions have been normalized around zero for each of the growth rate series in each year which effectively removes any common macroeconomic trends such as inflation.

## 2.2 Summary statistics

Table 1 presents some year-wise summary statistics, which gives the reader a rough idea of the range of firm sizes in our dataset. Table 2 presents some summary statistics of the growth rate series.

Figure 1 shows the (unconditional) growth rate distributions for the years 1974, 1984, 1994, 2004. These growth rate distributions resemble the familiar ‘tent-shaped’ Laplacian distribution that has been observed in other studies (see Stanley et al. (1996) and Bottazzi and Secchi (2003)). These plots give us an early hint that standard regression estimators such as OLS, which assume Gaussian residuals, may perform less well than Least Absolute Deviation (LAD) techniques which are robust to extreme observations. We also observe that the distribution of growth rates of gross operating surplus has a particularly wide support, which would indicate considerable heterogeneity between firms in terms of the dynamics of their profits.

<sup>4</sup>The precise Compustat definitions for these variables are employees (thousands), net sales (\$million), research and development expense (\$million) and operating income before depreciation (\$million). These definitions are obtained from Compustat North America chapter 3 – Financial formulas (8/2003 version).

<sup>5</sup>NAN is shorthand for Not a Number, which refers to the result of a numerical operation which cannot return a valid number value. In our case, we may obtain a NAN if we try to take the logarithm of a negative number, or if we try to divide a number by zero.

<sup>6</sup>Operating income is sometimes referred to as ‘profits’ in the following.

Table 1: Summary statistics for employment levels (in thousands) after cleaning the data, for the years 1973, 1984, 1994, 2004

	Mean	Std. Dev.	10%	25%	Median	75%	90%	obs.
<b>1973</b>								
Empl.	12.38	45.95	0.26	0.62	2.02	7.71	26.93	1306
<b>1984</b>								
Empl.	12.68	43.16	0.11	0.30	1.24	6.78	31.00	1332
<b>1994</b>								
Empl.	10.36	38.81	0.09	0.24	1.08	4.86	22.15	1577
<b>2004</b>								
Empl.	11.14	30.52	0.11	0.35	1.62	6.84	28.10	1219

Table 2: Summary statistics for the growth rate series, for the years 1974, 1984, 1994, 2004

	Mean	Std Dev	10%	25%	50%	75%	90%	obs
<b>1974</b>								
Empl. growth	0.0000	0.1907	-0.2010	-0.0898	-0.0074	0.0801	0.2146	1187
Sales growth	0.0000	0.1783	-0.1848	-0.0987	-0.0131	0.0780	0.1978	1187
R&D growth	0.0000	0.4423	-0.3751	-0.1279	-0.0100	0.1309	0.3682	1187
Op. Inc. growth	0.0000	0.5857	-0.4970	-0.1705	0.0393	0.2273	0.4847	1187
<b>1984</b>								
Empl. growth	0.0000	0.2221	-0.1772	-0.1061	-0.0350	0.0696	0.2373	1158
Sales growth	0.0000	0.2372	-0.2080	-0.1268	-0.0402	0.0822	0.2549	1158
R&D growth	0.0000	0.4157	-0.3291	-0.1566	-0.0469	0.1282	0.3918	1158
Op. Inc. growth	0.0000	0.6882	-0.5635	-0.2054	-0.0083	0.2530	0.6376	1158
<b>1994</b>								
Empl. growth	0.0000	0.2627	-0.1880	-0.1081	-0.0390	0.0731	0.2467	1332
Sales growth	0.0000	0.2158	-0.1912	-0.1104	-0.0295	0.0777	0.2306	1332
R&D growth	0.0000	0.3535	-0.3120	-0.1517	-0.0311	0.1247	0.3561	1332
Op. Inc. growth	0.0000	0.6573	-0.4579	-0.1657	-0.0071	0.2089	0.5490	1332
<b>2004</b>								
Empl. growth	0.0000	0.2050	-0.1533	-0.0881	-0.0329	0.0520	0.1805	1055
Sales growth	0.0000	0.1861	-0.1653	-0.0944	-0.0319	0.0759	0.2154	1055
R&D growth	0.0000	0.3411	-0.2633	-0.1268	-0.0257	0.0868	0.3019	1055
Op. Inc. growth	0.0000	0.6520	-0.4966	-0.2400	-0.0805	0.1710	0.6008	1055

Table 3: Matrix of contemporaneous correlations for the indicators of firm growth, pooling the years together. Conventional correlation coefficients are presented first, followed by Spearman's rank correlation coefficients.

	Empl. growth	Sales growth	R&D growth	Op. Inc. growth
Empl. growth	1.0000			
p-value	0.0000			
obs.	38958			
(Sp. Rank)	1.0000			
(p-value)	0.0000			
Sales growth	0.6318	1.0000		
p-value	0.0000	0.0000		
obs.	38958	38958		
(Sp. Rank)	0.6105	1.0000		
(p-value)	0.0000	0.0000		
R&D growth	0.3452	0.3075	1.0000	
p-value	0.0000	0.0000	0.0000	
obs.	38958	38958	38958	
(Sp. Rank)	0.3964	0.3588	1.0000	
(p-value)	0.0000	0.0000	0.0000	
Op. Inc. growth	0.5097	0.2526	0.0676	1.0000
p-value	0.0000	0.0000	0.0000	0.0000
obs.	38958	38958	38958	38958
(Sp. Rank)	0.6286	0.3398	0.1435	1.0000
(p-value)	0.0000	0.0000	0.0000	0.0000



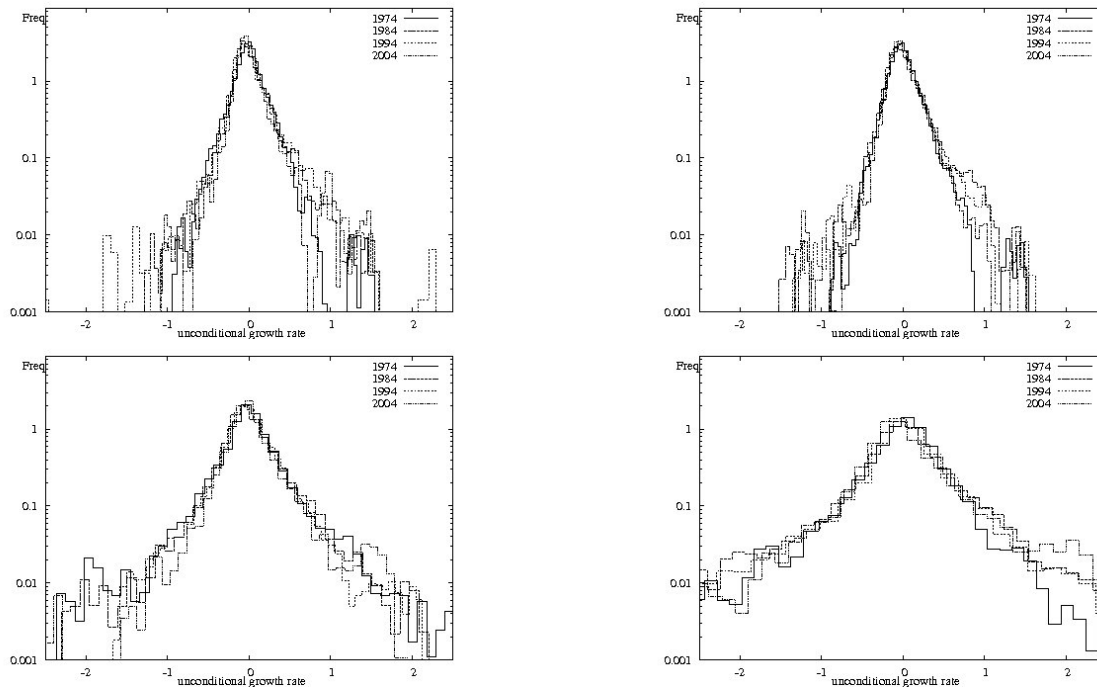


Figure 1: Distribution of the unconditional growth rates of our sample of US manufacturing firms. Top left: employment growth. Top right: sales growth. Bottom left: growth of R&D expenditure. Bottom right: growth of operating income. Note the log scale on the  $y$  axis.

Table 3 and Figure 2 show the correlations between our indicators of firm growth and firm performance. Spearman's rank correlation coefficients are also shown since these are more robust to outliers. All of the series are correlated between themselves at levels that are highly significant. However, the correlations are indeed far from perfect, as has been noted elsewhere (see Delmar et al. (2003) on Swedish data and Coad (2007a) on French data). The largest contemporary correlation is between sales growth and employment growth. Interestingly enough, the lowest correlation (0.0676) is between growth of profits (i.e. operating income) and growth of R&D expenditure. For these latter two variables, we observe neither a substitution effect (where a firm must divide its surplus between either profits or R&D) nor a strong complementarity. Although the contemporaneous correlation between growth of profits and growth of R&D is statistically significant (no doubt because of the large number of observations), in practical terms it might be a valid approximation to consider the two as independent (see also the corresponding plot in Figure 2).

Although there is a large degree of multicollinearity between these series, the lack of persistence in firm growth rates (despite a high degree of persistence of firm size) will, we hope, aid in identification in the regression analysis. Furthermore, the large number of observations will also be helpful in identification. Multicollinearity has the effect of making the coefficient estimates unreliable in the sense that they may vary considerably from one regression specification to another. With this in mind, we therefore pursue a relatively lengthy robustness

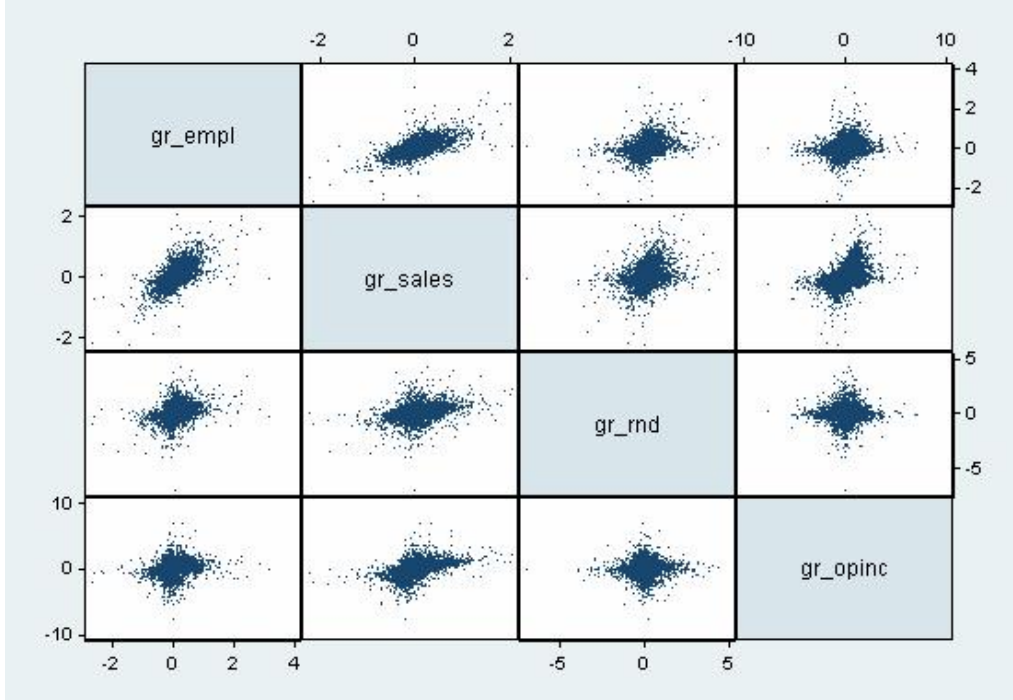


Figure 2: Scatterplot matrix of contemporaneous values of employment growth, sales growth, growth of R&D expenditure and operating income growth for a typical decade (the 1990s).

analysis in Section 5.

### 3 Methodology

**Introducing the VAR** The regression equation of interest is of the following form:

$$w_{it} = c + \beta w_{i,t-1} + \varepsilon_{it} \quad (2)$$

where  $w_{it}$  is an  $m \times 1$  vector of random variables for firm  $i$  at time  $t$ .  $\beta$  corresponds to an  $m \times m$  matrix of slope coefficients that are to be estimated. In our particular case,  $m=4$  and corresponds to the vector (Empl. growth(i,t), Sales growth (i,t), R&D growth (i,t), operating income growth(i,t)).  $\varepsilon$  is an  $m \times 1$  vector of disturbances.

We do not include any dummy control variables (such as year dummies or industry dummies) in the VAR equation because we anticipate that, if indeed there are any temporal or sectoral effects at work, then dummy variables will be of limited use in detecting these effects. Instead, we suspect that the specificities of individual years or sectors may have non-trivial consequences on the structure of interactions of the VAR series, and these cannot be detected through the use of appended dummy variables alone. We explore the influence of temporal disaggregation and sector of activity in detail in Section 5. Although we do not attempt clean

the series of size dependence before applying the VAR, we explore how our results change across firm size groups in detail in Section 5

We estimate equation (2) via ‘reduced-form’ VARs, which do not impose any *a priori* causal structure on the relationships between the variables, and are therefore suitable for the preliminary nature of our analysis. These reduced-form VARs effectively correspond to a series of  $m$  individual OLS regressions (Stock and Watson (2001)).

One problem with OLS regressions in this particular case, however, is that the distribution of firm growth rates is typically exponentially distributed and has much heavier tails than the Gaussian. In this case OLS may provide unreliable results, and as argued in Bottazzi et al. (2005) we would prefer Least Absolute Deviation (LAD) estimation.

**Allowing for firm-specific fixed effects** A further reason why OLS (and also LAD) estimation of equation (2) is likely to perform poorly is if there is unobserved heterogeneity between firms in the form of firm-specific effects (i.e. firm-specific components in *growth rates*). If these ‘fixed effects’ are correlated with the explanatory variables, then OLS (and LAD) estimates will be biased. One way of doing accounting for these fixed effects would be to introduce a dummy variable for each firm and to include this in the regression equation to obtain something resembling a standard ‘fixed-effects’ panel data model. The drawback with this, however, is that the inclusion of lagged dependent variables can be a source of bias for fixed-effect estimation of dynamic panel-data models. The intuition is that the fixed effect would be in some sense ‘double-counted’ if the dependent variable is included in the regression equation at time  $t$  and also at previous times due to the lag structure (this problem is known as ‘Nickell-bias’ after Nickell (1981)). Nickell-bias is often observed to be rather small, however, and so its importance is a matter of debate.

This ‘Nickell-bias’ problem can be dealt with by using instrumental variables (IV) techniques, such as the ‘System GMM’ estimator (Blundell and Bond (1998)). The performance of instrumental variables estimators, however, depends on the quality of the instruments. If the instruments are effective then the estimates will be relatively precisely defined. If the instruments are weak, however, the confidence intervals surrounding the resulting estimates will be large. This is likely to be the case in this study because it is difficult to find suitable instruments for firm growth rates because they are characteristically random and lack persistence (see the discussion in Geroski (2000) and Coad (2007c)). IV estimation of a panel VAR with weak instruments thus leads to imprecise estimates.

Binder et al. (2005) present a panel VAR model which can include firm-specific fixed effects but that does not require the use of instrumental variables. The model is estimated using Quasi-maximum-likelihood optimization techniques. They propose the following model:

$$w_{it} = (I_m - \Phi)\mu_i + \Phi w_{i,t-1} + \epsilon \quad (3)$$

where  $\mu$  corresponds to the firm-specific fixed effects and  $\Phi$  is the  $m \times m$  coefficient matrix to be estimated.  $\epsilon$  is the usual vector of disturbance terms. BHP (2005) present evidence from Monte Carlo simulations that demonstrates that their estimator is more efficient (i.e. the estimates have lower standard errors) than IV GMM. The drawback with the BHP estimator for this particular application, however, is that it assumes normally distributed errors (whereas the distributions of firm growth rates are approximately Laplace-distributed).

The approach taken in this paper, however, is that any firm-specific component has been largely removed by the fact that we are dealing with growth rates (i.e., differences) rather than size levels. Instead the issue of non-Gaussian residuals seems to us to be a more pressing econometric issue than any firm-specific component in *growth rates*, and as a result our estimator of choice is the LAD estimator (following on from Coad (2007a)), which is best suited to the case of Laplacian error terms. We also base our inference upon standard errors obtained using the computationally intensive ‘bootstrapping’ resampling technique (see Efron and Gong (1983) for an introduction).

**Causality or association?** Our intentions in this paper are to summarize the comovements of the growth series. We remind the reader of the important distinction between correlation and causality. We have no strong *a priori* theoretical positions, and we make no attempt at any serious identification of the underlying causality at this early stage, instead preferring to describe the associations. Indeed, much can be learned simply by considering the associations between the variables without mentioning issues of causality (see Moneta (2005) for a discussion).

## 4 Aggregate analysis

The regression results obtained from the OLS and LAD estimators are presented in Tables 4 and 5 respectively. (For the sake of curiosity, the bootstrapped LAD results (with up to three lags) are in the Appendix in Table 10, although these results mimic those obtained from our other models.) Although the results are reasonably stable across specifications, one major difference between OLS and LAD is that the magnitudes of the autocorrelation coefficients (along the ‘diagonals’) are much smaller using the LAD estimator. This was observed by Bottazzi et al. (2005) and is explored in Coad (2006). For reasons discussed above, we base our interpretations mainly on the LAD results.

Many of the results concerning the interactions between sales growth, employment growth

Table 4: OLS estimation of equation (2).

$w_t$	$\beta_{t-1}$					$\beta_{t-2}$					$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		Empl. growth	Sales growth	R&D growth	Op. Inc. growth			
Empl gr	<b>0.0329</b>	<b>0.1823</b>	<b>0.0190</b>	<b>0.0063</b>							0.0540	33166
<i>t</i> -stat	3.12	15.25	5.12	2.38								
Sales gr	<b>0.3155</b>	<b>0.0351</b>	0.0056	0.0044							0.1398	33166
<i>t</i> -stat	27.54	3.12	1.60	1.75								
R&D gr	<b>0.2178</b>	<b>0.2592</b>	<b>-0.1228</b>	<b>0.0247</b>							0.0606	33166
<i>t</i> -stat	9.74	10.58	-8.07	4.75								
Op Inc gr	<b>0.1535</b>	<b>0.3923</b>	<b>-0.0751</b>	<b>-0.2927</b>							0.0631	33166
<i>t</i> -stat	5.96	11.12	-6.51	-19.27								
Empl gr	0.0170	<b>0.1388</b>	<b>0.0201</b>	<b>0.0131</b>		<b>-0.0236</b>	<b>0.0782</b>	<b>0.0234</b>	<b>0.0096</b>		0.0518	28538
<i>t</i> -stat	1.44	10.26	4.72	4.29		-2.13	5.63	4.68	3.07			
Sales gr	<b>0.3341</b>	-0.0224	0.0063	0.0053		<b>0.0412</b>	-0.0024	<b>0.0202</b>	-0.0030		0.1319	28538
<i>t</i> -stat	26.95	-1.62	1.57	1.77		4.03	-0.20	5.30	-1.12			
R&D gr	<b>0.2248</b>	<b>0.1723</b>	<b>-0.1334</b>	<b>0.0399</b>		-0.0076	<b>0.1541</b>	<b>-0.0350</b>	<b>0.0288</b>		0.0648	28538
<i>t</i> -stat	10.44	6.29	-7.69	6.57		-0.41	6.78	-2.89	4.69			
Op Inc Gr	<b>0.1456</b>	<b>0.6314</b>	<b>-0.0587</b>	<b>-0.4021</b>		<b>-0.1496</b>	<b>0.1236</b>	-0.0033	<b>-0.1825</b>		0.1015	28538
<i>t</i> -stat	5.03	14.92	-4.45	-23.71		-5.30	3.65	-0.29	-14.94			

Table 5: LAD estimation of equation (2).

$w_t$	$\beta_{t-1}$					$\beta_{t-2}$					$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth	Inc. growth	Empl. growth	Sales growth	R&D growth	Op. Inc. growth	Inc. growth		
Empl gr	<b>0.0590</b>	<b>0.1382</b>	<b>0.0188</b>	<b>0.0067</b>							0.0330	33166
$t$ -stat	12.83	25.59	8.97	4.58								
Sales gr	<b>0.3221</b>	<b>0.0437</b>	<b>0.0073</b>	<b>0.0045</b>							0.0815	33166
$t$ -stat	74.01	8.55	3.69	3.28								
R&D gr	<b>0.2163</b>	<b>0.1792</b>	-0.0054	<b>0.0276</b>							0.0440	33166
$t$ -stat	31.92	22.52	-1.76	12.84								
Op Inc gr	<b>0.1905</b>	<b>0.2624</b>	<b>-0.0258</b>	<b>-0.1468</b>							0.0151	33166
$t$ -stat	19.21	22.55	-5.72	-46.64								
Empl gr	<b>0.0403</b>	<b>0.1017</b>	<b>0.0166</b>	<b>0.0122</b>			<b>0.0633</b>	<b>0.0181</b>	<b>0.0053</b>		0.0353	28538
$t$ -stat	8.65	16.98	7.69	7.80			11.86	8.67	3.50			
Sales gr	<b>0.3200</b>	0.0060	<b>0.0140</b>	<b>0.0038</b>			<b>0.0259</b>	<b>0.0169</b>	<b>-0.0035</b>		0.0770	28538
$t$ -stat	61.61	0.90	5.84	2.19			4.91	7.27	-2.07			
R&D gr	<b>0.2122</b>	<b>0.0935</b>	<b>-0.0175</b>	<b>0.0460</b>			0.0047	<b>0.0932</b>	<b>0.0229</b>		0.0451	28538
$t$ -stat	27.33	9.39	-4.87	17.75			0.60	-0.040	9.14			
Op Inc gr	<b>0.1893</b>	<b>0.3773</b>	<b>-0.0195</b>	<b>-0.2272</b>			<b>-0.0405</b>	<b>0.0771</b>	<b>-0.1164</b>		0.0240	28538
$t$ -stat	14.24	22.11	-3.17	-51.19			-3.00	5.07	-27.20			

and growth of profits are similar to those in Coad (2007a). Whilst it is encouraging to observe that similar results can be found using both French and US data, we will focus on R&D growth here and not on the interactions between the growth of sales, employment and profits (the reader is referred to Coad (2007a)).

R&D growth does not seem to be very strongly associated with subsequent growth of the other series – this is no doubt due to the uncertainty of R&D and the long time lag required for a commercially valuable discovery to finally materialize in terms of growth of sales or profits. R&D growth seems to be positively associated with subsequent growth of employment and sales, although the magnitude of this association is particularly small. R&D growth is slightly negatively associated with growth of profits one year later, but this seems to be reversed after two periods since the coefficient is (small but) positive for the second lag. Finally, we observe that growth of R&D expenditure displays a small, perhaps negative serial correlation (see Table 5).

Our more interesting results concern the processes of investment in R&D. We observe that both employment growth and sales growth are strongly associated with subsequent growth of R&D expenditure. Although it appears that employment growth has a larger influence after one period, sales growth may have a longer-term contribution to subsequent R&D (still highly significant at the second and third lags). In contrast, growth of operating income is relatively weakly associated with subsequent growth of R&D expenditure. Whilst Himmelberg and Petersen (1994) and Bougheas et al. (2003) observe a higher influence of current financial performance on subsequent R&D investment in their samples of small firms, it should be noted that larger firms (such as those analyzed here) typically display a lower sensitivity of R&D investment to financial performance, perhaps because of easier access to external finance (Himmelberg and Petersen (1994)).<sup>7</sup>

It is rather straightforward to interpret the magnitudes of the coefficients. If we observe that the growth rate of employment increases by 1 percentage point, then *ceteris paribus* we can expect R&D expenditure to rise by 0.21-0.22 percentage points in the following year. In comparison, a 1 percentage point increase in the growth of operating income can be expected to be followed by a 0.02-0.05 percentage point increase in the growth rate of R&D expenditure in the following year. However, these point estimates are likely to be slightly downward-biased, for two reasons. First, general measurement error in the growth rates of the variables will lead to downward bias. Second, in the likely event that firms smooth their R&D levels, there will be a low amount of variation in the R&D series over time which will also have a downward effect on the corresponding coefficient estimates (see Himmelberg and Petersen (1994) for a

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<sup>7</sup>It is nonetheless puzzling that Grabowski and Vernon (2000) observe a very high sensitivity of R&D investment to cash flow in their sample of 11 major pharmaceutical firms. They observe that “a \$1 million increase (decrease) in cash flow will lead approximately to a \$310’000 increase (decrease) in R&D expenditures” (Grabowski and Vernon, 2000, p. 211).

discussion).

Finally, we remark that the  $R^2$  coefficients are rather low, with the highest value corresponding to the sales growth equations. Including the second and third lags does not increase the  $R^2$  much. In the following robustness analysis, we consider that a one-lag model provides a concise yet meaningful representation of the system's dynamics.

## 5 Robustness analysis

In the following section we explore the robustness of our results in a number of ways. First, we consider a simpler regression specification and investigate whether we obtain similar coefficient estimates when we exclude one of the VAR series (Section 5.1).

We also investigate the robustness of our findings by repeating the analysis at a more disaggregated level. We disaggregate firms according to size (Section 5.2) and sector of activity (Section 5.3), as well as repeating our regressions for individual years (Section 5.4). We also explore potential asymmetries in the growth process between growing and shrinking firms (Section 5.5).

### 5.1 Sensitivity to specification

In Table 3 we observed that the highest contemporaneous correlations between the VAR series were between employment growth and sales growth, and also between employment growth and growth of operating income. This high degree of multicollinearity may lead to excessively sensitive coefficient estimates. To explore this sensitivity, we repeat the analysis excluding either the sales growth or the operating income growth variables, and we hope to obtain similar coefficient estimates to those obtained earlier.

Table 6 presents the regression results when sales growth is excluded, and Table 7 presents the regression results when growth of operating income is excluded. Broadly speaking, we can consider that these results lend support to those obtained earlier. In particular, we observe that growth of employment and sales have roughly similar associations with subsequent R&D growth in the one-lag model in Table 7, whereas the two-lag specification reveals that sales growth has more persistent influence.

### 5.2 Size disaggregation

In order to investigate how size effects play a role in firm growth, we repeat the analysis for 5 size groups where firms have been sorted according to their mean number of employees. Regression results for the size disaggregation are presented in Table 8. These results are very much in line with those obtained at the aggregate level. One observation worth making is that



Table 6: LAD estimation of equation (2) where  $m=3$  and corresponds to the vector (Empl. growth(i,t), R&D growth (i,t), and growth of operating income (i,t))'. Standard errors (and hence  $t$ -statistics) obtained from 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$			$\beta_{t-2}$			$R^2$	obs
	Empl. gr.	R&D gr.	Op. Inc. gr.	Empl. gr.	R&D gr.	Op. Inc. gr.		
Empl. growth	<b>0.1281</b>	<b>0.0283</b>	<b>0.0237</b>				0.0262	33166
$t$ -stat	20.53	8.67	12.72					
R&D growth	<b>0.2930</b>	<b>0.0124</b>	<b>0.0524</b>				0.0399	33166
$t$ -stat	26.95	2.33	16.63					
Op. Inc. growth	<b>0.3040</b>	-0.0042	<b>-0.0989</b>				0.0117	33166
$t$ -stat	18.28	-0.67	-8.77					
Empl. growth	<b>0.0916</b>	<b>0.0264</b>	<b>0.0255</b>	<b>0.0466</b>	<b>0.0251</b>	<b>0.0147</b>	0.0309	28538
$t$ -stat	13.01	7.65	12.71	7.43	8.79	8.85		
R&D growth	<b>0.2519</b>	-0.0061	<b>0.0613</b>	<b>0.0681</b>	0.0065	<b>0.0396</b>	0.0429	28538
$t$ -stat	20.91	-0.75	19.09	6.18	0.92	12.08		
Op. Inc. growth	<b>0.3447</b>	0.0060	<b>-0.1528</b>	<b>0.0529</b>	<b>0.0247</b>	<b>-0.0908</b>	0.0190	28538
$t$ -stat	20.42	0.92	-14.91	3.42	3.42	-11.40		

Table 7: LAD estimation of equation (2) where  $m=3$  and corresponds to the vector (Empl. growth(i,t), Sales growth (i,t), and R&D growth (i,t))'. Standard errors (and hence  $t$ -statistics) obtained from 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$			$\beta_{t-2}$			$R^2$	obs
	Empl. gr.	Sales gr.	R&D gr.	Empl. gr.	Sales gr.	R&D gr.		
Empl. growth	<b>0.0561</b>	<b>0.1524</b>	<b>0.0178</b>				0.0328	33166
$t$ -stat	5.96	16.84	5.49					
Sales growth	<b>0.3218</b>	<b>0.0515</b>	<b>0.0069</b>				0.0814	33166
$t$ -stat	31.30	7.23	2.40					
R&D growth	<b>0.2069</b>	<b>0.2347</b>	<b>-0.0150</b>				0.0424	33166
$t$ -stat	14.47	18.75	-2.31					
Empl. growth	<b>0.0385</b>	<b>0.1250</b>	<b>0.0163</b>	-0.0073	<b>0.0697</b>	<b>0.0176</b>	0.0345	28538
$t$ -stat	4.95	16.06	4.97	-0.97	10.09	6.70		
Sales growth	<b>0.3194</b>	0.0119	<b>0.0134</b>	<b>0.0254</b>	-0.0011	<b>0.0173</b>	0.0769	28538
$t$ -stat	31.61	1.31	3.62	3.50	-0.15	4.65		
R&D growth	<b>0.1994</b>	<b>0.1888</b>	<b>-0.0213</b>	-0.0118	<b>0.1250</b>	-0.0105	0.0414	28538
$t$ -stat	16.19	16.42	-3.01	-1.22	11.89	-1.60		

the autocorrelation profile of R&D growth changes across the size groups, with the largest firms experiencing positive serial correlation in R&D expenditure. The dependence of growth rate autocorrelation upon firm size has been discussed in Coad (2006) and in this particular case it would suggest that the R&D expansion schemes in large firms are much smoother than those in small firms, perhaps because larger firms enjoy a longer-term planning horizon and engage in larger R&D expansion projects than their smaller counterparts.

It is also worth making two other observations. First, it appears that the coefficients on lagged growth of employment and sales on R&D growth are smaller for the largest group of firms. This indicates that the growth of larger firms will *ceteris paribus* lead to relatively smaller investments in R&D, at least for the model with one lag. Second, R&D growth has a slightly more positive association with subsequent profits growth for larger firms, perhaps because larger firms have faster and more effective ways of capitalizing on innovation outlays.

### 5.3 Sectoral disaggregation

Since space is not as scarce in working paper versions, we repeat the analysis for the 20 two-digit manufacturing sectors.<sup>8</sup> This enables us not only to observe inter-sectoral heterogeneity but also provides further evidence in favour of the robustness of the previous findings. The results are presented in the Appendix, in Tables 11, 12, 13 and 14.

We observe some variation concerning the relative importance of employment growth or sales growth for subsequent growth of R&D. In seven cases, sales growth is more strongly associated (i.e., higher coefficient) with subsequent R&D growth, whilst in the other thirteen cases it is employment growth that has the strongest association. In seven of the twenty sectors, growth of profits is positively and significantly associated with subsequent growth of R&D, although the magnitude of these coefficients is often rather small.

### 5.4 Temporal disaggregation

We now repeat the analysis for individual decades in order to observe if our results are sensitive to the period of analysis. The results are presented in Table 9.

It appears that R&D growth has a fairly constant association to subsequent employment growth, although this has been decreasing for sales. These effects are relatively modest in magnitude, however.

Some other results that are not directly related to the question of R&D investment also deserve to be mentioned. First, it is interesting to observe that the sensitivity of the growth of both sales and employment to previous growth of profits has increased over time from the

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<sup>8</sup>For details on the industrial classification system, see [http://www.osha.gov/pls/imis/sic\\_manual.html](http://www.osha.gov/pls/imis/sic_manual.html).

Table 8: LAD estimation of equation (2) across different size groups. Firms sorted into size groups according to their mean size (mean number of employees). Group 1 contains the smallest firms. Standard errors (and hence  $t$ -statistics) obtained from using 500 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
Empl. growth	Sales growth	R&D growth	Op. Inc. growth			
Size group 1						
Empl gr	0.0410	<b>0.1186</b>	<b>0.0186</b>	0.0012	0.0218	4884
$t$ -stat	1.74	7.06	2.75	0.34		
Sales gr	<b>0.3182</b>	0.0007	-0.0017	-0.0023	0.0545	4884
$t$ -stat	11.98	0.03	-0.28	-0.52		
R&D gr	<b>0.2118</b>	<b>0.1978</b>	-0.0375	<b>0.0221</b>	0.0335	4884
$t$ -stat	5.08	5.45	-1.93	3.50		
Op Inc gr	<b>0.1949</b>	<b>0.2694</b>	<b>-0.0418</b>	<b>-0.2393</b>	0.0199	4884
$t$ -stat	3.12	3.43	-2.04	-7.97		
Size group 2						
Empl gr	0.0267	<b>0.1759</b>	<b>0.0174</b>	<b>0.0085</b>	0.0317	6134
$t$ -stat	1.77	8.25	2.72	2.08		
Sales gr	<b>0.2920</b>	<b>0.0792</b>	0.0028	-0.0025	0.0836	6134
$t$ -stat	14.30	4.50	0.44	-0.62		
R&D gr	<b>0.1986</b>	<b>0.2468</b>	-0.0279	0.0107	0.0461	6134
$t$ -stat	8.82	8.77	-1.70	1.79		
Op Inc gr	<b>0.1347</b>	<b>0.3448</b>	<b>-0.0529</b>	<b>-0.1796</b>	0.0163	6134
$t$ -stat	3.47	6.44	-3.18	-6.26		
Size group 3						
Empl gr	<b>0.0454</b>	<b>0.1470</b>	<b>0.0216</b>	0.0064	0.0353	6860
$t$ -stat	2.08	7.03	3.23	1.42		
Sales gr	<b>0.3430</b>	<b>0.0452</b>	<b>0.0163</b>	0.0075	0.1002	6860
$t$ -stat	18.62	3.19	2.49	1.91		
R&D gr	<b>0.2008</b>	<b>0.2360</b>	<b>-0.0382</b>	<b>0.0348</b>	0.0501	6860
$t$ -stat	8.21	7.52	-2.33	4.19		
Op Inc gr	<b>0.1926</b>	<b>0.2648</b>	-0.0039	<b>-0.1351</b>	0.0170	6860
$t$ -stat	5.23	6.48	-0.30	-6.04		
Size group 4						
Empl gr	<b>0.0372</b>	<b>0.1447</b>	<b>0.0178</b>	<b>0.0125</b>	0.0299	7388
$t$ -stat	2.60	6.49	2.42	2.61		
Sales gr	<b>0.3706</b>	0.0067	<b>0.0193</b>	<b>0.0194</b>	0.0979	7388
$t$ -stat	17.53	0.38	3.12	3.79		
R&D gr	<b>0.2616</b>	<b>0.0572</b>	0.0251	<b>0.0558</b>	0.0433	7388
$t$ -stat	11.40	2.23	1.84	7.08		
Op Inc gr	<b>0.2289</b>	<b>0.2137</b>	-0.0158	<b>-0.0794</b>	0.0181	7388
$t$ -stat	5.98	4.59	-1.25	-3.26		
Size group 5						
Empl gr	<b>0.0812</b>	<b>0.0942</b>	<b>0.0133</b>	0.0072	0.0294	7900
$t$ -stat	6.01	7.68	2.30	1.80		
Sales gr	<b>0.2729</b>	<b>0.0316</b>	-0.0035	0.0101	0.0523	7900
$t$ -stat	15.81	2.13	-0.50	1.85		
R&D gr	<b>0.1473</b>	<b>0.1143</b>	<b>0.0477</b>	<b>0.0349</b>	0.0408	7900
$t$ -stat	6.29	4.95	3.15	3.78		
Op Inc gr	<b>0.1556</b>	<b>0.1228</b>	-0.0264	<b>-0.0587</b>	0.0076	7900
$t$ -stat	4.11	2.70	-1.28	-2.40		

Table 9: LAD estimation of equation (2) for different decades. Standard errors (and hence  $t$ -statistics) obtained from using 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		
<b>1973-79</b>						
Empl. growth	<b>0.0645</b>	<b>0.0956</b>	<b>0.0214</b>	-0.0057	0.0158	6934
t-stat	3.51	5.01	3.56	-1.01		
Sales growth	<b>0.3753</b>	-0.0324	<b>0.0140</b>	-0.0009	0.0811	6934
t-stat	19.77	-1.81	2.32	-0.17		
R&D growth	<b>0.2251</b>	<b>0.1202</b>	0.0058	<b>0.0396</b>	0.0322	6934
t-stat	9.43	4.56	0.52	4.79		
Op. Inc. growth	<b>0.2698</b>	<b>0.1617</b>	-0.0183	<b>-0.1559</b>	0.0167	6934
t-stat	6.55	2.89	-1.37	-5.41		
<b>1980-89</b>						
Empl. growth	<b>0.0656</b>	<b>0.1396</b>	<b>0.0198</b>	0.0016	0.0361	9977
t-stat	4.15	8.30	3.17	0.50		
Sales growth	<b>0.3542</b>	<b>0.0416</b>	0.0024	0.0036	0.0885	9977
t-stat	19.26	3.28	0.42	0.88		
R&D growth	<b>0.2251</b>	<b>0.1865</b>	0.0029	<b>0.0221</b>	0.0456	9977
t-stat	10.24	7.77	0.26	4.63		
Op. Inc. growth	<b>0.2179</b>	<b>0.2701</b>	<b>-0.0331</b>	<b>-0.1662</b>	0.0168	9977
t-stat	5.63	6.16	-2.22	-7.24		
<b>1990-99</b>						
Empl. growth	<b>0.0493</b>	<b>0.1924</b>	<b>0.0219</b>	<b>0.0106</b>	0.0492	11310
t-stat	3.82	12.98	3.80	3.55		
Sales growth	<b>0.2919</b>	<b>0.0967</b>	0.0073	0.0040	0.0917	11310
t-stat	16.50	5.88	1.33	1.23		
R&D growth	<b>0.2220</b>	<b>0.2307</b>	<b>-0.0304</b>	<b>0.0292</b>	0.0549	11310
t-stat	10.91	8.98	-2.04	4.70		
Op. Inc. growth	<b>0.1477</b>	<b>0.3025</b>	-0.0207	<b>-0.1195</b>	0.0160	11310
t-stat	4.47	6.66	-1.68	-5.70		
<b>2000-04</b>						
Empl. growth	<b>0.0571</b>	<b>0.0558</b>	0.0081	<b>0.0200</b>	0.0206	4945
t-stat	2.48	2.64	1.13	4.67		
Sales growth	<b>0.2456</b>	0.0254	0.0059	<b>0.0127</b>	0.0523	4945
t-stat	10.98	1.35	0.83	2.95		
R&D growth	<b>0.1798</b>	<b>0.1261</b>	-0.0195	<b>0.0294</b>	0.0368	4945
t-stat	5.13	4.48	-1.35	4.51		
Op. Inc. growth	<b>0.1283</b>	<b>0.2918</b>	<b>-0.0570</b>	<b>-0.1490</b>	0.0121	4945
t-stat	2.71	4.85	-2.36	-5.19		

1970s to the 1990s. If we accept the proposition that financial markets have not deteriorated over time, then this provides some further evidence that the standard ‘financial constraints’ interpretation of the sensitivity of firm growth to financial performance is not very helpful (for a discussion see Kaplan and Zingales (1997) and Coad (2007b)). Second, it appears that employment growth is steadily becoming less strongly associated with subsequent growth of sales and profits.

## 5.5 Asymmetric effects for growing or shrinking firms

We noted in the introduction that R&D programmes cannot be started and stopped at will but are the most effective when they can proceed without interruptions. As a result, whilst growing firms can increase their R&D expenditure relatively easily, firms in decline must think more carefully about closing down R&D programmes because of the specific costs that this would entail. It thus makes sense to suppose that the dynamics of R&D investment are not symmetric for growing and shrinking firms. In this section, we apply quantile regression techniques to investigate these asymmetric effects of R&D growth across the (conditional) R&D growth distribution. (For an introduction to quantile regression, see Koenker and Hallock (2001).)

Figure 3 shows the quantile autoregression plot for R&D expenditure. This plot shows that, for firms who have a R&D growth rate that is close to the median quantiles (i.e., those firms with R&D growth close to zero) that these firms do not experience much autocorrelation at all. The story is different for those firms experiencing fast growth or decline of R&D. In the cases where R&D grows the most rapidly (positive or negative growth), the growth of R&D in the next period is subject to powerful forces of negative correlation, such that these firms are quite unlikely to repeat their R&D growth performance in the following period.

Figure 4 shows the quantile regression plots for the associations of growth of both sales and employment on subsequent R&D growth. At the upper quantiles of these plots (corresponding to the fastest-growth growth firms), we observe that the growth of sales and employment is relatively strongly associated with subsequent R&D growth. For declining firms, however (towards the lowest quantiles, at the left of the  $x$ -axis), we observe that the coefficient decreases considerably. This suggests that declining firms do not decrease R&D expenditure with the same ease that growing firms can increase R&D expenditure.

## 6 Discussion

To help us to digest the results we have just seen, it might be useful to consider an alternative representation of the previous results. In this spirit, Figure 5 provides a stylized illustration of the processes of firm growth and R&D expenditure. This diagram is an (admittedly subjective)

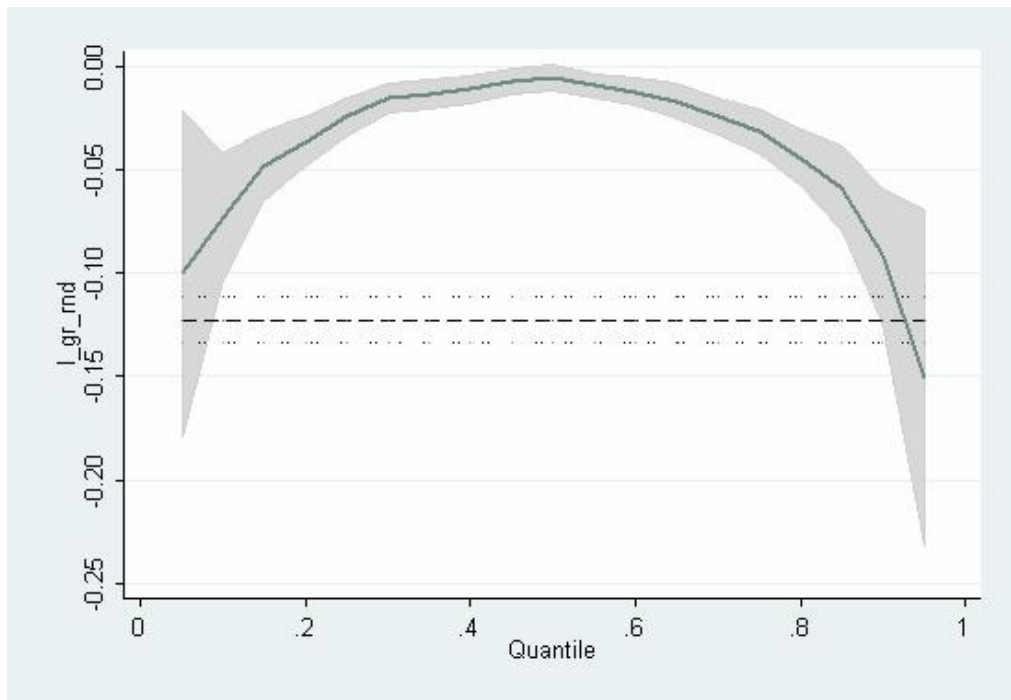


Figure 3: Quantile autoregression plot for R&D expenditure, obtained from estimation of equation (2). Variation in the coefficient on lagged growth of R&D expenditure (at time  $t-1$ ) over the conditional quantiles of the distribution of growth of R&D expenditure at time  $t$ . Conditional quantiles (on the  $x$ -axis) range from 0 (for the extreme negative-R&D-growth firms) to 1 (for the fastest-R&D-growth firms). Confidence intervals (non-bootstrapped) extend to 95% confidence intervals in either direction. Horizontal lines represent OLS estimates with 95% confidence intervals. Graphs made using the ‘grqreg’ Stata module (Azevedo (2004)).

interpretation of the results emerging from the previous analysis.

Figure 5 suggests that it is the growth of employment and sales that leads to growth of R&D expenditure. Growth of profits, on the other hand, is not as strongly associated with subsequent growth of R&D or, for that matter, other dimensions of firm growth. This goes against the ‘Schumpeterian’ intuition which argues in favour of innovation systems based on large profitable oligopolies that reinvest their profits into R&D. Other researchers have arrived at similar conclusions: “Since Schumpeter, economists have argued that internal finance should be an important determinant of R&D expenditures ...almost without exception, previous empirical studies have not found evidence of such a relationship” (Himmelberg and Petersen, 1994, p. 38). In contrast, one may argue that it is the anticipation of profits is the driver of R&D. We are unable to comment on this hypothesis, because our data and analysis does not take into account teleological factors. However, our results cast some doubt upon the idea that, once firms have profits, they reinvest these in R&D. Instead, it seems that sales growth and employment growth are much more strongly associated with subsequent R&D growth.

We are also unable to detect any feedback of R&D expenditure growth on growth of em-

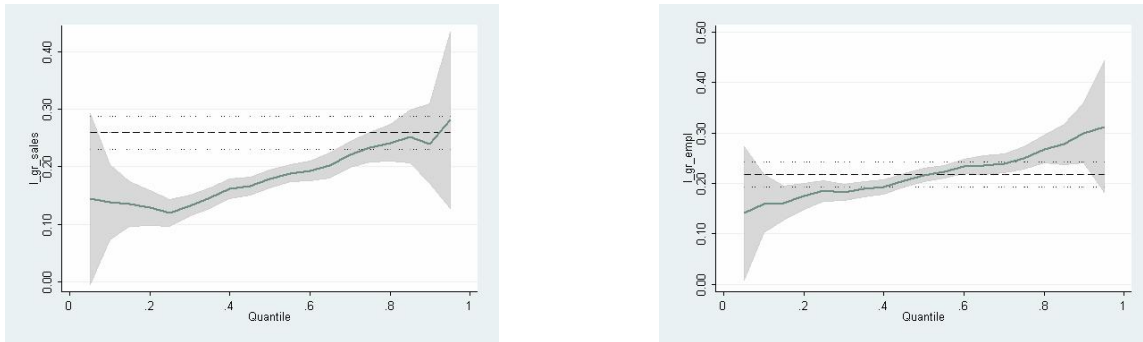


Figure 4: Quantile regression plot of the responsiveness of R&D expenditure  $t$  to either sales growth ( $t-1$ ; see left) or employment growth ( $t-1$ ; see right), obtained from estimation of equation (2). Variation in the coefficient on lagged growth of R&D expenditure (at time  $t-1$ ) over the conditional quantiles of the distribution of sales (left) or employment (right) growth at time  $t$ . Conditional quantiles (on the  $x$ -axis) range from 0 (for the extreme negative-growth firms) to 1 (for the fastest-growing firms). Confidence intervals (non-bootstrapped) extend to 95% confidence intervals in either direction. Horizontal lines represent OLS estimates with 95% confidence intervals. Graphs made using the ‘grqreg’ Stata module (Azevedo (2004)).

ployment, sales, or profits. This result is not particularly surprising, however. First, we know that the returns to innovation are very heterogeneous, such that R&D leads to successful innovation in a minority of cases only (Coad and Rao (2006a), Coad and Rao (2006b), Grabowski et al. (2002)). Second, there may well be a considerable time-lag (over 10 years in some cases) between investments in innovation and the associated increases in performance. Indeed, successful R&D may even entail further short-term costs (e.g., costs related to product development) before yielding long-term benefits. As a result, our inability to detect any major association between innovation and subsequent growth performance should by no means be taken to mean that investment in R&D expenditure is a futile exercise.

## 7 Conclusion

Our analysis has suggested, in a rather robust fashion, that past growth of employment and sales are followed by growth of R&D expenditure. Whilst both of these firm growth variables have a comparable influence on R&D growth one year later, growth of sales has a more persistent influence on R&D growth that is detectable even at the third lag. However, given that R&D expenditure is ‘sticky’, it’s difficult to reduce R&D expenditure after a negative growth shock. As a result, R&D expenditure is less sensitive to decreases in sales or employment than it is for increases in these. To summarize, we could suggest that firms behave *as if* they follow two behavioural rules for investment in R&D. First – if employment or sales has grown recently, increase R&D expenditure (less than proportionally). Second – if employment or sales has decreased, try to keep R&D roughly constant.



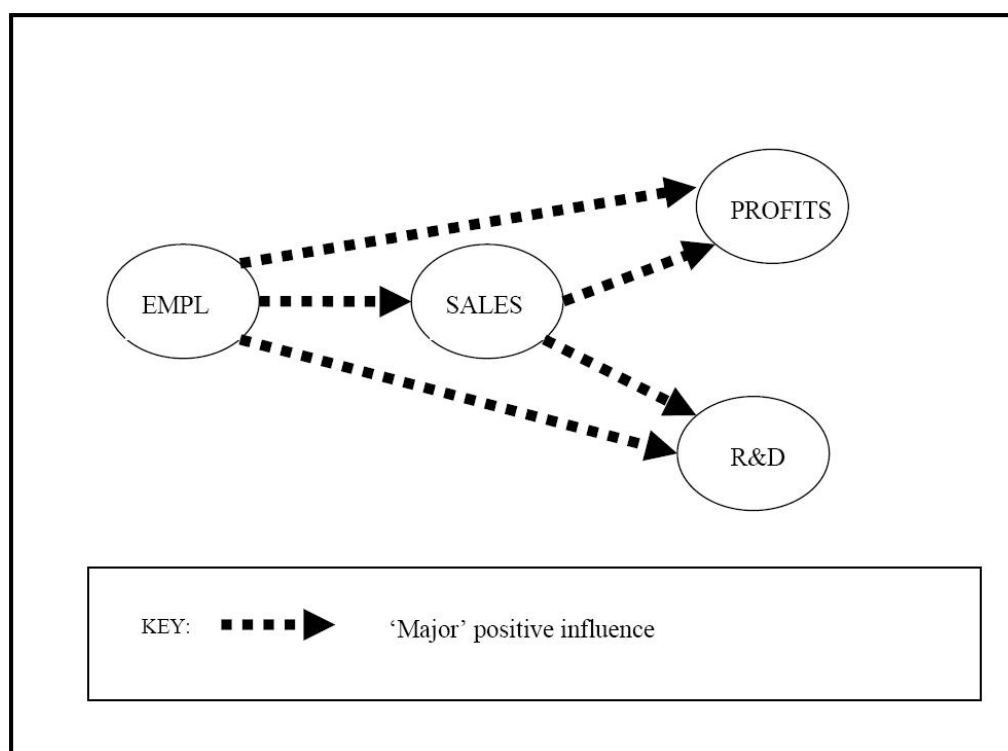


Figure 5: A stylized depiction of the time profile of the processes of firm growth and R&D investment. EMPL = employment growth, SALES = sales growth, R&D = growth of R&D expenditure, PROFITS = growth of operating income.

But is this really an accurate model of private R&D investment? Do firms really just follow rules of thumb instead of optimizing future return on investment? If we ask these firms (or senior officers concerned with R&D decisions), they may well be reluctant to refer to 'broad rules of thumb' which would make them appear relatively unsophisticated. Furthermore, they may not want to reveal how they make these strategic R&D decisions because they may not want competitors to know their operating procedures. Therefore, we anticipate that using interviews and questionnaires to test the validity of this simple behavioural model of R&D investment might not be very fruitful.

Contrary to 'Schumpeterian' intuitions, we did not detect any strong association of growth of profits with subsequent investment in R&D. (However, we are unable to test the hypothesis that it is the *expectation* of profits that drives R&D investment.) If anything, our results would lean in favour of the speculation that a government initiative to stimulate private R&D would do better to remove the obstacles to firm growth (because growing firms invest in R&D) rather than taking a favourable stance towards market imperfections in the hope that profitable firms will reinvest their high profits into R&D. For example, it might be possible to stimulate firms to invest in R&D by encouraging them to grow in overseas markets, if domestic markets offer limited opportunities for growth.



## Appendix

Table 10: LAD estimation of equation (2). Standard errors (and hence  $t$ -statistics) obtained using 1000 bootstrap replications

$w_t$	$\beta_{t-1}$				$\beta_{t-2}$				$\beta_{t-3}$				$R^2$	obs
	Empl. gr.	Sales gr.	R&D gr.	Op. Inc. gr.	Empl. gr.	Sales gr.	R&D gr.	Op. Inc. gr.	Empl. gr.	Sales gr.	R&D gr.	Op. Inc. gr.		
Empl gr	<b>0.0590</b> 6.45	<b>0.1382</b> 14.64	<b>0.0188</b> 6.35	<b>0.0067</b> 3.71									0.0330	33166
Sales gr	<b>0.3221</b> 31.31	<b>0.0437</b> 5.75	<b>0.0073</b> 2.57	<b>0.0045</b> 2.00									0.0815	33166
R&D gr	<b>0.2163</b> 17.92	<b>0.1792</b> 12.52	-0.0054 -0.71	<b>0.0276</b> 7.56									0.0440	33166
Op Inc gr	<b>0.1905</b> 10.65	<b>0.2624</b> 11.75	<b>-0.0258</b> -3.74	<b>-0.1468</b> -12.87									0.0151	33166
Empl gr	<b>0.0403</b> 4.82	<b>0.1017</b> 10.78	<b>0.0166</b> 5.02	<b>0.0122</b> 5.16	-0.0029 -0.39	<b>0.0633</b> 9.02	<b>0.0181</b> 6.82	<b>0.0053</b> 2.59					0.0353	28538
Sales gr	<b>0.3200</b> 33.37	0.0060 0.55	<b>0.0140</b> 3.85	0.0038 1.56	<b>0.0259</b> 3.43	0.0037 0.40	<b>0.0169</b> 4.50	-0.0035 -1.35					0.0770	28538
R&D gr	<b>0.2122</b> 15.72	<b>0.0935</b> 6.25	<b>-0.0175</b> -2.18	<b>0.0460</b> 11.66	0.0047 0.48	<b>0.0932</b> 9.05	-0.0040 -0.60	<b>0.0229</b> 6.39					0.0451	28538
Op Inc gr	<b>0.1893</b> 9.16	<b>0.3773</b> 12.49	<b>-0.0195</b> -2.49	<b>-0.2272</b> -15.06	<b>-0.0405</b> -2.39	<b>0.0771</b> 3.76	<b>0.0157</b> 2.02	<b>-0.1164</b> -9.80					0.0240	28538
Empl gr	<b>0.0325</b> 3.72	<b>0.0877</b> 8.44	<b>0.0165</b> 4.90	<b>0.0179</b> 6.26	0.0010 0.13	0.0183 1.95	<b>0.0165</b> 5.13	<b>0.0161</b> 5.84	<b>0.0162</b> 2.33	<b>0.0378</b> 4.41	<b>0.0171</b> 4.72	<b>0.0091</b> 3.50	0.0374	24731
Sales gr	<b>0.3106</b> 31.20	-0.0063 -0.58	<b>0.0103</b> 2.83	<b>0.0078</b> 3.24	<b>0.0324</b> 4.17	<b>-0.0300</b> -2.89	<b>0.0137</b> 3.76	0.0041 0.00	<b>0.0400</b> 5.26	0.0117 1.35	<b>0.0102</b> 3.11	0.0013 0.50	0.0745	24731
R&D gr	<b>0.2036</b> 14.05	<b>0.0636</b> 4.01	<b>-0.0167</b> -2.11	<b>0.0557</b> 12.02	0.0102 0.87	<b>0.0427</b> 3.00	-0.0076 -1.03	<b>0.0387</b> 9.23	0.0165 1.49	<b>0.0511</b> 3.94	0.0063 1.02	<b>0.0238</b> 4.97	0.0460	24731
Op Inc gr	<b>0.1825</b> 8.44	<b>0.3697</b> 11.58	-0.0174 -1.80	<b>-0.2374</b> -14.21	-0.0326 -1.58	<b>0.1034</b> 3.80	0.0055 0.70	<b>-0.1577</b> -12.82	<b>0.0535</b> 3.31	<b>0.0643</b> 2.77	-0.0044 -0.57	<b>-0.0896</b> -7.82	0.0262	24731

Table 11: LAD estimation of equation (2) across different industries. Standard errors (and hence  $t$ -statistics) obtained from using 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		
SIC 20: Food						
Empl gr	0.0244	<b>0.0941</b>	-0.0172	<b>0.0281</b>	0.0217	1079
t-stat	1.10	2.73	-1.12	3.11		
Sales gr	<b>0.1081</b>	0.0581	0.0002	-0.0230	0.0219	1079
t-stat	2.61	1.40	0.02	-1.86		
R&D gr	0.0507	<b>0.1611</b>	<b>-0.0752</b>	0.0266	0.0203	1079
t-stat	1.10	2.48	-2.97	1.28		
Op Inc gr	0.0844	<b>0.3401</b>	-0.0812	<b>-0.2134</b>	0.0260	1079
t-stat	1.47	3.77	-1.80	-3.56		
SIC 21: Tobacco						
Empl gr	0.1159	0.0917	-0.0527	0.0154	0.0186	110
t-stat	1.39	0.66	-0.47	0.38		
Sales gr	0.0835	0.1216	-0.0884	0.0047	0.0402	110
t-stat	1.08	1.15	-0.92	0.14		
R&D gr	-0.1008	0.0649	0.1010	<b>0.1750</b>	0.1216	110
t-stat	-1.07	0.42	0.83	3.00		
Op Inc gr	-0.0264	0.1104	-0.3750	0.0404	0.0190	110
t-stat	-0.23	0.49	-1.56	0.15		
SIC 22: Textile Mill Products						
Empl gr	0.0550	0.0255	<b>0.0499</b>	0.0254	0.0320	412
t-stat	0.71	0.32	2.26	1.20		
Sales gr	<b>0.5152</b>	-0.1462	0.0357	-0.0003	0.0954	412
t-stat	5.75	-1.55	1.61	-0.01		
R&D gr	0.1964	0.2005	0.0518	0.0002	0.0345	412
t-stat	1.62	1.53	0.83	0.01		
Op Inc gr	0.3455	0.2524	0.0474	<b>-0.3678</b>	0.0465	412
t-stat	1.42	1.12	0.56	-3.34		
SIC 23: Apparel and Fabric products						
Empl gr	-0.0658	0.2023	-0.0182	0.0137	0.0170	134
t-stat	-0.46	1.15	-0.59	0.34		
Sales gr	0.2040	0.1460	-0.0369	0.0605	0.0850	134
t-stat	1.32	0.83	-0.94	1.63		
R&D gr	0.3261	0.3050	<b>-0.2562</b>	-0.0315	0.0306	134
t-stat	1.24	0.88	-0.85	-0.36		
Op Inc gr	0.4218	-0.1545	-0.1090	0.1450	0.0465	134
t-stat	1.64	-0.43	-1.50	0.68		
SIC 24: Lumber and Wood products, except furniture						
Empl gr	<b>0.2562</b>	0.0640	-0.0001	-0.0039	0.0319	202
t-stat	2.53	0.89	-0.00	-0.14		
Sales gr	<b>0.5094</b>	-0.0076	-0.0025	-0.0086	0.0931	202
t-stat	3.86	-0.09	-0.05	-0.32		
R&D gr	0.1721	0.1141	-0.0859	0.0175	0.0166	202
t-stat	1.04	1.06	-0.78	0.33		
Op Inc gr	0.4107	0.0090	-0.0228	-0.0831	0.0214	202
t-stat	1.85	0.04	-0.18	-0.50		

Table 12: LAD estimation of equation (2) across different industries. Standard errors (and hence  $t$ -statistics) obtained from using 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		
SIC 25: Furniture and Fixtures						
Empl gr	<b>0.0895</b>	0.0296	<b>0.0413</b>	-0.0049	0.0232	521
t-stat	2.00	0.51	2.08	-0.45		
Sales gr	<b>0.2643</b>	0.0262	0.0358	-0.0097	0.0467	521
t-stat	3.85	0.40	1.24	-0.46		
R&D gr	0.1611	-0.1241	-0.0252	<b>0.1219</b>	0.0193	521
t-stat	1.39	-0.90	-0.76	2.66		
Op Inc gr	<b>0.2649</b>	0.0186	-0.0168	-0.1339	0.0230	521
t-stat	2.33	0.08	-0.30	-1.62		
SIC 26: Paper and Allied Products						
Empl gr	0.0145	0.0538	0.0180	0.0190	0.0121	845
t-stat	0.36	0.97	1.37	1.48		
Sales gr	<b>0.2607</b>	-0.0275	0.0145	-0.0094	0.0420	845
t-stat	5.13	-0.53	1.14	-0.64		
R&D gr	0.1382	0.0992	<b>0.0891</b>	0.0186	0.0219	845
t-stat	1.52	0.93	1.96	0.45		
Op Inc gr	-0.0242	0.2585	-0.0023	<b>-0.1624</b>	0.0138	845
t-stat	-0.20	1.69	-0.04	-2.33		
SIC 27: Printing and Publishing						
Empl gr	-0.0702	0.1023	0.0379	0.0087	0.0114	248
t-stat	-0.82	1.09	1.51	0.41		
Sales gr	0.2417	0.1573	-0.0094	-0.0186	0.0666	248
t-stat	2.67	1.30	-0.32	-0.73		
R&D gr	0.3073	-0.2365	0.0375	0.0187	0.0149	248
t-stat	1.39	-1.03	0.42	0.53		
Op Inc gr	0.2352	0.3560	0.0288	-0.3144	0.0308	248
t-stat	0.83	0.94	0.39	-1.87		
SIC 28: Chemicals						
Empl gr	<b>0.0606</b>	<b>0.1404</b>	0.0041	0.0086	0.0400	4467
t-stat	3.04	7.50	0.48	1.80		
Sales gr	<b>0.2414</b>	<b>0.0927</b>	0.0180	<b>0.0192</b>	0.0757	4467
t-stat	7.35	3.54	1.78	2.69		
R&D gr	<b>0.1685</b>	<b>0.1651</b>	0.0138	<b>0.0502</b>	0.0453	4467
t-stat	4.55	4.83	0.62	4.84		
Op Inc gr	<b>0.0947</b>	<b>0.2413</b>	0.0383	-0.0517	0.0146	4467
t-stat	2.16	4.21	1.59	-1.51		
SIC 29: Petroleum refining						
Empl gr	0.0405	<b>0.1646</b>	0.0143	0.0075	0.0794	627
t-stat	0.61	4.92	0.62	0.36		
Sales gr	0.0877	<b>0.1755</b>	0.0429	0.0124	0.0447	627
t-stat	1.01	3.21	1.40	0.43		
R&D gr	<b>0.3611</b>	<b>0.1492</b>	0.0144	0.0730	0.0553	627
t-stat	3.23	2.14	0.23	1.61		
Op Inc gr	0.0362	<b>0.1830</b>	0.0028	-0.0359	0.0080	627
t-stat	0.42	2.02	0.05	-0.55		

Table 13: LAD estimation of equation (2) across different industries. Standard errors (and hence  $t$ -statistics) obtained from using 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		
SIC 30: Rubber and miscellaneous plastic products						
Empl gr	-0.0026	0.0636	0.0120	0.0086	0.0062	1115
t-stat	-0.07	1.22	0.62	0.68		
Sales gr	<b>0.3514</b>	-0.0507	0.0062	0.0012	0.0938	1115
t-stat	11.00	-1.12	0.60	0.08		
R&D gr	<b>0.2356</b>	0.0640	0.0038	<b>0.0467</b>	0.0272	1115
t-stat	4.00	0.87	0.10	2.13		
Op Inc gr	<b>0.2285</b>	0.0975	-0.0255	-0.1009	0.0155	1115
t-stat	4.32	0.85	-0.74	-1.45		
SIC 31: Leather and leather products						
Empl gr	0.1091	0.0624	0.0355	0.0055	0.0106	89
t-stat	0.51	0.34	0.28	0.14		
Sales gr	<b>0.3988</b>	-0.0487	0.0475	0.0150	0.0781	89
t-stat	2.04	-0.23	0.47	0.36		
R&D gr	0.1325	0.1939	0.0132	-0.0271	0.0324	89
t-stat	0.60	0.78	0.06	-0.41		
Op Inc gr	0.3719	0.0180	-0.0119	-0.1866	0.0576	89
t-stat	0.91	0.04	-0.05	-1.81		
SIC 32: Stone, Clay, Glass and Concrete products						
Empl gr	-0.0498	<b>0.2188</b>	0.0044	-0.0032	0.0253	519
t-stat	-0.77	2.50	0.34	-0.21		
Sales gr	<b>0.2842</b>	-0.0301	0.0066	<b>0.0332</b>	0.0687	519
t-stat	4.38	-0.62	0.54	2.28		
R&D gr	0.1257	0.2488	-0.1237	0.0017	0.0199	519
t-stat	1.10	1.82	-1.57	0.05		
Op Inc gr	0.2792	0.0243	-0.0154	0.0071	0.0096	519
t-stat	1.61	0.14	-0.36	0.11		
SIC 33: Primary Metal Industries						
Empl gr	0.0337	<b>0.0810</b>	-0.0109	-0.0045	0.0105	1031
t-stat	0.99	2.41	-0.70	-0.86		
Sales gr	<b>0.3836</b>	0.0320	<b>-0.0387</b>	-0.0117	0.0639	1031
t-stat	7.07	0.59	-3.46	-1.29		
R&D gr	<b>0.2348</b>	0.1319	0.0076	0.0186	0.0280	1031
t-stat	5.36	1.93	0.34	0.89		
Op Inc gr	0.1090	<b>0.4863</b>	<b>-0.1221</b>	<b>-0.1570</b>	0.0161	1031
t-stat	0.81	2.72	-2.40	-2.27		
SIC 34: Fabricated Metal Products						
Empl gr	0.0214	<b>0.0561</b>	<b>0.0173</b>	0.0071	0.0110	1635
t-stat	0.73	2.02	2.18	1.00		
Sales gr	<b>0.3454</b>	-0.0413	0.0151	0.0154	0.0765	1635
t-stat	7.46	-0.91	1.11	1.43		
R&D gr	<b>0.2871</b>	-0.0626	-0.0162	0.0451	0.0201	1635
t-stat	5.45	-1.03	-0.69	1.95		
Op Inc gr	<b>0.1432</b>	<b>0.2300</b>	-0.0279	-0.0816	0.0105	1635
t-stat	2.15	2.55	-1.05	-1.76		

Table 14: LAD estimation of equation (2) across different industries. Standard errors (and hence  $t$ -statistics) obtained from using 1000 bootstrap replications.

$w_t$	$\beta_{t-1}$				$R^2$	obs
	Empl. growth	Sales growth	R&D growth	Op. Inc. growth		
SIC 35: Industry and Commercial Machinery and Computer equipment						
Empl gr	<b>0.1036</b>	<b>0.1553</b>	<b>0.0267</b>	<b>0.0105</b>	0.0526	6003
t-stat	4.93	7.70	3.03	2.47		
Sales gr	<b>0.3941</b>	<b>0.0400</b>	0.0042	0.0053	0.1155	6003
t-stat	16.37	2.14	0.59	1.48		
R&D gr	<b>0.2831</b>	<b>0.2348</b>	<b>-0.0389</b>	<b>0.0201</b>	0.0798	6003
t-stat	10.30	7.56	-2.16	3.32		
Op Inc gr	<b>0.2644</b>	<b>0.2698</b>	<b>-0.0538</b>	<b>-0.1651</b>	0.0180	6003
t-stat	5.58	5.14	-3.07	-6.18		
SIC 36: Electronic and other Electrical equipment						
Empl gr	<b>0.0645</b>	<b>0.1508</b>	<b>0.0216</b>	0.0003	0.0356	6170
t-stat	3.27	6.84	2.39	0.06		
Sales gr	<b>0.3477</b>	0.0186	0.0121	-0.0012	0.0799	6170
t-stat	15.01	1.04	1.47	-0.27		
R&D gr	<b>0.1463</b>	<b>0.2261</b>	0.0135	<b>0.0213</b>	0.0466	6170
t-stat	5.57	7.96	0.84	4.60		
Op Inc gr	<b>0.2664</b>	<b>0.2493</b>	<b>-0.0448</b>	<b>-0.1873</b>	0.0179	6170
t-stat	5.84	4.02	-2.45	-5.50		
SIC 37: Transportation equipment						
Empl gr	0.0324	0.0631	0.0168	0.0080	0.0117	2164
t-stat	0.95	1.90	1.74	0.97		
Sales gr	<b>0.3760</b>	-0.0351	-0.0111	0.0104	0.0725	2164
t-stat	9.77	-1.09	-1.11	1.09		
R&D gr	<b>0.1841</b>	0.0770	-0.0291	0.0212	0.0182	2164
t-stat	3.83	1.43	-1.08	1.21		
Op Inc gr	<b>0.2057</b>	0.1024	-0.0369	<b>-0.0827</b>	0.0082	2164
t-stat	3.26	1.24	-0.83	-2.08		
SIC 38: Instruments						
Empl gr	0.0273	<b>0.1648</b>	<b>0.0140</b>	0.0065	0.0322	5158
t-stat	1.12	5.85	2.14	1.31		
Sales gr	<b>0.3176</b>	0.0477	0.0116	0.0041	0.0820	5158
t-stat	14.74	1.88	1.38	0.67		
R&D gr	<b>0.2486</b>	<b>0.1171</b>	-0.0310	<b>0.0361</b>	0.0418	5158
t-stat	7.10	3.17	-1.33	6.23		
Op Inc gr	<b>0.1752</b>	<b>0.3240</b>	-0.0335	<b>-0.1846</b>	0.0188	5158
t-stat	3.62	5.17	-1.79	-6.55		
SIC 39: Miscellaneous						
Empl gr	<b>-0.1106</b>	<b>0.2044</b>	0.0208	0.0014	0.0281	637
t-stat	-2.79	4.09	0.68	0.10		
Sales gr	0.0930	<b>0.1284</b>	0.0094	-0.0001	0.0372	637
t-stat	1.81	2.21	0.63	-0.00		
R&D gr	0.1217	<b>0.2590</b>	-0.0208	0.0384	0.0421	637
t-stat	1.74	2.46	-0.49	1.72		
Op Inc gr	-0.2189	<b>0.5296</b>	0.0354	<b>-0.2811</b>	0.0290	637
t-stat	-1.84	3.20	1.23	-3.39		

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