



Firm growth and R&D: Evidence from the Portuguese manufacturing industry

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Abstract This work studies the effects of R&D activities and investment, both physical and R&D, on the growth of firms by considering a dynamic firm growth model with serial correlation. The main hypotheses maintain that firms with a strong commitment to R&D have a higher growth rate, and investment has a positive effect on firm growth. We investigate such relations with reference to an unbalanced panel data set of Portuguese manufacturing firms over the period of 1990 to 2001. We find that a systematic tendency for smaller firms to grow more quickly is the main reason why firm growth is not entirely stochastic.

Keywords Firm growth · R&D · GMM system estimator

JEL classification L11 · L13 · C23

1 Introduction

Innovation has been identified as an important driver of economic growth (Schumpeter 1934; Nelson and Winter 1982) and one of the major drivers in defining differences in firm performance and the evolution of industrial structure (Nelson and Winter 1982; Dosi 1982; Dosi et al. 1995, 1997).

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The influence of innovation on firm growth has been of great interest to academics (e.g. Mansfield, 1962; Hall 1987; Audretsch 1995; Geroski et al. 1997) and policy makers. Firm heterogeneity such as R&D is quite persistent over a number of years and might result in a substantial difference to the performance of the firm (Cefis and Orsenigo 2001).

In recent years, the influence of innovation in the explanation of firm growth has grown in relevance. As a result, since 2000 the number of empirical studies concerning the effect of R&D on firm growth has been increasing. For instance, Coad (2009) and Audretsch and Coad (2014) works strengthen the role played by innovation as a determinant of firm growth. Taking into account different types of models, estimation methods, measures of corporate performance and innovation activity, some researchers such as Del Monte and Papagni (2003), Yasuda (2005) and Coad and Rao (2008, 2010, 2011) examined the relationship between innovation and firm performance.

Based on the dynamic firm growth model, the purpose of this research is to analyse the relationship between firm growth rate measured by the number of employees and variables other than firm size that represent firm strategy expressed as R&D activities and investment (physical and R&D), which could have some influence on firm growth.

This research makes significant contributions to the empirical literature on the dynamics of firm growth. To our knowledge, no previous study has considered both a dynamic firm growth model with serial correlation in the error term and a GMM-system estimator to analyse the effect of R&D and investment on firm growth. It is also important to emphasize that our panel data includes all firm size classes of the manufacturing industry, including the smallest firms which have been neglected until now. Therefore, to analyse the differences between the growth patterns of micro and small firms versus medium and large firms we did a breakdown in terms of firm size. In addition, because the high-tech sector has an above-average growth potential, a sub-sample of high-tech firms is also considered. However, we only deal with manufacture-based industries, because it is in this sector that the R&D activity affects performance of firms.

The organisation of this paper is as follows. Section 2 presents a literature framework. Section 3 presents an empirical growth model that incorporates serial correlation and some systematic factors which may have some influence on firm growth, whilst Section 4 describes our sample and presents some descriptive statistics. Section 5 comments on results and Section 6 draws conclusions.

2 Literature review

The influence of innovation on firm growth has been of great interest to both theoretical and empirical scholars (e.g. see Coad (2009) and Audretsch and Coad (2014)). Schumpeter's framework was the starting point of the interpretation of firm dynamics as an evolutionary process related to the introduction of new innovations to the market. Firm growth is based on a process of creative destruction in which firms have a capacity to introduce new products and processes to the market.

Later, Nelson and Winter (1982) assumed a Schumpeterian framework as an engine of change, and they were interested in studying the different patterns across industries

and firms in terms of their innovation dynamics. These authors developed a formal evolutionary model of the growth of firms. The agents or decision-makers operate under a scheme of bounded rationality, in which relatively simple and occasionally adaptive behavioural rules are used to make decisions. These are not fixed, but can be changed over time, especially so under the influence of feedback from economic performance. Instead of optimising, agents tend to adapt to changes in the market environment using routines which are often specific to the firm. They stem from the skills and experience of the managers and workers in the firm and this “know-how” is passed on to the new members of the firm.

Therefore, successful routines which produced growth in the past are likely to continue to do so in the future. It is true that circumstances change, but successful firms have successful routines for changing previous methods, in order to meet new market environments. Nelson and Winter’s model predicts that firm growth initially increases but then decreases with firm size for mature firms. This prediction is based on simulation results of a model for 20-year-old firms or older.

In the context of empirical literature, the relationship between innovation and firm growth has been examined by different types of models, estimation methods, measures of firm growth and innovation activity (e.g. Geroski et al. 1997; Bottazzi et al. 2001; Del Monte and Papagni 2003). Despite theoretical literature that demonstrates it is the more innovative and efficient firms which will grow more (Nelson and Winter 1982), empirical research has found different results.

Using a panel data on publicly traded firms in the US manufacturing sector, Hall (1987) analysed the relationship between firm size and firm employment growth. In addition, she states empirically that R&D expenditure per employee has a positive influence on the future growth rate. According to this author, firm R&D investment is a more important prediction factor of firm growth rate than the investment in material capital.

Bottazzi et al. (2001) studied the processes of growth of the worldwide top 150 pharmaceutical firms over an 11 year period (1987–1997). They found that R&D investment has no detectable effect on firm performance. The introduction of neither new chemical entities nor patented products affects firm growth performance (sales growth).

Del Monte and Papagni (2003) studied firm growth (sales growth) and innovative activities (R&D/sales) by considering a database of 500 Italian manufacturing firms, with a time series in the range 1989–1997. The authors concluded that firm growth rate is positively correlated with research intensity.

Based on data from nearly 14,000 Japanese manufacturing firms, Yasuda (2005) investigated the relationship between firm growth and firm size measured by the number of employees, firm age and firm behaviour, such as R&D activity and subcontracting. This author found that firm size and age have a negative effect on firm growth and R&D activities (R&D dummy variable, R&D expenditure per employee and R&D per sales) have a significant positive effect on firm growth, which justifies the argument made by Hall (1987).

Yang and Huang (2005) studied the relationship between R&D, firm size (number of employees), and growth rate by considering panel data of Taiwanese electronics firms. These authors state that an increase in R&D induces a higher growth rate and this impact is particularly higher for small firms.

Using a semi-parametric quantile regression, Coad and Rao (2008) investigated the effects of patenting and R&D on the sales growth of US manufacturing firms. Their results indicate that most firms do not grow very fast, and their growth is hardly related to their attempts at innovation. They conclude that the positive impact of innovative activities on firm growth is concentrated among the fastest growing firms. They also found that only among a small proportion of fast growers did innovation activities have a strong effect on sales growth; however, the evidence is limited to incumbent firms. Finally, they suggest that innovation success is the driver of growth, not the fact that firms invest in R&D.

On the other hand, Hölzl (2009) studied the effects of innovation activities on employment growth in a stratified random sample of manufacturing firms in 16 EU countries between 1998 and 2000. He found that innovation in the form of R&D and turnover share of products new to the market is more important for the growth of fast-growing SMEs. Innovation can be seen as a high-risk high-gain strategy: if successful, innovation might provide a growth premium, but it is also very likely that the innovation turns out to be a failure and even a drag on the growth rate of most firms.

Stam and Wennberg (2009) studied the effects of R&D on new product development, interfirm alliances and employment growth during the early life course of start-ups firms. These authors, in order to explore and to explain the effects of R&D on the growth of new firms, use a dataset of firms established in 1994 in The Netherlands. The main finding of this study is that R&D plays several roles during the early life course of high-tech as well as high-growth firms. The effect of initial R&D on firm growth seems to be through increasing levels of interfirm alliances in the first post-entry years. R&D efforts enable the exploitation of external knowledge. Initial R&D also stimulates new product development later on in the life course of high-tech firms, but this does not seem to affect firm growth. Indirectly, this might affect the growth of other related firms that learn from these development activities (knowledge spillovers).

Based on large listed US firms, Coad and Rao (2010a) investigated the processes of firm level investment in R&D. Their model focuses on growth of employment, growth sales, growth of profits and growth of R&D expenditure. They conclude that investment in R&D is positively associated with the variance of sales growth and, to a lesser extent, employment growth. In addition, Coad and Rao (2010b) applied a panel vector autoregression model to a firm-level longitudinal database to observe the co-evolution of sales growth, employment growth, profits growth and the growth of research and development (R&D) expenditure. They state that profit growth seems to have little detectable association with subsequent R&D investment. In turn, firms appear to increase their total R&D expenditure following growth in sales and employment.

Subsequently, Coad and Rao (2011) state that product innovation tends to have a positive effect on labour demand, but process innovation tends to create a displacement effect on labour demand in manufacturing firms.

Demirel and Mazzucato (2012) studied how innovation affects firm growth (sales growth) in US pharmaceutical firms. They found that the positive impact of R&D on firm growth is highly conditional upon a combination of firm characteristics such as firm size, patenting and persistence in patenting. A closer look into different types of firms reveals that the expected positive impact of R&D only applies to a subset of small firms.

Deschryvere (2014) and Triguero et al. (2014) examined the persistence of innovation on firm growth from two different approaches. Using a sample of Finnish firms during the period 1998–2008, Deschryvere (2014) analysed how the relationship between R&D and firm growth varies between continuous and occasional innovators. This author concluded that only continuous product and process innovators show positive associations between R&D growth and sales growth. The links between sales growth and subsequent R&D growth were stronger for continuous innovators than for occasional innovators, but only for product innovators. Triguero et al. (2014) considered the effect of the persistence of innovation on employment in Spanish manufacturing firms during the period 1990–2008. The empirical results indicate that process innovation measures show a positive effect on employment while the effect of product innovation is positive but not significant.

Finally, Segarra and Teruel (2014) analysed the heterogeneous impact that R&D effort may exert on the firm growth distribution (employment and sales growth). They verify that investing in R&D increases the likelihood of becoming a high-growth firm. Internal and external R&D investments show varying impacts according to the firm growth distribution. Internal R&D shows a positive impact among high-growth firms, while external R&D has a significant positive impact for firms with median growth rates.

3 Models and testable hypotheses

Econometric model specification of firm growth rate is a fundamental step towards the testing of our hypotheses. In the context of stochastic growth theory, the growth rate of firms is stochastic in nature and unpredictable; it cannot be explained by other variables (Gibrat's Law, 1931). There are three main hypotheses: (i) that firms of different size classes have the same average proportionate growth; (ii) that the dispersion of growth rates about the common mean is the same for all size classes; and (iii) that there is no serial correlation on growth rates.

However, one limitation of most of these studies (static approach) is that they only look at the relation between firm growth and the initial firm size, thereby ignoring the possible effect that past growth history or serial correlation could have had on firm growth. This finding contrasts with Gibrat's stochastic model, which assumes that the proportionate growth of firms is independent of previous periods.

Taking into consideration the evolutionary approach to firm growth there is some serial correlation on growth: "success breeds success and failure breeds failure". This approach suggests that the growth of successful firms should persist over time: there should be positive serial correlation of growth between consecutive periods, and those older companies should have faster average growth than younger companies (Hart 2000).

According to Verspagen (2004), regions or agents that are growing rapidly accumulate experience and hence learn faster than others. This leads to a better competitive position for those already ahead and enables them to move further ahead. Hence, the crucial tendency here is one of divergence, in which some nations (regions or agents) are able to grow rapidly while others are left behind. This idea contrasts with purely

stochastic models of growth which takes into account that the proportionate growth of surviving firms is random and hence independent from previous success.

Unlike most empirical studies, which have utilised a static approach, in order to take into account the aims of this research work and to carry out this empirical work on the relationship between firm growth rate and firm strategy expressed as R&D activities and investment (physical and R&D), we have considered a dynamic firm growth model with serial correlation in the error term and have extended this model to include these variables.

Therefore, our starting point is the following specification:

$$\Delta y_{i,t} = \alpha_i + (\beta - 1)y_{i,t-1} + \rho \Delta y_{i,t-1} + \delta_t + \eta_{i,t} \quad (1)$$

The analysis of the relationship between growth and size consists in testing the null hypothesis of $H_0: \beta - 1 = 0$, which states that the probability of distribution of growth rates is the same for all classes of firm, that is to say, growth is unrelated to size, with the alternative that $H_1: \beta - 1 < 0$, firm sizes are mean-reverting. Another factor, which has been tested, is the persistence in growth rates.¹ Thus, because our model includes serial correlation in the error term, to test Gibrat's Law we should also test the null hypothesis of no serial correlation ($H_0: \rho = 0$) under the alternative that $H_1: \rho \neq 0$. If $\rho = 0$ the growth rate of a firm is independent of its past growth history, that is, above or below average growth for any individual firm does not persist from one period to the next. In the evolutionary literature (Nelson and Winter 1982) firms have "routines" embodied in people and organizations; routines which are transferred from one period to another. Thus successful routines which produced growth in the past are likely to continue to produce growth in the future. Hence, the evolutionary approach implies that there is some serial correlation in growth. This contrasts with Gibrat's Law of proportionate growth (1931), which postulates that the proportionate growth of (surviving) firms is random, and accordingly independent of previous success. Empirically, authors like Geroski (2000) have proposed that firms do not display persistent differences in their growth performance. However, it should be pointed out that some empirical studies have shown weak signs of serial correlation on firm performance (Hart 2000).

The relative importance of systematic and stochastic factors in the growth of companies may be indicated by the degree of serial correlation of growth (Hart 2000). Systematic factors should be expected to produce persistent company growth and hence a high degree of serial correlation. Hart and Oulton (1998) found that between the two periods 1986–1989 and 1989–92, the serial correlation of growth was 0.024, compared with 0.046 between 1989–92 and 1992–95. There appears to be some serial correlation but it is very small. The implication is that stochastic factors are more important than systematic factors in determining company growth. Hart (2000) states that while firm growth to a large extent is stochastic or random there are some systematic factors involved, such as capital investment and R&D.

To allow for these systematic factors we extended the previous model presented at equation (1) as follows:

¹ See for example Singh and Whittington (1975), Chesher (1979), Kumar (1985), Wagner (1992), Dunne and Hughes (1994), Tschogl (1996), Hart and Oulton (1998), Almus and Nerlinger (2000), Vander Venet (2001), Goddard et al (2002) and Audretsch et al. (2004).

$$\Delta y_{i,t} = \alpha_i + (\beta-1)y_{i,t-1} + \rho\Delta y_{i,t-1} + \chi_1 \left(\frac{R\&D}{sales} \right)_{i,t-1} + \chi_2 \left(\frac{R\&D}{sales} \right)_{i,t-2} + \delta_t + \eta_{i,t} \quad (2)$$

$$\Delta y_{i,t} = \alpha_i + (\beta-1)y_{i,t-1} + \rho\Delta y_{i,t-1} + \theta_1 \left(\frac{I_{i,t-1}}{K_{i,t-2}} \right) + \theta_2 \left(\frac{R\&D_{i,t-1}}{C_{i,t-2}} \right) + \delta_t + \eta_{i,t} \quad (3)$$

With respect to specification (2) the presence of intensity of R&D, measured by the ratio between R&D expenditure over total sales, constitutes a structural factor which can explain the prospects of growth and can differentiate the firms. We expect that research intensity has a positive effect on the growth rate of firms. Many empirical studies have sought to ascertain the relationship between R&D and the performance of a firm.

Finally, equation (3) makes it possible to relate the firm growth rates to the level of investment, both physical (I/K) and R&D ($R\&D/C$).

According to model specification, a dynamic regression model using panels containing many firms and a small number of time periods, we apply a system GMM estimator developed by Blundell and Bond (1998). Contrary to the use of other techniques, we chose this methodology because this estimator controls the presence of unobserved firm-specific effects and the endogeneity of the current-dated explanatory variables. Therefore, we also use the GMM method to control potential endogeneity of R&D and unobserved firm heterogeneity.

The system GMM estimator uses equations in first-differences, from which the firm-specific effects are eliminated by the transformation, and for which endogenous variables lagged two or more periods will be valid instruments provided there is no serial correlation in the time-varying component of the error terms. This is tested by examining tests for serial correlation in the first-differenced residuals. These differenced equations are combined with equations in levels for which the instruments used must be orthogonal to the firm-specific effects. Obviously the level of the dependent variable must be correlated with the firm-specific effects, and we want to allow for the levels of all the explanatory variables to be potentially correlated with the firm-specific effects, so this rules out using the levels of any variables as instruments for the levels equations. However, Blundell and Bond (1998) showed that in autoregressive-distributed lag models, the first-differences of the series can be uncorrelated with the firm-specific effects provided that the series have stationary means. We therefore experimented with lagged differences of the variables as instruments for the levels equations.

Instrument validity was tested using a Sargan test of over-identifying restrictions. The system GMM estimators reported here generally produced more reasonable estimates of the autoregressive dynamics than the basic first-differenced estimators. This is consistent with the analysis of Blundell and Bond (1998), which showed that in autoregressive models with persistent series, the first-differenced estimator can be subject to serious finite sample biases as a result of weak instruments, and that these biases can be greatly reduced by the inclusion of the levels equations in the system

estimator. We report results for a two-step GMM estimator, with standard errors and test statistics that are asymptotically robust to general heteroskedasticity.²

4 Data and variables

The database we use was constructed by the Banco de Portugal (Portuguese Central Bank) and it is known as the Central Balance Sheet. This database contains extensive economic and financial information about a firm's income statement and balance sheet variables. The source for constructing the panel data consists of the annual accounts of quoted and unquoted Portuguese firms which are not legally bound to file their annual accounts at the Central Balance Sheet Office.

Although firms have been surveyed since 1987, due to changes in the National Plan of Accounts, statistical information was only made available from 1990 to 2005. The Simplified Corporate Information database was created in 2006 which replaced the Central Balance Sheet. Unlike the Central Balance Sheet, this new database includes all firms. However, it is not possible to crosscheck information between these databases. For this reason, and also because after 2002 only a few firms answered the questionnaires, our research work focused on a period from 1990 to 2001.

For the purpose of the present paper, the following cleaning procedures have been carried out. Firstly, we removed firms with unknown industry activity from the original sample. Secondly, we excluded observations with either missing or non-positive values for the variables used. Thirdly, for the empirical part of this paper the data is limited to surviving firms. Finally, given the requirements of the adopted econometric methodology we selected only firms with at least four consecutive periods.

At the same time, firms were selected according to the criterion of having positive R&D expenses in not less than three consecutive years during the period under consideration. In the literature, it is often emphasized that product and process innovation may have a different impact on employment. Unfortunately, the database used in this study has no information which allows us to distinguish between product and process innovation.

Therefore, we selected an unbalanced panel of 1248 Portuguese surviving firms with 5709 observations covering the years from 1990 to 2001 in the manufacturing industry. Note that, we have considered only surviving firms because it is not possible to analyse the persistence of growth on firms that left the industry during the observation period. Due to the higher probability of slowly-growing small firms exiting, sample selection issues may be a problem when the data sample consists only of surviving firms. However, because of the growth interval used, it is believed that the sample selection bias is not likely to be very large for the data set used.

Regarding the variables used, firm size can be measured in a number of ways, with employment, assets, value added and sales being some of the common measures. According to Heshmati (2001), the results may be sensitive to the definition of firm size. Firm size (*size*) is the natural logarithm of the number of employees. Employment

² Although a more efficient two-step GMM estimator is available, the asymptotic standard errors for the two-step estimator can be an unreliable guide for inference in finite samples. The system GMM estimates that we report are computed using DPD for OX (see Doornik, Arellano, and Bond, 2002).

is chosen as a unit of analysis in order to allow comparisons with previous studies, to avoid the effects of inflation and to draw policy conclusions from the employment perspective. Firm growth rate (*growth*) is computed by the difference between $\ln(SIZE_{it}) - \ln(SIZE_{it-1})$. R&D intensity ($R\&D/SALES$) is the ratio between R&D expenditure and sales. Investment (*I*) is an addition to plant, property and equipment. Capital stock (*K*) is obtained by applying the perpetual inventory procedure described by Bond et al. (1999: 43). Finally, to calculate knowledge capital (*C*) we adopt the “steady state” approximation, as described by Bond et al. (1999: 19) to compute the R&D capital stock.

Table 1 reports means, standard errors and inter-quartile ranges of the most important variables. The firm mean, median, and percentile 75 figures for employment denote less than 250 employees, confirming the relevance of small and medium firms in our sample. The growth rate variable has a mean equal to 0.022. However, a negative value at the first percentile means that 25% of firms have a growth rate less than or equal to -0.036. Considering percentile 75 we could state that only 25% of firms have a growth rate higher or equal to 0.075. According to standard error values R&D is more volatile than physical investment.

5 Empirical results

In the presence of dynamic models the pooled OLS estimator is biased upwards and inconsistent. To correct some of the problems in estimating such a relationship we have used the GMM system estimator developed by Blundell and Bond (1998). The results of estimating dynamic growth specifications with serial correlation (equations (2) and (3)) by GMM-SYS estimator for an unbalanced panel of Portuguese manufacturing firms for the period 1990–2001 are reported in Tables 2, 3 and 4.

Table 2 reports GMM-SYS estimates the parameters of growth specification with persistence of chance for the whole sample. As we can see, the coefficient of firm size is always negative and significant, which means that small firms grow faster than larger firms.

In relation to the persistence of chance, an interesting question is how the observed serial correlation measured by ρ can be interpreted. Serial correlation in proportionate growth rates can be ascribed to persistence of chance factors which make a company

Table 1 Summary statistics for the whole sample

Variables	Mean	Std. dev.	Median	Perc. 25 th	Perc. 75 th
EMPLOYMENT	135.3	216.3	68	33	149
GROWTH RATE	0.022	0.174	0	-0.036	0.075
R&D	229059.6	784117.1	34,527	8170	121,826
I	1,041,236	5,948,618	239829.5	62,525	754,671
K	4.46e + 07	1.72e + 08	1.19e + 07	4,123,066	3.43e + 07
C	87870.21	299284.3	13263.78	3023.022	48251.07
R & D / SALES	0.0272	0.0657	0.0097	0.0029	0.0278
I / K	0.0474	0.0907	0.0085	0.0535	0.0224
R & D / C	12.614	263.598	3.145	2.718	4.170

Table 2 GMM-sys results for whole sample

	(1)	(2)	(3)
$size_{it-1}$	-0.0419** (0.019)	-0.0105*** (0.0037)	-0.0487* (0.0257)
$growth_{it-1}$	0.0116 (0.0397)	0.0564 (0.1339)	0.0401 (0.0453)
$(R \& D/sales)_{it-1}$	–	0.0064 (0.0039)	–
$(R \& D/sales)_{it-2}$	–	0.004 (0.0037)	–
I_{it-1}/K_{it-2}	–	–	0.0244*** (0.008)
$R \& D_{it-2}/C_{it-2}$	–	–	0.002 (0.0036)
Constant	0.1432 (0.0885)	0.0228 (0.113)	0.2718* (0.1542)
w_{JS}	16.42 [0.000]	17.09 [0.002]	18.23 [0.001]
Sargan	14.90 [0.602]	35.04 [0.514]	35.24 [0.943]
m_2	0.7876 [0.431]	-1.561 [0.119]	0.2310 [0.817]
Instrument matrix	$size_{it-2} \Delta size_{it-1}$	$size_{it-2} (R \& D/sales)_{it-1}$ $\Delta size_{it-1} \Delta (R \& D/sales)_{it}$	$size_{it-2} (I/K)_{it-1} (R \& D/C)_{it-1}$ $\Delta size_{it-1} \Delta ((I/K)_{it} \Delta (R \& D/C)_{it})$

Notes: Asymptotic standard errors robust to general cross-section and time-series heteroskedasticity are reported in parenthesis. w_{JS} is the Wald statistic of joint significance of the independent variables (excluding time dummies and the constant term). Sargan is a test of the over-identifying restrictions, asymptotically distributed as χ^2 under the null hypothesis of instrument validity. m_2 is a test for second-order serial correlation in the first differenced residual, asymptotically distributed as $N(0, 1)$ under the nullity of no serial correlation. The p -value of Sargan's test for over-identifying restrictions and m_2 test are reported in square brackets. The core sample consists of 1248 manufacturing firms with a total of 4276 observations

grow abnormally fast or abnormally slowly. According to the theory, consistently positive serially correlated growth implies that advantages acquired over time are carried over from one period to the next. There is consistent evidence with positive serial correlation; those firms with above average growth in one period tend to experience above average growth in the next. However, because the serial correlation is low the success is not prolonged. Most studies of other industrial and financial sectors have found there is no persistence of growth (Acs and Audretsch 1990; Dunne and Hughes 1994), or no positive persistence (Chesher 1979; Kumar 1985; Wagner 1992; Tschoegl 1996). A smaller number of researchers found evidence of negative persistence of growth (Contini and Revelli 1989; Almus and Nerlinger 2000; Goodard et al. 2002). In this work the tests for persistence of growth ρ is always non-significant. This result means that growth for any individual firm does not persist from one period to the next and it is independent of its past growth.

To ascertain whether Gibrat's Law is in operation both β and ρ must be rejected. According to the Wald joint significance test, column 1, the null hypothesis that both β and ρ are equal to zero is rejected at 1% level, which means that Gibrat's Law does not hold.

The R&D intensity coefficient presents only 1 and 2 lags because a contemporaneous relationship with the growth rate of the firms cannot be easily justified. The work which has been carried out reveals that the research intensity coefficient is small and not statistically significant. Some previous studies also found no relationship between innovation and firm growth, for example, Cesaratto and Stirati (1996), Geroski et al. (1997), Almus and Nerlinger (1999), Bottazzi et al. (2001), Geroski and Mazzucato (2002) and Loof and Heshmati (2006).

Table 3 GMM-sys results split sample by firm size

	Micro and small firms (50 employees)			Medium and large firms (50 employees)		
	(1)	(2)	(3)	(4)	(5)	(6)
$size_{it-1}$	-0.0595 ^{***} (0.0223)	-0.0328 ^{***} (0.0158)	-0.0515 ^{**} (0.019)	-0.007 (0.0265)	-0.0203 (0.0322)	-0.0069 (0.0424)
$growth_{it-1}$	0.024 (0.0485)	0.0281 (0.0428)	0.0254 (0.0406)	0.0161 (0.0794)	0.0154 (0.0492)	0.0199 (0.0562)
$(R \& D/sales)_{it-1}$	-	0.016 (0.0085)	-	-	0.0043 (0.0273)	-
$(R \& D/sales)_{it-2}$	-	0.013 (0.007)	-	-	0.0014 (0.0293)	-
I_{it-1}/K_{it-2}	-	-	0.0241 ^{**} (0.0119)	-	-	0.019 ^{**} (0.01)
$R \& D_{it-1}/C_{it-2}$	-	-	0.006 (0.0068)	-	-	0.006 (0.0045)
<i>Constant</i>	0.1706 (0.2721)	-0.0072 (0.1554)	0.0999 (0.2281)	-0.0868 (0.1343)	0.0377 (0.1524)	0.3963 [*] (0.2381)
w_{JS}	6.936 [0.031]	8.564 [0.004]	13.632 [0.000]	0.6207 [0.733]	1.687 [0.793]	8.120 [0.087]
<i>Sargan</i>	15.23 [0.579]	34.19 [0.555]	32.96 [0.568]	23.01 [0.149]	39.73 [0.230]	30.47 [0.987]
m_2	0.6697 [0.503]	-1.479 [0.139]	-1.140 [0.254]	0.3404 [0.734]	-0.8727 [0.383]	0.03592 [0.971]
<i>Instrument matrix</i>	$size_{it-2}$	$size_{it-2}(R \& D/sales)_{it-1}$	$size_{it-2}(I/K)_{it-1}$	$size_{it-2}\Delta size_{it-1}$	$size_{it-2}(R \& D/sales)_{it-1}$	$size_{it-2}(I/K)_{it-1}$
	$\Delta size_{it-1}$	$\Delta(R \& D/sales)_{it}$	$\Delta size_{it-1}\Delta(I/K)_{it}$	$\Delta size_{it-1}\Delta(R \& D/sales)_{it}$	$\Delta size_{it-1}\Delta(R \& D/sales)_{it}$	$\Delta size_{it-1}\Delta(I/K)_{it}$
			$\Delta(R \& D/C)_{it}$			$\Delta(R \& D/C)_{it}$

Notes: as in Table 1. The underlying sample of micro and small firms consists of 561 firms with a total of 1747 observations. The sample of medium and large firms consists of 687 firms with a total of 2529

Table 4 GMM-sys results for high-tech firms

	(1)	(2)	(3)
$size_{it-1}$	-0.0442*** (0.0162)	-0.0457*** (0.0184)	-0.0446*** (0.0141)
$growth_{it-1}$	0.027 (0.0364)	0.0332 (0.027)	0.034 (0.021)
$(R \& D/sales)_{it-1}$	–	0.0312 (0.0345)	–
$(R \& D/sales)_{it-2}$	–	0.0271 (0.0346)	–
I_{it-1}/K_{it-2}	–	–	0.0352*** (0.0145)
$R \& D_{it-1}/C_{it-2}$	–	–	0.0147 (0.0088)
Constant	-0.0162 (0.1791)	0.0061 (0.1365)	0.1694 (0.1417)
w_{JS}	15.64 [0.000]	13.52 [0.000]	19.73 [0.001]
Sargan	13.49 [0.637]	23.72 [0.785]	40.31 [0.671]
m_2	-0.3107 [0.756]	-0.2886 [0.773]	1.178 [0.239]
Instrument matrix	$size_{it-2} \Delta size_{it-1}$	$size_{it-2} (R \& D/sales)_{it-1}$ $\Delta size_{it-1} \Delta (R \& D/sales)_{it}$	$size_{it-2} (I/K)_{it-1} (R \& D/C)_{it-1}$ $\Delta size_{it-1} \Delta ((I/K)_{it} \Delta (R \& D/C)_{it})$

Notes: as in Table 1. The underlying sample of high-tech firms consists of 117 firms with a total of 350 observations

This result indicates that R&D expenditure has no effect on firm growth. One reason is that the Portuguese manufacturing firms have low R&D expenditure. Based on empirical findings, another possible explanation for this result is that, typically, all factors except size have a fairly small impact on firm growth. The argument here is that size may indirectly affect sales dynamics by conditioning the effects of other factors on it (Geroski 1998). Thus, firms are aware that growth from innovation will be limited by their size (Cohen and Klepper 1996).

Lastly, the results reported in column (3) confirm that only physical investment has a positive and significant effect on growth. The physical investment coefficient is significant at 1% level. Unlike Hall's findings (1987), physical investment is a predictor of firm growth while R&D investment does not have any effect. Bottazzi et al. (2001) also found no influence of R&D investment on firm growth. For each regression, we report the p-value of the Wald test of joint significance of the coefficients. The joint insignificance of the coefficients included in the regression is clearly rejected by the Wald test for the whole sample.

Because the growth process of small companies is quite different from large companies they merit separate treatment (Penrose 1980). Some studies (Hall 1987; Evans 1987) split the sample according to firm size whereas others use firm age criteria. When considering firm age the sample could be divided into young firms versus old firms. Evans (1987) considered a firm young if its age is less than 7 years and an old firm is otherwise. Because small firms are usually younger and large firms are older, firm age could be used as a proxy for firm size. In this work we have also divided our sample by firm age. However, we have reached the same conclusions. For this reason we only present the results for a sample divided by firm size.

Table 3 reports the GMM-SYS results when we divided the sample according to the exogenous criterion of firm size. In columns (1) and (4), according to the Wald joint test, we find that Gibrat's Law is rejected for a sub-sample of micro and small firms at

5% level, whilst it is accepted for medium and large firms. With respect to research intensity, we obtain a positive but non-significant coefficient. Lastly, the physical investment coefficient is higher for smaller firms than larger firms and is always significant. This confirms that physical investment plays a different role in the growth of smaller and larger firms. If we consider the R&D investment, the estimated coefficient is equal and non-significant for smaller and larger firms. However, if we compare physical with R&D investment we observe that smaller firms “prefer” physical investment.

Table 4 reports the results for a sample of high-tech firms. High-tech firms include manufacturers of Chemical Products, Machine Products, Office Equipment and Computers, Electrical Machinery, Radio, TV and TLC Equipment, Medical Equipment, Measuring Instruments, Motor Vehicles and Other Transport Equipment. The departures from Gibrat’s Law are more evident for a sub-sample of high-tech firms which are generally characterised by a fast-growth path. The null hypothesis that β and ρ are equal to zero is rejected by the Wald joint test, at 1% level. Furthermore, these firms have a positive and higher research intensity coefficient but it still remains non-significant. The estimated coefficient for physical investment is positive and significant at 1% level. In respect to R&D investment, this estimated coefficient is non-significant. Physical investment continues to play an important role in the growth of the high-tech firms.

Arellano and Bond (1991) consider specification tests that must be applied after estimating a dynamic model from panel data by the GMM estimators: a direct test on the second-order residual serial correlation coefficient (m_2) and a Sargan test of over-identifying restrictions. In this context the key identifying assumption that there is no serial correlation in the ε_{it} disturbances can be demonstrated by testing for no second-order serial correlation in the first-differenced residuals. The consistency of the GMM estimator depends on the absence of second-order serial correlation in the residuals of the growth specifications. Another test of specification is a Sargan test of over-identifying restrictions, which has an asymptotic χ^2 distribution under the null hypothesis that these moment conditions are valid. Thus, the validity of the dynamic models depends on a lack of second-order serial correlation (see the m_2 statistics) and the validity of the instrument set measured by the Sargan test. The Sargan and m_2 tests are always accepted, which confirms the validity of the instruments chosen and the consistency of the results obtained.

6 Conclusions

In this paper we have taken into account the role of persistence of chance in the growth process. On the other hand, because firm growth is not quite random we consider systematic factors, such as R&D intensity and both physical and R&D investment, which could have some influence on the growth of firms. The relative importance of systematic and stochastic factors on the growth of firms may be indicated by the degree of serial correlation of growth. These dynamic growth specifications were estimated by applying dynamic panel data techniques (GMM-SYS estimator).

Our empirical evidence, obtained from an unbalanced panel of 1248 Portuguese manufacturing (surviving) firms, covering a complete firm size distribution, for the

period from 1990 to 2001, provides some support for the notion that log firm sizes are mean-reverting. Over this period smaller firms grew more quickly than larger firms, thus generating proportionally more jobs, and there is some positive but non-significant persistence on firm growth over the period examined. The balance of evidence seems to suggest that Gibrat's Law should be rejected in respect of Portuguese manufacturing firms for the whole period. If we consider a firm size breakdown and a sample of high-tech firms we find that the departures from Gibrat's Law are higher for smaller and high-tech firms.

When we consider some systematic factors that may explain firm growth, the results obtained reveal that R&D intensity and R&D investment have no effect on firm growth rate. However, physical investment has a positive effect on the growth of the firms. For smaller and high-tech firms this finding is even more noticeable. The investment in physical capital is more relevant for smaller than larger firms. In addition, we may also find that stochastic factors are more important than systematic factors in determining company growth.

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