How to invest in R&D during downturns? Exploring the differences between fast-growing and slow-growing high-technology SMEs

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HOW TO INVEST IN R&D DURING DOWNTURNS? EXPLORING THE DIFFERENCES BETWEEN FAST-GROWING AND SLOW-GROWING HIGH-TECHNOLOGY SMES

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Abstract

This paper examines the relationship between R&D investments, innovation and growth in high-technology SMEs during a period of economic downturn. We conduct a quantile regression analysis of longitudinal data collected on a panel of 460 high-technology SMEs over a 6 years period, to test the impact of different activities characterising firms' innovation strategies (internal R&D investments, external knowledge sourcing through collaborative R&D and the introduction of new products to the market) over the distribution of firms' growth. We show that the impact of R&D investments is considerably different over the distribution of growth for firms in the sample during a period of economic downturn. More specifically, two distinct profiles emerge. Younger, smaller and innovating companies still experience fast growth rates as a result of the introduction of new products to the market. Conversely, negative returns on R&D investments characterise slow-growing high-technology SMEs. In such cases, a balanced approach between internal R&D investments and collaborative R&D activities positively contributes to growth.

1. Introduction

Fast-growing Small and Medium-sized Enterprises (SMEs), especially those from the high-technology sectors, figure high on the European innovation policy initiatives as global drivers of technological innovation (European Commission, 2019a), given their relevant contribution to job creation, productivity and growth across countries (Muller *et al*., 2017; OECD, 2019). In the last decades, a large body of literature has been investigating the positive relationship between R&D investments, innovation activities and growth at the firm level, both in terms of profit and employment (see, among others, Cefis and Ciccarelli, 2005 and Lööf and Heshmati, 2006; 2008). However, and despite SMEs represent the largest share of economic activities in most European economies (OECD, 2019), most empirical studies addressing this relation have been conducted on 'top R&D investors', typically large and very large companies (European Commission, 2019b). Furthermore, only a few studies have investigated if business R&D investments and innovation activities still represent a source of growth during periods of economic downturns. Given these knowledge gaps in the existing literature, this paper provides evidence of the relationship between R&D investments, innovation activities and growth in high-technology SMEs during a period of time characterized by a very severe financial crisis (started in late 2008) and a global economic downturn in the following years (2009-2013)[1]. This study has two objectives. First, it aims to empirically verify if the observed positive relationship between R&D investments, innovation activities and growth in high technology sectors – which has been assessed in periods of economic development (Coad and Rao, 2006) – still holds during a period of economic downturn. In fact, during such periods, firms may be induced to reduce their investments in R&D to survive the crises (Cincera et al., 2010), rather than increasing investments in R&D to adapt to the changed competitive environment and transform an existing threat into a potential market opportunity (Vossen, 1998). Second, it aims to investigate if the pursuit of different types of R&D efforts (internal R&D vs. external knowledge acquisition through collaborative R&D) and innovative activities influences such a relationship. To meet these purposes, we exploited a unique dataset combining firm-level information

[1] To the purpose of this study we take into consideration the entire time period between 2009 and 2013. Following the global financial crisis started in late 2008, Italy experienced a dramatic fall in external demand and, consequently, a huge decrease in the levels of industrial production and firms' investments in the following years. Notwithstanding the partial recovery of the international markets in 2012 and 2013, industrial production and firms' investments remained well below their pre-crisis levels. Furthermore, from 2012 onwards, the emergence of liquidity constraints in the financial market and conditions of very weak internal demand determined a new worsening of the general economic conditions.

gathered from different sources[2] on a panel of 460 high-technology SMEs over a 6 years period, therefore allowing for the use of longitudinal estimation methods. Albeit the assessment of the relationship between R&D investments, innovative activity and growth may be problematic for SMEs in general (as the latter show a lower attitude towards formalized R&D processes with respect to their larger counterparts – e.g., Vossen, 1998), our focus on high-technology SMEs should prevent such a problem. In fact, high-technology SMEs are usually focused on the development of one or a few leading-edge technologies as their main asset (Oakey, 2013) and, more in general, are used to complement in-house technical skills with external knowledge throughout the innovation chain (Rothwell and Dodgson, 1991). In turn, following prior studies that have adopted a similar approach (Ahn et al., 2015), this focus on high-technology innovating SMEs may lead to a clearer evidence of the linkage between R&D investments and growth during a period of economic downturn. To evaluate the R&D-growth paths of high-technology SMEs we adopted an empirical strategy based on quantile pooled regression. Such an approach differs from OLS regression as it provides multiple estimates of the relationship at different points of the growth distribution (e.g. for "slow-growing" vs. "fast-growing" firms), rather than a single point average estimate. This methodological choice allowed us to estimate the relationship between R&D investments, innovation activities and growth for different profiles of high-technology SMEs and to shed light on existing differences while, at the same time, accounting for firms' unobserved heterogeneity.

Our results confirm the relevance of R&D and innovation activities for growth also during periods of economic downturn. In particular, R&D effectiveness of high-technology SMEs is linked to their capability to adapt to turbulent market conditions by reconfiguring their innovation processes towards the exploitation of internal R&D and the introduction of innovative products and services to the market. However, more novel and interesting are our findings concerning high-technology SMEs with R&D investments and slow or negative growth. In fact, only firms which have been able to complement internal R&D investments with external (collaborative) R&D activities experience a positive return on their R&D investments during periods of economic downturn. Evidence emerging from our study adds to extant literature by shedding light on the considerable heterogeneity observed in the relation between R&D investments and growth during periods of economic downturn. Moreover, it offers potential useful information for the design of evidence-based policies.

[2] As better detailed in the methodological section, the dataset combines survey-based data on SMEs R&D investments and innovation activities with economic and financial data gathered from Bureau van Dijk Amadeus Database.

2. Background and hypotheses

The effect of R&D investments and innovation activities on firms' growth is a well-discussed topic in the field of economics of innovation. However, the theoretical debate about this issue gained new impetus after the global downturn started with the financial crisis in late 2008[3].

A vast and longstanding literature has shown that R&D investments are linked to growth as a result of their positive effects on productivity, technological competitiveness and new knowledge creation at the macro level (Dasgupta, 1986; Griliches, 1990; Crépon *et al*., 1998). The current empirical discussion on the nexus between R&D investments and growth at the firm level is still controversial. While evidence of a positive linear relation has been found at the country-level, considerable heterogeneity is observed across industries and firms (Malerba *et al*., 1997; Cefis and Orsenigo 2001). Notably, firm-specific patterns characterise the relationship between R&D and profitability (Cefis and Ciccarelli, 2005), R&D and survival (Lefebvre *et al*., 1998), as well as between R&D and growth (Del Monte and Papagni, 2003).

Furthermore, the impact of economic downturns on R&D investments is a matter of controversy in the current literature.

Divergent results in empirical findings are attributed to a substantial lack of official data and to some significant knowledge gaps in SMEs' R&D and innovation management literature concerning firms' behaviour in reaction to economic downturns.

On the one hand, a vast literature has elicited the contention that firms do not treat R&D activities differently from other investment activities, therefore supporting the hypothesis of pro-cyclical behaviour (i.e. firms cut R&D investments to reduce costs to survive the crisis). To this point, Cincera *et a*l. (2010) find a negative impact of R&D intensity on the expected R&D investments during economic crises for both large and small companies. Also, from a financial perspective, R&D investments are significantly pro-cyclical in firms facing tighter constraints on capital supply; in fact, due to the prevalent cash-flow nature of their R&D budgets, SMEs seem to show high sensitivity to the economic cycle (Voigt and Moncada Paternò Castello, 2009).

On the other hand, according to the Shumpeterian view of 'creative destruction' (1947), a period of economic downturn may represent a source of an *opportunity* for those firms able to re-organize their R&D and inno-

[3] Time series analyses report the biggest fluctuations of R&D financed by the business sector during the period 2009-2013. R&D investments from the business sector experienced a sharp drop in 2009 and a partial recovery in 2010-2011, with caution about the worsening of the general economic context in 2012, due to liquidity constraints on the financial market. (EU Commission, 2012a; 2012b).

vation processes, since the impact of recessions forces firms to focus on the most promising segments of their value chains. From this perspective, while larger firms tend to preserve their R&D investments while spreading the risk among projects in a medium- and long-term planning horizon, smaller firms formally engaged in R&D activities rather tend to delay R&D investments while turning from R&D-based innovation towards business innovation (i.e. the introduction of new products and services to the market) (Leadbeater and Meadway, 2008; Ortega Argiles *et al.*, 2009; Voigt and Moncada Paternò Castello, 2009; Archibugi *et al.*, 2013). Large evidence seems therefore to confirm the relevance of SMEs behavioural advantages in terms of adaptability and attitude to risk taking (Acs and Audretsch, 1987; Vossen, 1998) also during periods of economic downturn.

As a matter of fact, high-technology firms with short-term R&D budgets and operating in highly competitive markets should be better able to adjust their R&D strategies to turbulent (i.e. rapidly changing) environmental circumstances, to avoid falling behind competitors. To preserve their competitive advantage, such companies should be therefore more inclined to adopt a countercyclical behaviour than large companies during a period of recession. In fact, a positive relationship between R&D investments and growth has been observed over time only in small sub-populations of SMEs with persistent innovation activities (Cefis and Ciccarelli, 2005). Such firms have been identified as New Technology-Based Firms (NTBFs), Fast-Growing Firms (FGFs), Young Innovative Companies (YICs). They differ from Basic SMEs, which do not conduct repetitive innovation processes and undertake little or no internal R&D, or from Adapting SMEs, defined as incremental innovators with no significant in-house R&D (Veugelers, 2008; Shneider and Veugelers, 2010). Summing up, large empirical evidence supports the hypothesis that, during a period of economic downturn, high-technology SMEs are capable to find effective ways to reconfigure their ongoing R&D activities towards the development of new products and services and their introduction to the market (Leadbeater and Meadway, 2008; Voigt and Moncada-Paternò-Castello, 2009).

Consistently, we expect that high-technology SMEs investing in R&D and in innovation will have a significant advantage in terms of growth during an economic downturn.

(H1) During a period of economic downturn, the impact of R&D investments on growth will be positive and significant for high-technology and innovating SMEs.

When examining the relationship between R&D investments, innovation activities and growth in high-technology SMEs, it is also important to evaluate the effects that different types of firm-specific innovation activities exert on the performance outcomes during economic downturns. To this point, earlier works on small business economics and entrepreneurship has widely illustrated the peculiar characteristics of SMEs' innovation processes (Acs and Audretsch, 1987; Vossen, 1988; Freel, 2000), emphasising SMEs' inherited organizational weakness, more commonly addressed as "liabilities of smallness". Due to limited R&D funding, small innovation portfolios, shortness of ability in R&D planning and management and limited market influence, SMEs often lack crucial resources and capabilities needed to transform inventions into new products, and the complementary assets to commercialize their innovations (i.e. manufacturing, distribution, marketing assets).

To this point, more recent literature on alliances and networks (Baum, Calabrese, and Silverman 2000; Lee *et al*. 2010) and on open innovation in SMEs (Brunswicker and van de Vrande, 2014) has widely demonstrated that innovation in SMEs almost always has an interorganizational and boundary-spanning component. In fact, collaborative R&D activities within firms' (open) innovation processes (Chesbrough, 2003), help SMEs to access critical resources and complementary assets and to extend the range of internal technological competencies, driving innovation performance (Brunswicker and Vanhaverbeke, 2015).

Building on prior literature, it is therefore reasonable to expect that combinations of internal and external innovative activities (i.e. internal R&D activities and external technology acquisition through collaborative R&D) will influence high-technology SMEs' growth paths during downturns. In fact, as a large scientific evidence suggests, firms' growth should be regarded as a multidimensional construct, since it is contingent on different combinations of innovation inputs (Yasuda, 2005; Chen *et al.*, 2011; Catozzella and Vivarelli, 2014), on complementarities between internal and external innovative activities (Cassiman and Veugelers, 2006), and on the possible interactions between firms' innovation strategies and other complementary growth strategies (Lefebvre *et al.*, 1998; Golovko and Valentini, 2011). From such a perspective, the link between R&D, innovative activities and growth in high-technology SMEs may therefore be affected by the interplay between internal R&D activities – aimed at increasing the internal knowledge base of firms – and collaborative R&D activities – aimed at sourcing relevant external knowledge and technologies.

Accordingly, we hypothesize that:

(H2) During a period of economic downturn, R&D investments will have a positive impact on growth for firms able to balance internal R&D investments and external technology acquisition through collaborative R&D activities.

3. Data and methods

3.1 Sample characteristics and data collection

This study is based on longitudinal data gathered from different sources. Firstly, cross-sectional year-wise survey data were collected during the 2008-2015 time period on a population of 1,600 high-technology firms with R&D laboratories localised in Italy[4]. In each survey wave, firms' owners and managers were interviewed through Computer Assisted Telephonic Interviews (CATI)[5]. The questionnaire included specific questions related to the companies' R&D and innovation processes: amount of R&D investments, number of employees working in R&D departments, types of R&D activities (explorative vs exploitative; internal vs collaborative), number of products and services new to the market introduced as a result of prior R&D activities (i.e. technological innovations, OECD 2005). Secondly, we matched cross-sectional year-wise data from 493 companies with available information over the 2009-2014 period with economic and financial data collected from their profit and loss accounts (Source: Bureau Van Dijk). By combining different data sources, we managed to rule out the risk of common method biases, that may have led to erroneous conclusions about the relationship between the independent variables and the dependent one (growth).

Our final dataset consists of a panel of 460 high-technology SMEs with available data for 6 years (Table 1).

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[4] In this context, high-technology SMEs have been identified following two criteria: 1) share of R&D expenditure over sales larger than 50% in year; and/or, 2) share of R&D employees over total employees larger than 20% in year. Similar criteria have been adopted by the Italian Ministry of Economic Development for the identification of Innovative Startups within the Italian Startup Act (www.mise.gov.it).

[5] CATI is a procedure which is frequently used to optimize the number of interviews according to the sample strata (in this case industry and location), and therefore to guarantee the generalizability of the results from the interviewed sample to the entire population.

Tab. 1: Sample characteristics

Industry	**Number of firms** *(n)*	**Number of employees** *(mean)*	**Age** *(mean)*	**Average R&D intensity*** *(%)*
Life Sciences	49	26	13	37.9
Chemical	31	31	13	20.8
Energy/Environment	30	15	13	32.2
Electronics/Optics	49	20	12	30.5
Industrial automation	110	24	13	31.3
ICT	164	14	12	39.3
Knowledge-intensive services	27	11	9	36.1
Total	460	20	12	32.6

**R&D expenditures over sales*

Table 2 reports the R&D-growth profiles of high-technology SMEs in the sample. The strength of the relationship between R&D investments rates and growth rates is measured by the Pearson correlation coefficients, controlled by year, for different types of firms in the sample (i.e. firms at different quantiles of the growth distribution).

Tab. 2: R&D-Growth profiles of high-technology SMEs in the sample.
Pearson correlation coefficients between R&D investments rates and sales growth rates for SMEs at different quantiles of the growth distribution*

Growth (quantiles)	Correlation coefficients (r) between R&D Investments$_{(t-1)}$ and Growth $_{(t)}$
q10	-0.330**
q25	-0.078†
q50	-0.001
q75	0.137**
q90	0.333***

*Sig. (two tailed): †= p≤0.1; *≤p<0.05; **p ≤0.01; ***p≤0.001*
**R&D investments lagged by one year*

The statistics showed in Table 2 allow to compare two categories of high-technology SMEs in the sample: 1) firms with a positive return on R&D investments during downturn and 2) firms which a negative return on R&D investments during downturn. For the first category, including firms in the 90th quantile of the growth distribution (i.e. those who "tried and succeeded"), a positive and significant relationship between R&D investments and growth is observed (r=0.333, p=0.012); conversely, for firms in the 10th quantile (i.e. those who "tried and failed") a negative and significant relationship between R&D investments and growth is observed in the period (r=0.333, p=0.000). Notably, firms in the 75th quantile and in the 25th quantile of the growth distribution follow the same patterns.

3.2 Empirical strategy

In line with prior empirical studies evaluating the impact of R&D and innovation over an observed distribution of firms' growth (Coad and Rao, 2006), we used a pooled quantile regression model to obtain a complete view of the R&D-growth paths of different companies in the sample. The advantage of using quantile regression models is that such an approach provides multiple estimates of the impact of independent variables on the outcome variable at different points of the conditional distribution (99 quantiles), rather than estimating the average relationship (OLS single-point estimates for the "average firm").

More in detail, the choice of this empirical strategy was motivated by three reasons:

1) The sampled firms experienced very little growth over the entire period. As Figure 1 shows, both the mean and the median values of the of the GROWTH distribution were near to zero, with high dispersion; these features are typically recurrent in SMEs during periods of economic downturn.

2) The quantile plot (Figure 2) confirmed that GROWTH varied at different points of the distribution: while a first fraction of firms in the distribution experienced negative growth over the period of downturn, the last fraction of firms experienced positive and high growth. A single OLS estimation of GROWTH for the "average firm" would be therefore of little interest. Rather, quantile estimations would have allowed us to evaluate the differences in the relationship between the independent variables and the outcome variable at different points of the distribution (i.e. to calculate coefficients estimates at different quantiles) and to provide a richer characterisation of the R&D-growth profiles of different types of firms at different points of the GROWTH distribution.

3) Quantile regression is more robust than OLS regression to non-normal errors and outliers. Relaxing the assumption that error terms are identically distributed at all points of the GROWTH distribution, allowed us to account for inter-firm heterogeneity. Finally, through quantile regression, we would be able to obtain robust slope coefficient estimations which are not influenced by outliers in the dependent variable.

Fig. 1: Distribution of GROWTH for firms in the sample

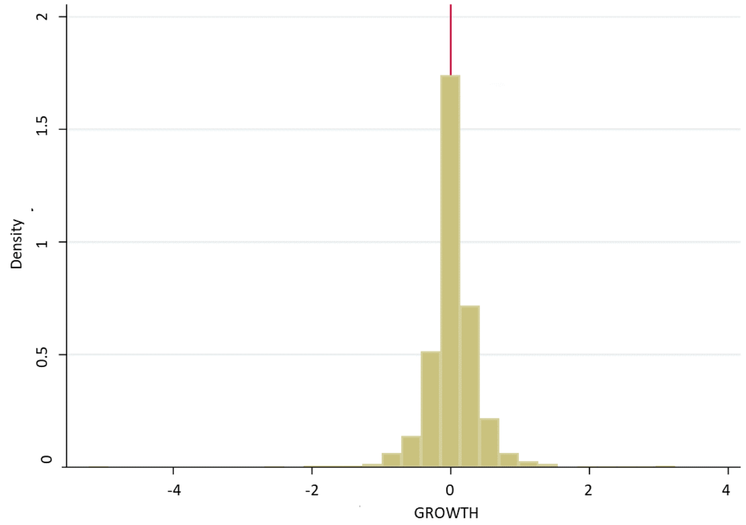
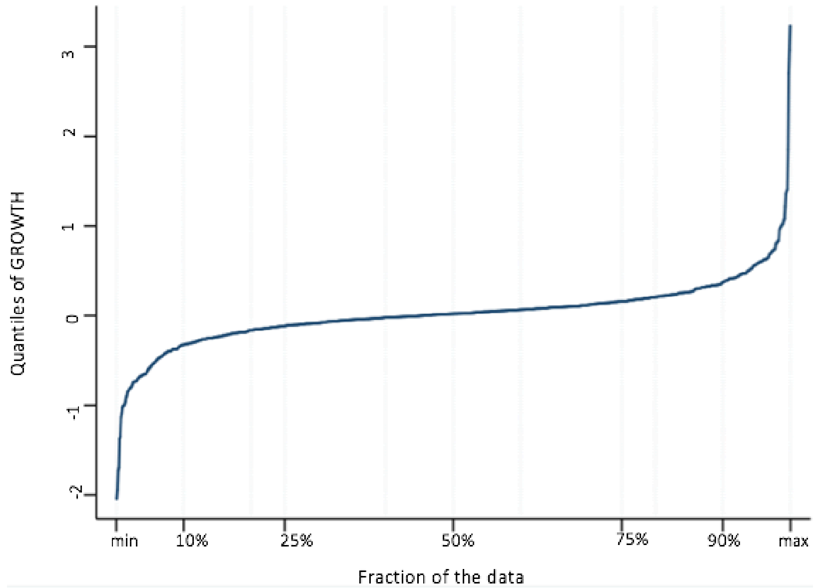


Fig. 2: Quantile plot of GROWTH



3.3 Variables definition and operationalization

3.3.1 Dependent variable

Firms' sales and employment are among the most used measures of organisational growth (Delmar *et al.*, 2003). In the context of this study, we considered net sales growth as a meaningful indicator of firm's post-innovation performance (Del Monte and Papagni, 2003; Coad and Rao, 2006). The main reason underlying this choice is that other performance indicators (like firms' market share, innovation income or financial performance) might present drawbacks that limit their applicability in a context of economic downturn, since they are industry-specific and very sensitive to changes over time (Delmar *et al.*, 2003). In light of these considerations, GROWTH was measured by a continuous variable, operationalised as the difference in the natural logarithm of net sales for the firm *i* between year *t* and year *t-1*.

3.3.2 Independent variables

The first independent variable, RD, is a continuous variable operationalized as the growth rate of R&D expenditures for the firm *i* between year *t* and year *t-1*. To rule out the risk of endogeneity, the variable was lagged by one year.

To test H1, we operationalized Innovation (INN) as a binary variable. For each firm-year observation, INN indicates whether a firm introduced one or more products/services new to the market (1) or not (0) as a result of prior R&D investments.

To test H2, we calculated three dummy variables characterising non-exclusive combinations of internal and external innovation activities undertaken by the firm *i* in each time period.

More in detail:

- INT_only is a binary variable indicating whether firm *i* invested in internal R&D (1) or not (0) in year *t*;
- EXT_only is a binary variable indicating whether firm *i* engaged in collaborative R&D activities aimed at external technology acquisition (1) or not (0) in year *t*;
- INT_EXT is a binary variable indicating whether firm *i* pursued both internal and collaborative R&D activities (1) or not (0) in year *t*.

3.3.3 Control variables

Firms' export intensity (EXT) was introduced to control for the influence of sales on the international markets on growth during the period (Golovko and Valentini, 2011). EXT was operationalized as a continuous variable through the share of sales on international markets over total sales for firm *i* in year *t*.

Firms' SIZE and AGE were operationalized as the number of employees of firm *i* in year *t* and the number of years since its foundation in year *t*, respectively.

Finally, we introduced 7 industry dummy variables and 5 year dummy variables to control for both industry and time effects.

3.4 Test of hypotheses

To test our research hypotheses, we estimated two distinct models, using the STATA 13 software package. To test H1 (Model 1), we ran a quantile regression of GROWTH over RD and INN (Model 1), including controls. To test H2 (Model 2), we further introduced the three binary variables characterising different R&D activities as combinations of internal and collaborative activities (INT_only, EXT_only, INT_EXT).

4. Results and discussion

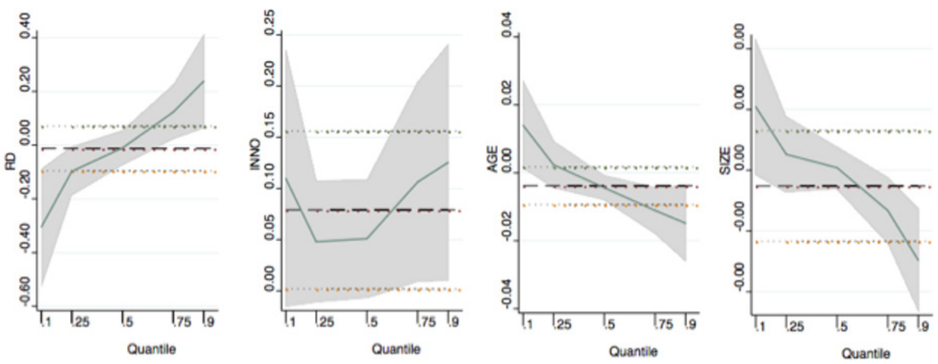
Table 3 reports the quantile regression estimates[6] at 10th, 25th, 50th, 75th and 90th percentiles of SMEs' growth distribution for both Model 1 and Model 2. A first important result is related to the significant differences observed in the coefficients of RD, INN, AGE and SIZE over the conditional distribution of GROWTH (Model 1 and Figure 2). Two R&D-growth paths emerge, which are associated to two different profiles of high-technology SMEs in the sample.More specifically, we observed that the marginal effect of an increase of RD on GROWTH is negative and significant for firms at the lower quantiles of the distribution (q10 and q25), and positive and significant at the upper quantiles (q75 and q90). That is, the marginal effect of an increase in RD is positive and strong for fast-growing firms (at q75, the coefficient is 12 times larger than the median; at q90, it is 24 times larger than the median), and it is negative for poorly performing firms (i.e. firms that are experiencing steady or negative GROWTH). The coefficients of INN are positive and significant at both the highest and the lowest quantiles of the growth distribution (p75, p90, p10). On the one side, this result indicates that sub-populations of small, young and innovative firms experience faster growth rates as a result of R&D investments and innovation activities during economic downturns; on the other side, this result reveals that firms able to adjust their ongoing R&D activities towards innovation activities benefit from a positive effect on growth during periods of economic downturn. This evidence strongly supports H1.

*Tab. 3: Quantile regression estimates**

	Model 1					Model 2				
	q10	q25	q50	q75	q90	q10	q25	q50	**q75**	**q90**
RD	-0.280**	-0.098*	-0.007	0.111*	0.220**	-0.308**	-0.121**	-0.025	0.111*	0.226*
INN	0.125*	0.05†	0.043	0.114**	0.154**	0.059	0.03	0.042	0.110*	0.139*
INT_only						0.086	0.068*	0.006	0.007	-0.005
EXT_only						0.097	0.087*	0.063*	0.031	0.068
INT_EXT						0.177*	0.096**	0.042*	0.006	0.006
EXP	-0.108	0.029	0.029	0.059a	0.094	-0.216	-0.004	0.012	0.068	0.061
AGE	0.014*	0.002	-0.004*	-0.011***	-0.016**	0.019**	0.002	-0.003*	-0.011***	-0.016**
SIZE	0.001**	0.000	0.000	-0.001**	-0.001**	0.001	0.000	0.000	-0.007**	-0.013**
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
cons	-0.994**	-0.977**	-0.314	-0.137	-0.190	-0.983**	-0.970**	-0.352	-0.129	-0.197
Pseudo R^2	0.068	0.035	0.0223	0.053	0.100	0.079	0.040	0.027	0.054	0.102
N	932	932	932	932	932	932	932	932	932	932

**Robust SE (1000 bootstrap replications)* †= $p \leq 0.1$; $* \leq p < 0.05$; $** p \leq 0.01$; $*** p \leq 0.001$

Fig. 2: Variation of the coefficients of RD, INNO, AGE and SIZE over the conditional quantile distribution of GROWTH.



In Model 2 we observed an increase in the quality of fit of our estimates in q10 and in q90, indicating that the full model explains an additional amount of variance between fast-growing and slow-growing high-technology SMEs.

[6] Robust standard errors were obtained using 1000 bootstrap replications.

First of all, the coefficients of INT_EXT (the dummy variable indicating firms undertaking both internal R&D activities and collaborative R&D activities for external technology acquisition) is positive and significant in the first two quantiles of the growth distribution (i.e. for slow-growing firms). This result clearly suggests a positive effect generated by the combination of internal and collaborative R&D activities on GROWTH for firms which experience negative returns on their internal R&D investments during downturns. Interestingly, for these firms, a balanced combination of internal R&D and external technology acquisition has a higher impact on growth with respect to single approaches (OnlyINT; OnlyEXT).

This evidence confirms H2 only for "slow growing firms".

Overall, in line with prior empirical research on high-technology SMEs in Europe (see, e.g. Coad and Rao, 2006 and Hölzl, 2009), two distinct R&D-growth profiles emerge from this study. First, a small sub-population of young, small and innovative high-technology SMEs experienced positive returns on R&D investments during the period of downturn as a result of persistent innovation activities (i.e. the introduction of new products and services to the market). Fast growing SMEs are therefore those which were able, during the period of economic downturn, to reconfigure their R&D processes towards product innovation.

A second profile includes high-technology SMEs with higher average age and size, which experienced a negative or slow growth over the recession. Notably, the negative relationship between R&D efforts and growth in this second category of firms may be the result of higher resource constraints and limited internal competencies for the successful exploitation of the results of R&D. The positive effect of balancing internal R&D with collaborative R&D aimed at external technology acquisition (i.e. to engage in open innovation approach) on growth, for this category of firms, strongly supports this argument.

As also noted by the literature on open innovation during downturns (see, e.g. Di Minin *et al.*, 2010), an increased degree of "openness" through collaborative R&D can be an effective approach to adapt firms' innovative activities to a turbulent environment. Our results therefore confirm that, during recessions, high-technology SMEs with low or negative returns on internal R&D benefit from external knowledge/technology sourcing to complement their internal capabilities and improve performance. More specifically, a balanced approach between different types of R&D activities within firms' innovation strategies, rather than single activities in isolation, will exert a positive impact on growth.

5. Conclusions, limitations and future research opportunities

The aim of this study was to provide evidence about the relationship between R&D and growth in high-technology SMEs during a period of economic downturn. As fast-growing and R&D-investing SMEs have been recognized as engines of growth in developed economies -being inclined to introduce radical innovations, develop new leading-edge technologies to introduce to the market and generate high-skilled workforce-, we conducted an in-depth analysis of the main elements characterizing different patterns of growth during a period of economic downturn. By means of a quantile regression we analysed the impact of R&D efforts over the conditional distribution of growth during a period of economic downturn. This approach allowed us to identify two different firms' profiles: fast growing and slow growing high-technology SMEs. For each profile, different characteristics of R&D investments and innovation activities appear to matter for growth. We show that fast growth in high-technology SMEs is not simply the direct result of R&D efforts: rather, sub-populations of such SMEs with different profiles in terms of R&D-growth paths exist (Freel, 2000). As already observed for EU high-technology firms (Coad and Rao, 2006) and innovative SMEs (Hölzl, 2009), we conclude that the distribution of "returns on R&D" is considerably different across firms.

Our findings about high-technology SMEs in Italy are largely in line with the empirical literature on R&D and innovation in European SMEs. In fact, we observed different SMEs profiles according to firms' size, age and innovativeness and these results are consistent with those of Tether and Massini (1998) and Mason *et al.* (2009) on high-technology SMEs in UK and with those of Delmar *et al.* (2003) in Sweden. Our study contributes to such a literature by showing how, additionally to other factors, also the type of R&D investments promoted by high-technology SMEs affects their growth paths in periods of economic downturn. In fact, for "R&D investing and fast-growing" SMEs – which are characterized by a smaller size, a younger age, and a higher ability to introduce technological innovations into the market with respect to their counterparts – investing in R&D plays a role on growth, irrespective of the type of R&D investment done. Conversely, the profile of "R&D investing and slow-growing" firms shows that growth in small high-technology SMEs is not simply the result of internal R&D efforts: companies with unfocused R&D activities may indeed grow less or experience a negative return on R&D. Therefore, firms experiencing slow growth during periods of economic downturn should complement their internal R&D investments with external technology acquisition in order to improve R&D effectiveness. In these cases, a balance between internal and collaborative R&D activities has a positive impact on growth. This last result represents the main contribution that this study offers and has relevant policy implications. Innovation policies targeting high-growth entrepreneurship (such as YICs, gazelles and high-tech startups) and typically supporting new product development and commercialization may indeed exert only a limited impact.

Similar to many other studies, the design of the current work is subject to limitations.

First, we intentionally focused our analysis on high-technology SMEs, to get a clear evidence of the linkage between R&D investments and firm performance during periods of economic downturns. Although we recognize that different degrees of R&D formalization exist across industries (Pavitt, 1974), our results might be affected by negligible errors as the sample selection was focused on the identification of high-technology firms pursuing continuous and formalized R&D activities. In light of this limitation, our results are not generalizable to the overall population of SMEs.

Second, to the purpose of this study we considered the entire time period 2009-2013 period as a phase of economic downturn, although different types of crises (financial crisis, economic crisis, liquidity constraints in the credit market) with different intensities occurred. Our choice was motivated by two reasons. First, from a methodological perspective, our model did not intend to estimate pre- and post-crisis effects. Second, and regardless of the nature of the recession, a period of downturn represents a good research setting to evaluate the effects of exogenous shocks on the relation between SMEs' R&D investments and performance and to compare it with prior evidences in different years.

Third, the type of data and the methodology used did not allow to explore and evaluate firms' strategic intentions nor organizational choices during a period of economic downturn. Also, the nature of variables used did not allow to provide empirical evidence of important theoretical concepts, like firms' absorptive capacity (Cohen and Levinthal, 1989) to evaluate the effects of learning on innovation. Qualitative analyses may be needed to address these aspects. We believe that all these limitations represent, at the same time, opportunities for future research.

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