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Innovation complementarities and firm growth

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Abstract

This article explores the relations between firm growth and a set of four innovation indicators (in-house R&D, external sourcing, product innovation, and process innovation) that capture the different sources, modes, and outcomes of the innovative strategies adopted by firms. While existing studies tend to focus on the individual effects on growth of each innovation activity, we stress that firms adopt heterogeneous innovation strategies, choosing to perform different combinations of the basic innovation activities. We directly address the empirical question as to whether jointly performing two basic innovation activities boosts sales growth above and beyond the separate contribution of each innovation activity when performed individually. Exploiting a panel of Spanish manufacturing firms observed between 2004 and 2011, we document instances of super-modularity of the growth function, and reveal the presence of complementarities between internal R&D and product innovation, and between product and process innovations. As such, the combination of these three basic innovation activities appears to be the most effective strategy for sustaining growth and market shares, while external sourcing does not appear to make any systematic contribution.

JEL classification: C21, D22, O31, O32

1. Introduction

Firms face many strategic decisions during their history, not least those concerning whether and how they should innovate. Indeed, in recent decades, innovation has become a vital component of firm strategies, against a backdrop of unprecedented rates of technology and market change, domestic and global competition, and the shortening of product life-cycles. "[N]ot to innovate is to die" (Freeman and Soete, 1997: 266) and similar slogans have been widely endorsed not only by managers and practitioners but also within the policy-making debate. In fact, initiatives to support firm innovation have come to be viewed as central to sustaining competitiveness and the specialization of sectors and countries, and to spurring employment and gross domestic product growth.

While theoretical models that take an aggregate, macroeconomic perspective—albeit from different traditions, ranging from the Schumpeterian evolutionary models inspired to Nelson and Winter (1982) to the new-growth theories and neoclassical interpretations of Schumpeterian dynamics that underpin the work of Aghion and Howitt (1992) and Aghion *et al.* (2005) among others—may have contributed to this view of innovation as an engine of growth, an in-depth analysis of the underlying micro-dynamics suggests a more nuanced picture. Innovation, by its very nature, involves high levels of uncertainty, idiosyncrasy, and risk-taking, as firms probe and re-probe, and experiment and test, and the effects of innovation on firm performance can be extremely heterogeneous and difficult to foresee (Dosi and Nelson, 2010). While the empirical evidence seems to confirm that innovative firms outperform their non-innovative counterparts across a variety of dimensions (including profits, productivity, and export performance—see Cohen, 2010, for a survey), the strength of the link between innovation and firm growth, especially in terms of sales and market shares, is far from clear-cut (Coad, 2009; Audretsch *et al.*, 2014).

Several explanations have been offered to account for this. First, the absence of any robust links between innovation effort and growth in output echoes the notion that the patterns of firm growth in the market are largely unpredictable (Bain, 1968; Geroski, 2002). A large body of empirical research confirms the difficulties encountered in identifying variables that can account for growth; yet, most scholars remain reluctant to accept that randomness or luck, as opposed to structural factors, might provide a convincing explanation of market dynamics (Denrell *et al.*, 2014). A different line forwarded in the literature is that the expected outcomes of innovation may be overshadowed by other factors, such as managerial practices (Bloom and Van Reenen, 2007), demand conditions and price competition (Pozzi and Schivardi, 2016), and marketing intensity (Arkolakis, 2016). However, the notion that such factors might constitute the main drivers of growth is inconsistent with the enormous volume of case studies reported in the strategic management literature, in which innovation is unequivocally considered the fundamental tool for ensuring firm competitiveness and growth. However, it is also argued that, while firms may appropriate the benefits of their innovative efforts through patents, secrecy, lead times, and other appropriability mechanisms, imitation can quickly erode the competitive advantage that firms gain through innovation. Yet, while this argument is theoretically plausible, it is not readily clear why imitation would adversely affect growth but not other dimensions of performance, such as profits or exports.

In this study, we explore the relations linking innovation and growth in the market, but we do so by adopting a different perspective, i.e., by recognizing that firms' innovative efforts can take many different forms. Indeed, firms engage in a wide range of innovation activities, by undertaking R&D, acquiring knowledge and/or technologies from external sources (i.e., other firms in the value chain, universities, PROs, etc.), developing and launching new products, implementing new processes, or changing organizational practices, to name just a few. As we discuss below, an expanding literature has examined the connections between firm growth and these activities, taking the latter as alternative proxies of an underlying continuous (and not readily measured) innovation process. Here, we consider the different innovation activities as separate activities that firms may decide to perform or to forgo. There is evidence of considerable heterogeneity in the way firms design their overall innovation strategies—opting, in some cases, to focus their efforts on just one activity, or, in other cases, to combine them, the decision being guided by a scarcity of resources (e.g., financial constraints or a lack of skilled personnel) or the difficulties in efficiently coordinating multiple activities. Moreover, firms tend to persist in their strategy preferences (Gunday *et al.*, 2011; Karlsson and Tavassoli, 2016). This heterogeneity in innovation strategies needs to be considered in any study of the links between innovation and the dynamics of firm growth and market shares.

Here, we focus on the following four dimensions of the innovation process: intramural R&D; the acquisition of external knowledge and technologies; the introduction of new-to-the-market products; and process innovation. Different combinations of these dimensions identify different innovation strategies. It is our conjecture that business growth trajectories, measured in terms of sales and market shares, depend on the specific strategy that firms decide to implement. Clearly, each strategy is associated with its own specific costs and challenges; yet, at the same time, each strategy has the potential to improve the ability to create and capture growth opportunities. To facilitate comparisons with the extant literature on the innovation–growth nexus, we first investigate the separate role of in-house R&D, external sourcing, and product and process innovations on market share dynamics. Then, we expand upon existing studies by asking whether specific combinations of basic innovation activities constitute more effective strategies for market success. To this end, we exploit the notion of modularity of the growth–innovation relation to empirically quantify whether in-house R&D, external sourcing, and product and process innovations display pairwise complementarities in fostering growth in the market.

To address these issues, we study the innovation–growth dynamics of 5064 Spanish firms observed between 2004 and 2011. In common with the European Community Innovation Surveys (CISs), our data set contains detailed information about the innovative activities of firms. However, unlike the CIS and most other innovation surveys, our dataset is longitudinal in nature and includes yearly information on the same set of firms over time.

We identify a considerable degree of heterogeneity in the contribution of innovation activities to expansion in the market. When considering the four activities separately, we find internal R&D to be the sole variable to display a strong relation with growth. In contrast, external sourcing and product innovation seem to ease only the growth of high-growth firms, while a negative but extremely weak association emerges between growth and process innovation. These results are partly in line with previous studies. More novel and interesting is our finding that the growth function exhibits innovation complementarities. Yet, not all combinations of innovation activities boost growth. We find complementarity between in-house R&D and product innovation, and between product and process innovations. This evidence highlights the complexity underlying the innovation–growth relations and offers a potential explanation for the inconclusive results reported in earlier studies that rely upon a unidimensional approach.

2. Literature review and working hypotheses

Our starting point is the notion that intramural R&D, the acquisition of knowledge and technologies from outside the firm, the development of new products, and the development of new processes are four distinct types of innovation activity that firms may choose to undertake or not, and to employ in different combinations as part of their innovation strategy. As such, we endorse the view that innovation is an ongoing, evolutionary (continuous and heterogeneous) learning process in which firms are constantly refining, and occasionally transforming, their products and processes, individually or in different combinations, by exploiting resources, ideas, information, and knowledge that originate from their in-house capabilities, R&D investments, and interaction with the external environment (Dosi, 1988; Dosi and Nelson, 2010).

What is already known about the relations between these activities and the ability of firms to sustain their growth in terms of sales? And what has already been documented regarding the possibility that relevant complementarities emerge in terms of their ability to contribute to firm growth? In this section, we examine the literature dedicated to analyzing these two points, as we seek to provide a framework guiding our empirical analysis.[1]

2.1 Innovation activities and firm growth

While innovation serves as a catchall term in macro or aggregate analyses of the innovation–growth nexus, the specificities of different types of innovative activity emerge quite clearly from micro-analyses that highlight how different activities serve different functions in the overall innovation process and in the mechanism that links innovation to performance. The Knowledge Production Function approach (Griliches, 1979, 1995; Crepon *et al*., 1998) describes a stylized mechanism that moves from the creation of knowledge by means of investment in innovative inputs (R&D primarily, but also the acquisition of external knowledge) to the ability to produce innovative outputs (new products and processes). In contrast, the Schumpeterian/evolutionary analysis of innovation and industrial dynamics describes a process that is far from "linear", in which the links between innovation inputs, innovation outputs, and firm performance are far from sequential. Seen from this perspective, the micro-dynamics underlying innovation are much more complex, idiosyncratic, uncertain, and, potentially, heterogeneous (Nelson and Winter, 1982; Dosi, 1988; Nelson and Winter, 2002).

Overall, innovation emerges as a multidimensional process, and its distinct dimensions matter differently for output and growth. Some innovation activities may impact quite directly on a firm's ability to sustain market success, whereas others do so more indirectly, via linkages with other intermediate dimensions of performance (e.g., productivity or profits).

Formal R&D is usually considered as having a positive effect on growth. Investing in the creation of new knowledge and exploring new solutions tend to increase the probability of significant discoveries. These in turn allow firms to develop new products and, eventually, to seize growth opportunities, sometimes serendipitously. By means of in-house R&D, firms can constantly refine, or transform, their products and processes to meet customer needs. Yet, these potential benefits may be hampered by the uncertainty inherent in the translation of R&D spending into valuable outcomes, as identified in the classical exploration/exploitation dichotomy (March, 1991; Greve, 2007).

Theoretically, various constraints may also hamper the link between firm growth and the acquisition of new knowledge/techniques from outside a firm's boundaries. On the one hand, much like internal R&D, different forms

1 We do not consider all those mechanisms explaining the contribution of innovation to employment growth and related to the long-standing debate on the labor-saving vs. labor-augmenting effects of innovation (see Vivarelli, 2014; Calvino and Virgillito, 2018 for exhaustive surveys on the topic).

of external sourcing (extramural R&D, improved machinery, new know-how, and acquired patents) can increase the overall knowledge base and innovative capabilities of a firm, thus boosting competitiveness and growth. On the other hand, specific challenges often arise from the nontrivial adaptation of outsourced innovative inputs to the specific characteristics, competences, and needs of each firm. Firms may lack the absorptive capacity necessary to master external knowledge (Cohen and Levinthal, 1990). Coordination issues within the knowledge user-knowledge producer interactions may be complex and difficult to manage (Laursen and Salter, 2006). Moreover, the ultimate effect may also vary, depending on whether firms outsource knowledge and technologies that are "core" to the development of new products and market positioning, or rather they place the focus on what are more "marginal" inputs (Cassiman and Veugelers, 2006; Leiponen and Helfat, 2010).

Theoretical studies are not unequivocal also about the links between firm growth and innovation output. In the case of product innovation, a direct positive effect would seem obvious, since the commercialization of new products is generally viewed as the direct way to achieve growth and market expansion (Hay and Kamshad, 1994; Cohen, 2010). Yet, the effect of product innovation depends on whether the new product expands upon or substitutes for ("cannibalizes," to use the jargon) the products already present in a firm's product portfolio. Similarly, the degree of product market competition also matters, that is, whether the new product represents a "radical" innovation new-to-the-market, or rather an incremental improvement new solely to the firm introducing it.

The potential effects of process innovations work indirectly via different channels. The classical interpretation is that new processes are implemented primarily to drive costs down, thereby improving cost efficiency and price competitiveness vis a vis the competitors. Thus, any benefits for sales growth and market shares are mediated by how strongly these new processes affect productivity, and by the extent to which efficiency is the main driver of market share reallocation across competing firms (something that is called into question by recent empirical evidence; see Bottazzi *et al*., 2010; Dosi *et al*., 2015). Moreover, returns from process innovation often depend on specific complementary assets and resources, which may be unavailable or of insufficient quality. All this hampers the development of strong links with output growth, and the benefits of process innovation may only become apparent during later stages.

In line with these theoretical predictions suggesting that many and possibly contrasting mechanisms interact, the empirical studies that seek to identify the separate role of each innovation activity confirm remarkable heterogeneities in the observed effects (see Cohen, 2010; Audretsch *et al*., 2014, for latest reviews).

First, a review of the extant literature suggests that finding convincing support for the positive effect of R&D is by no means easy. While early papers tend to document a positive link (Mansfield, 1962; Mowery, 1983), subsequent studies failed to find a significant association (see, among others, Geroski *et al*., 1997; Bottazzi *et al*., 2001; Geroski and Mazzucato, 2002). Second, and perhaps because the literature has long focused on R&D as the sole innovation input, there is a lack of systematic evidence regarding the effect of external sourcing of innovation on sales growth and market shares. An exception is Segarra and Teruel (2014), who document that external R&D has a significantly smaller impact than that of in-house R&D. Third, and in a similar vein, evidence is scattered and inconclusive regarding the direct impact of process innovation on output and market share dynamics. In fact, the bulk of the literature connects process innovation to productivity (see Griffith *et al*., 2006; Hall *et al*., 2009; Mairesse and Robin, 2009, among others). Of the few studies that seek to detect a direct link between process innovation and growth of sales or market shares, Freel and Robson (2004) show that incremental process innovations may positively correlate with sales growth, but their result only holds in the case of service firms. Cohen and Klepper (1996) find that the benefits of process innovation increase with firm size, but only in certain industries. And Goedhuys and Veugelers (2012) find no effect of process innovation on sales growth in a sample of Brazilian manufacturing firms. Fourth, and finally, evidence in the case of product innovation is mixed. Cucculelli and Ermini (2012) show that product innovation does not impact sales growth, unless tenure from the last product introduction is controlled for. Other studies suggest that the characteristics of the market and of newly introduced products are relevant. In general, more "radical" innovations, as captured by new-to-the-market products, make a stronger contribution to market share expansion (see the cross-country evidence in Hölzl, 2009). Yet, more incremental or imitative efforts related to introducing products that are new only to the firm, may also contribute to growth in specific contexts, as reported for Italy in Corsino and Gabriele (2011). In contrast, Freel and Robson (2004) record a negative correlation between product innovation (both incremental and novel) and the sales growth of manufacturing firms.

In view of the absence of robust direct relations between innovation variables and output growth, several studies explore a range of possible mediating channels. These show that relations are indeed mediated by firm-specific attributes, in particular size and age (with smaller and younger innovators achieving more rapid growth, see Storey, 1994) and access to finance (Revest and Sapio, 2013), and that results tend to vary across low- vs. high-tech sectors (Stam and Wennberg, 2009; Nunes *et al.*, 2012). Moreover, a recent strand in the literature shows that most innovation activities tend to present a positive, stronger effect for high-growth firms (Freel, 2000; Coad and Rao, 2008; Hölzl, 2009; Falk, 2012; Colombelli *et al.*, 2013; Mazzucato and Parris, 2015; Coad *et al.*, 2016).

The preliminary step included in our analysis, in which we separately estimate the effect of each basic innovation activity on sales growth, directly addresses this part of the literature. This paves the way for our more novel contribution, in which we examine the complementarities between combinations of innovative activity in eventually spurring sales growth and market shares. To date, very little is known about this, be it on the theoretical or empirical front.

2.2 Innovation strategies, complementarities, and firm growth

Influenced in the main by the Knowledge Production Function, previous studies considering the coexistence of different innovation activities within the same firm seek to reconstruct the supposedly linear relations moving from innovation inputs to innovation outputs, and their effects on performance. The well-known CDM model (Crepon *et al.*, 1998) provides an accompanying empirical framework to reconstruct these mechanisms. In what is a vast literature, studies often consider just one input (typically, R&D) and one output (typically, patents, but also product or process innovations) at a time, and take productivity as the relevant dimension of firm performance, although several variants do exist (see Mairesse and Mohnen, 2010, for a review). To the best of our knowledge, Goedhuys and Veugelers (2012) represent the only attempt to assess the relevance of internal vs. external knowledge sourcing in the generation of product and process innovations, and then to estimate the impact of successful new processes or products on sales growth.

Here, our contribution is unique in that we set out to determine whether growth and market expansion benefit from the complementarities that arise from different combinations of four innovation activities (namely, R&D, external sourcing, product innovation, and process innovation). The notion that a given innovation activity may be more beneficial if carried out in conjunction with another is, clearly, not new. Indeed, innovation studies have stressed a number of complementarities among innovation activities *within the innovation process*. However, what has yet to be addressed, either theoretically or empirically, is whether innovation activities display complementarities *within the growth function*. For instance, in-house and extra-mural R&D tend to complement each other, since internal R&D helps strengthening the absorptive capacities needed to master external knowledge. Or, similarly, R&D is often a prerequisite for successful development of new products and processes, as well as there is evidence that external sourcing favors both product and process innovations (Santamaria *et al.*, 2009; Pellegrino *et al.*, 2012; Goedhuys and Veugelers, 2012; Conte and Vivarelli, 2014). Can we also predict that innovation inputs and innovation outputs are likely to present complementarities when we take firm growth has the relevant outcome variable?

Our focus is specifically on pairwise complementarities. The question we pose is whether a firm that performs two innovation activities at the same time is likely to grow more than firms that perform only one of the two activities. Among the many empirical methods available for assessing complementarities, we opt for the general notion of super-modularity (Topkis, 1998). Innovation studies adopt this framework to determine whether different innovation inputs, or different obstacles to innovation, are pairwise complements in the generation of innovation outputs (Leiponen, 2005; Mohnen and Roller, 2005; Cassiman and Veugelers, 2006; Catozzella and Vivarelli, 2014). We apply the same conceptual and statistical framework to assess the role of pairwise complementarities in the process of firm growth.

Lacking any clear theoretical guidelines, and in the absence of previous attempts in this same direction, it is difficult to make accurate predictions. However, based upon the above considerations concerning the benefits and constraints that might characterize the innovation–growth nexus in relation to the different innovation activities, we forward the following working hypotheses.

First, we expect in-house R&D to present growth-enhancing complementarities with all the other innovation activities. R&D is likely to ease the introduction of new and qualitatively better products and to improve the ability to master new processes, ultimately creating the conditions to compete on the market and foster growth more strongly than when product and process innovations are conducted separately from R&D, and *vice versa*. Moreover, in-house R&D should improve the absorptive capacity and help facing the challenges posed by the external sourcing of knowledge and technology, thus enhancing the growth potential of firms that perform external sourcing in conjunction with R&D.

Second, and to some extent conversely, the challenges associated with external sourcing are likely to be more critical in relation to product and process innovations. Some firms might successfully combine the additional innovation capacity accrued via external sourcing with the ability to introduce new products or new processes; in other instances, however, the additional complexities associated with "buying innovation" from outside may put too much pressure on innovation management. As a result, the sign and direction of the complementarity between external sourcing and product and process innovations are highly uncertain. Firms performing just product or process innovation alone are not necessarily sentenced to grow less than firms that undertake such activities in conjunction with external sourcing.

Third, and finally, a specific caveat applies to the observation that the impact of process innovation is often mediated by productivity which, in turn, can lead to market expansion only under certain market conditions. While process innovation may, as discussed above, present positive complementarities with R&D and external sourcing, we expect innovation of this type to exhibit particularly strong complementarity with product innovation, since the combination of new processes and new products should ensure particularly high price–cost margins. Indeed, process innovation lowers production costs, while product innovation increases the price customers are willing to pay for improved goods or services: their joint effect should boost the ability to compete on the sales front well beyond the contribution the two activities would have if performed separately.

Whether our findings corroborate these predictions or not, they will at least provide a foundation for further empirical and theoretical developments that examine the role of innovation complementarities as a relevant source of firm growth and market success.

3. Data

3.1 Sources and working sample

We exploit a firm-level data set drawn from the Spanish Technological Innovation Panel (henceforth PITEC), jointly developed by the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT), and the Foundation for Technical Innovation (COTEC). The data are collected following the guidelines of the Oslo Manual (OECD/Eurostat, 2005) and, as such, they share the definitions and collection practices of a CIS-type data set. Thus, PITEC provides a rich set of variables that measure firms' engagement in different types of innovation activity, economic and noneconomic effects of innovation, self-reported evaluations of factors hampering or fostering innovation, participation in cooperative innovation activities, access to public funding, and engagement in complementary activities such as organizational innovation and marketing. Much like other CIS-type surveys, however, information about the firms' structural and industrial characteristics is limited. For each firm, the data set only records its annual sales and employment, main sector of activity, founding year, export status, industrial group affiliation, and little else.

Yet, unlike the CIS, the PITEC is longitudinal in nature. Indeed, since 2003, systematic data collection has ensured the consistent representativeness of the population of Spanish manufacturing and service firms over time, allowing us to monitor the same firms over a good number of years. This means we can control for unobserved factors that might have an impact on the relationship between innovation variables and sales growth patterns.

We select our working sample from an initial data set of 100,016 firm-year observations for the period 2004–2011. We focus on manufacturing firms, and focus on "organic growth"; hence we discard all firms involved in M&A events. The resulting sample is an unbalanced panel of 26,386 firm-year observations for which the variables used in our empirical exercise are nonmissing. Table 1 shows that the large majority of firms (62.09%) are observed over the entire sample period. A further 19.19% are present in the data for 7 years, while only a negligible percentage (7.31%) are present for less than 5 years.

Table 1. Composition of the panel

Time observed	#Firms	%	%Cum	#Observations
3	140	2.76	2.76	140
4	230	4.54	7.31	460
5	250	4.94	12.24	750
6	328	6.48	18.72	1312
7	972	19.19	37.91	4860
8	3144	62.09	100	18,864
Total	5064	100		26,386

Note: "Time observed" indicates the minimum number of years over which firms are observed: $T=3$ refers to firms that are observed for three periods; $T=4$ corresponds to firms that are observed for four periods, and so on.

3.2 Main variables

We focus on growth patterns as revealed by annual sales. Our dependent variable is defined as the log-difference:

$$G_{i,t} = s_{i,t} - s_{i,t-1}, \tag{1}$$

where

$$s_{i,t} = \log(S_{i,t}) - \frac{1}{N}\sum_{i} log(S_{i,t}), \tag{2}$$

and $S_{i,t}$ is sales of firm i in year t, and the sum is computed over the N firms populating the same (two-digit) sector. Normalization by sectoral averages removes trends common to all firms within the same sector, such as inflation and business cycle effects in sectoral demand. As a result, we essentially measure relative market expansion, capturing the dynamics of market shares.

We relate success in the market to four variables available in PITEC that refer to different types of innovation activity. These are:

1. *Internal R&D*—defined as intramural R&D expenditure, normalized by total sales.
2. *External Sourcing*—computed by summing the shares in total sales of three different activities that involve a decision to source innovation from other enterprises or organizations, namely, extramural R&D expenditure, investment in innovative machinery and equipment, and acquisition of external knowledge and technology (patents, know-how, etc.).
3. *Product Innov*—defined as the share of a firm's total sales due to new or significantly improved products that are new both to the firm and to the market.
4. *Process Innov*—a binary indicator equal to 1 if the firm introduces new or significantly improved production processes, and 0 otherwise.

The definitions of these variables in PITEC comply with international standards and have their equivalences in innovation surveys conducted in other countries. The interpretations made of these variables in the literature are broadly accepted. Internal R&D is the traditional proxy of innovative input, measuring formal efforts to generate new knowledge within the firm. Here, we adopt the usual approach and normalize by firm size (sales) to control for the well-known disparities across small-medium and larger firms. External sourcing is a summary term for three commonly used proxies of external inputs, and serves to contrast the choice between "making knowledge" internally and "buying innovation" from outside. Product and process innovations are two typical indicators of innovative outputs. Products perceived as being new-to-the-market (and not solely to the firm) are associated with the ability to develop more "radical" innovations and, therefore, more valuable products. The dummy for process innovation measures whether firms reorganize production or whether they implement new production processes.[2]

2 We do not have in the data a continuous variable measuring the expenses in process innovation.

Table 2. Innovation variables—descriptives

	Mean	SD	Median	Minimum	Maximum
Internal R&D	0.031	0.161	0.004	0	7.986
External Sourcing	0.012	0.079	0	0	5.158
Product Innov.	0.099	0.225	0	0	1
Process Innov.	0.633	0.482	1	0	1

Notes: Figures computed by pooling the working sample—26,386 observations. *Internal R&D* and *External Sourcing* expenditure are divided by sales; sales due to new products, *Product Innov.*, are expressed as a share of total sales; *Process Innov.* is a dummy variable.

4. Descriptive evidence

Table 2 shows the basic descriptive statistics for the innovation variables we study. All four indicators display highly skewed distributions, suggesting considerable heterogeneity in the extent to which each activity is performed by the firms in our sample. The firms appear more likely to engage in the internal generation of knowledge than they are to resort to external sources. Indeed, on average, internal R&D represents 3.1% of annual sales, while external sourcing absorbs 1.2% of their sales output. New-to-the-market products, on average, account for about 10% of yearly sales, which suggests that bringing to the market "genuinely" new products is, generally, not easy and a relatively infrequent occurrence. Finally, a relatively large proportion of firms perform process innovation (around 63% of observations).[3]

By way of an initial assessment of the relationship between growth G and innovation activities, Table 3 shows the basic descriptive statistics of relative growth rates G across firms that do vs. firms that do not perform a given activity. It is evident that the "innovators" tend to display larger mean and median rates of growth than those shown by the "non-innovators," regardless of the innovation variable considered. Notably, the median rate is positive for "innovators" and negative for "non-innovators," for all four proxies.[4]

Logically, non-innovators in relation to one variable may still be innovative firms, in the sense that they may perform one or more of the other activities. Since we work here with four basic innovation activities, there are 16 mutually exclusive combinations that firms can choose to perform. These combinations form the "innovation strategies" listed in Table 4, where INT, EXT, $PROD$ and $PROC$ are dummies indicating if a firm performs one of the four basic activities. For instance, strategy STR_0 refers to firms that do not innovate at all; strategy STR_1 identifies a firm that performs process innovation only; strategy STR_3 refers to a firm that performs product and process innovations simultaneously, but which performs neither R&D nor external sourcing; and so on, for firms that perform only two or three activities, or all of them jointly (STR_{15}).

We observe that firms do, in many instances, perform more activities simultaneously. Likewise, different combinations seem to be associated with different growth performance. On average, most strategies are associated with negative relative growth, while market success seems most likely in instances where firms perform internal R&D in conjunction with external sourcing, in combination with either of the two forms of innovation output. Clearly, these are merely descriptive results. Our analysis of complementarities shall add statistical robustness to addressing the question as to whether there are pairs of innovation activities that have a higher pay off when performed jointly than when firms undertake them separately.

3 Notice that we removed a number of outliers, i.e., values greater than 10 in the cases of internal R&D and external sourcing (34 and 19 firm-year observations, respectively). We also tested to ensure that the main results of the empirical analysis are not affected when applying a more stringent threshold on these two variables (thus, we retained only the firm-year observations with a value below 5). The results of these robustness checks are available upon request.

4 The median is usually more informative, since firm growth rates tend to display fat-tailed behavior (see Bottazzi and Secchi, 2006). This stylized fact is also confirmed in our data, both for "innovators" and "non-innovators," as regards the four innovation activities studied. See the distributional analysis in Appendix A.

Table 3. Sales growth by innovation status—descriptive statistics

		Mean	Median	Minimum	Maximum	#Observations
Internal R&D	NO	−0.040	−0.016	−4.813	3.853	11,225
	YES	0.009	0.006	−3.821	4.674	15,161
External Sourcing	NO	−0.026	−0.009	−4.104	3.853	15,053
	YES	0.007	0.005	−4.813	4.674	11,333
Product Innov.	NO	−0.027	−0.011	−4.813	4.674	10,237
	YES	−0.002	0.002	−3.958	3.57	16,149
Process Innov.	NO	−0.032	−0.016	−4.813	4.674	10,290
	YES	0.001	0.006	−3.958	3.57	16,096

Notes: Descriptive statistics of firm growth *G* by "innovators" vs. "non-innovators" defined as firms that do (YES) or do not (NO) engage in each innovation activity. Figures computed by pooling the working sample—26,386 observations.

Table 4. Innovation strategies

Strategy	INT	EXT	PROD	PROC	Combination	#Observations	Freq.	#Firms	G Mean	G SD
STR_0	0	0	0	0	No inno	5351	20.28	1057	−0.0552	0.4294
STR_1	0	0	0	1	PROC	2394	9.07	1005	−0.0373	0.3985
STR_2	0	0	1	0	PROD	535	2.03	266	−0.0561	0.4135
STR_3	0	0	1	1	PROD&PROC	739	2.80	411	−0.0507	0.4952
STR_4	0	1	0	0	EXT	340	1.29	186	−0.0258	0.3698
STR_5	0	1	0	1	EXT&PROC	1336	5.06	597	0.0018	0.3085
STR_6	0	1	1	0	EXT&PROD	86	0.33	66	−0.0206	0.2484
STR_7	0	1	1	1	EXT&PROD&PROC	443	1.68	261	0.0309	0.2807
STR_8	1	0	0	0	INT	1492	5.65	539	−0.0149	0.3603
STR_9	1	0	0	1	INT&PROC	2433	9.22	826	−0.0098	0.2912
STR_{10}	1	0	1	0	INT&PROD	941	3.57	368	−0.0114	0.3315
STR_{11}	1	0	1	1	INT&PROD&PROC	2143	8.12	800	−0.0010	0.3200
STR_{12}	1	1	0	0	INT&EXT	877	3.32	344	0.0261	0.3759
STR_{13}	1	1	0	1	INT&EXT&PROC	2977	11.28	755	0.0183	0.3160
STR_{14}	1	1	1	0	INT&EXT&PROD	668	2.53	238	0.0185	0.3179
STR_{15}	1	1	1	1	INT&EXT&PROD&PROC	3631	13.76	688	0.0276	0.3306

Notes: This table reports the 16 mutually exclusive innovation strategies, defined as combinations of the four basic innovation activities. For each strategy, we detail occurrences and descriptive statistics for sales growth (mean, *G Mean*, and SD, *G SD*). Figures computed by pooling the working sample—26,386 observations.

5. Main analysis

Our analysis proceeds in two steps. First, we examine the impact of each innovation activity on growth, by conducting a panel analysis of a standard innovation-augmented firm growth regression. This provides an initial understanding of the innovation–growth relations, before we address the key question concerning complementarities between pairs of innovation activities, which constitutes our second and main contribution.

5.1 The separate role of innovation activities

We start by examining a standard dynamic panel regression model:

$$G_{i,t} = \alpha\, G_{i,t-1} + \beta\, INNOV_{i,t-1} + \gamma \times \mathbf{Z}_{\mathrm{i,t-1}} + u_i + \epsilon_{i,t}, \tag{3}$$

where the dependent variable G is our measure of relative growth, the main regressor $INNOV$ represents the different innovation activities considered, while we also include a set of firm-level controls $\mathbf{Z}$, together with the usual composite error term (a firm fixed-effects u_i, plus a regular time-varying error $\epsilon_{i,t}$).

We explore different variants of the model in which the four innovation activities enter either separately or together at the same time. In all specifications, the innovation variables enter with a 1-year lag, which partially, at least, addresses potential simultaneity problems.[5] The inclusion of firm fixed-effects implies that identification works within firm over time. Thus, the coefficient of primary interest, β, captures the average effect of within-firm changes in the innovation variables on subsequent within-firm changes in relative sales growth.

Panel methods help to mitigate standard omitted variable bias, which in our case can represent a relatively severe source of inaccuracy in the estimation, due to the relatively small set of firm-level controls available. As discussed, and in common with other CIS-type data sets, the PITEC database contains only a limited list of firm-level attributes for inclusion in a typical Gibrat-type growth regression. Here, our control set $\boldsymbol{Z}$ includes the following lagged attributes: a proxy for firm size in terms of the number of employees (in logs, labeled as $\ln Empl$); firm age computed by year of foundation (in logs, $\ln Age$); three dummy variables, respectively, taking a value of 1 if firm i is an exporter (*Export*), receives public financial support for innovation (*PubFund*), or belongs to an industrial group (*Group*), and 0 otherwise; and the percentage of R&D technicians over the firm's total employment (*Techn*). Table 5 reports the basic descriptive statistics for this set of variables.[6]

PITEC provides no balance sheet information or details of financial statements that would enable us to control for other potentially relevant characteristics, such as productivity, financing structure and proxies of financial constraints, managerial and organizational traits, or input quality. Firm fixed-effects absorb at least the time-invariant component of these unmeasured firm attributes, while we resort to panel-GMM estimation to control for additional sources of endogeneity. We apply the GMM-DIFF estimator (Arellano and Bond, 1991), which mitigates the endogeneity of *INNOV*, lagged growth and other regressors by taking lags of the covariates as instruments after the differencing of the main regression equation.[7] The set of instruments varies depending on the specification used. *Age* and year dummies are always used as exogenous variables, while different lags of G, *INNOV*, $\ln Empl$, *Group*, *Export*, *PubFund*, and *Techn* are selected by applying the standard Arellano–Bond tests for serial correlation and the robust Hansen test for overidentifying restrictions.

Table 6 shows the results. In Columns 1–4 we present the estimates obtained when entering each *INNOV* proxy separately, that is, without controlling for the possibility that firms might also perform the other activities. As such, these estimates consider the impact of each activity on relative growth as if each of them was in fact an alternative proxy of the underlying innovation process. In Column 5, we estimate a full-model specification in which all four innovation variables enter simultaneously. In this case, by controlling for the possibility that firms perform more than one innovation activity at a time, the estimated effects of each *INNOV* proxy capture more precisely the notion that each innovation activity plays its own specific contribution to growth.

Our findings show that intramural R&D stands out as the only innovation activity having a marked effect on subsequent expansion in the market. In the case of the other variables, our analysis essentially presents negative results. The coefficients associated with external sourcing and product innovation are, in fact, statistically equal to 0 in all models, while process innovation actually appears to hamper growth (negative sign) when controlling for the other innovation activities in the full-model. However, this effect is barely significant.[8]

5 We also checked models including a full lag structure. The baseline model with a 1-year lag between *INNOV* and growth was chosen following the sequential rejection of the statistical significance of longer lags.

6 The *PubFund* dummy records any kind of public financial support for innovation activities from Spanish local or government authorities and from the European Union bodies, including tax credits or deductions, grants, and subsidized loans and loan guarantees, while excluding research or innovation activities entirely conducted for the public sector under a specific contract.

7 We prefer this estimator to the alternative GMM-SYS estimator (Blundell and Bond, 1998), since firm growth is known to display weak persistence over time. Thus, time-differences of growth are poor instruments for growth levels.

8 The coefficients on the control variables display robust patterns, irrespective of the specification considered. Negative autocorrelation of sales growth over time is partly explained by our definition of growth as being relative to that of other firms in the sector. The negative and significant coefficients on firm age confirm previous findings that younger firms grow more rapidly than do their more mature counterparts. Furthermore, since identification here works within-firm over time, the negative coefficients on export status imply that becoming an exporter reduces relative growth. This result should not be confused with the more common finding that, across-firms, exporters typically grow more than non-exporters.

Table 5. Descriptive statistics for the control variables

	Mean	SD	Median	Minimum	Maximum
G_{t-1}	0.026	0.376	0.027	−4.813	4.739
$\ln Empl_{t-1}$	4.088	1.309	3.932	0	9.234
$\ln Age_t$	3.223	0.598	3.258	0	5.088
$Export_{t-1}$	0.796	0.403	1	0	1
$PubFund_{t-1}$	0.354	0.478	0	0	1
$Group_{t-1}$	0.378	0.485	0	0	1
$Techn_{t-1}$	0.205	0.269	0	0	0.992

Note: Figures computed by pooling the working sample—26,386 observations.

Table 6. Innovation activities and firm growth

Dependent variable is G_t	(1)	(2)	(3)	(4)	(5)
$Internal\ R\&D_{t-1}$	0.3482***				0.3298***
	(0.039)				(0.074)
$External\ Sourcing_{t-1}$		0.2891			0.0472
		(0.303)			(0.065)
$Product\ Innov._{t-1}$			0.3411		−0.0330
			(0.246)		(0.186)
$Process\ Innov._{t-1}$				0.0617	−0.0947*
				(0.145)	(0.053)
G_{t-1}	−0.0877**	−0.3206***	−0.3754**	−0.2869*	−0.0544
	(0.036)	(0.116)	(0.161)	(0.157)	(0.036)
$\ln Empl_{t-1}$	−0.2034	−0.1865	−0.2448	−0.2642	0.0433
	(0.193)	(0.281)	(0.285)	(0.251)	(0.280)
$\ln Age_t$	−0.1554**	−0.2233**	−0.3285***	−0.3042***	−0.1526**
	(0.068)	(0.089)	(0.082)	(0.079)	(0.077)
$Export_{t-1}$	−0.0769**	−0.2455**	−0.2671**	−0.2235**	−0.0665*
	(0.036)	(0.117)	(0.115)	(0.108)	(0.037)
$PubFund_{t-1}$	−0.0091	0.0164	0.0479	0.0413	0.0344
	(0.018)	(0.063)	(0.059)	(0.054)	(0.055)
$Group_{t-1}$	−0.0246	−0.0236	−0.0252	−0.1471	−0.0267
	(0.032)	(0.030)	(0.029)	(0.090)	(0.034)
$Techn_{t-1}$	−0.0552	−0.1415	0.0909	−0.0308	−0.0004
	(0.084)	(0.177)	(0.258)	(0.098)	(0.044)
AR(1)	0.000	0.003	0.033	0.011	0.000
AR(2)	0.199	0.224	0.220	0.468	0.076
Hansen	0.102	0.100	0.125	0.118	0.225
Wald χ^2	173.68***	76.03***	78.75***	85.82***	131.52***
#Observation	21,291	21,291	21,291	21,291	21,291

Notes: GMM-DIFF estimates of equation (3). Regressions include a full set of year and sector dummies. Robust standard errors in parentheses, clustered at firm-level: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. We also report *P*-values of the Arellano–Bond test for first- and second-order serial correlation, AR(1) and AR(2), together with the *P*-value of the robust Hansen test of overidentifying restrictions for instruments validity.

The absence of any effect on growth observed for three out of the four innovation activities may in part have a statistical explanation, since within-firm identification eliminates the time-invariant component of the data. However, this interpretation would appear to carry some weight only in the case of the process innovation dummy, since the respective statuses of "process innovators" and "process non-innovators" remains relatively unchanged over the sample period, even though there are cases of status switching in the data. In contrast, product innovation and external sourcing are continuous variables that do change within firms over time.[9]

Other more convincing explanations for our findings lie in the diversity of the different innovation activities considered here. In the case of product innovation, our findings suggest that new products do not necessarily impact sales growth, as might be thought. And this fact emerges even if we consider here "more radical" innovations (products new-to-the-market) that would theoretically be particularly relevant for market share expansion. Instead, it appears that the cannibalization of existing products, or the fact that new products are marginal to a firm's portfolio, means the contribution of product innovation is, on average, vanishing. The insignificant effect of process innovation may be attributed to two, not mutually exclusive, mechanisms. On the one hand, the result may simply show that the type of process restructuring implemented is of "low quality" and marginal. On the other hand, our findings may simply reflect the notion that new processes primarily impact efficiency, and only affect market growth indirectly. In this regard, our result is in line with recent studies that document that market shares do not necessarily redistribute in favor of the most efficient firms (Bottazzi *et al*., 2010; Dosi *et al*., 2015). Finally, the negative result in the case of external sourcing appears to show that, at least on average, firms have difficulties in managing the challenges posed by having to integrate and exploit sources of innovation acquired outside the firms' boundaries.[10]

5.2 Complementarities between innovation activities

The results reported so far reveal that the different innovation activities are not all alike, and that they present heterogeneous relations with sales growth. We next address the key question posed here, namely, whether a superior growth performance can be achieved by combining different innovation activities. Resorting to the notion of complementarity, we seek to determine if the contribution to growth is higher when two activities are performed jointly than when a firm opts to perform just one of the two activities.

To assess the presence of complementarities, we exploit the general concept of super-modularity. In general terms, consider an objective function $f(\mathbf{X})$, where $\mathbf{X}$ is a vector of binary arguments $X = \{X_1, X_2, \ldots, X_n\}$, such that $X_j = 1$ if a certain action j is undertaken and 0 otherwise. Then, two actions X_j and X_i are complements if f is supermodular in X_j and X_i, that is, if the effect of choosing X_j on the objective function f is larger if also X_i is chosen at the same time, as compared to other possible combinations where X_j appears as not coupled with X_i. Equivalently, X_j and X_i are complements if the following inequality holds:

$$f(X_j \vee X_i) + f(X_j \wedge X_i) \geq f(X_j^c) + f(X_i^c), \quad (4)$$

where X^c stands for "non-X."

The application of this framework to examine super-modularity of firm growth with respect to innovation activities involves two steps. First, we need to specify and estimate a "growth function" where our measure of relative growth G depends on all the possible mutually exclusive combinations of the four basic innovation activities. These combinations correspond to the 16 strategy dummies presented in Table 4 above, which indicate whether firms do or do not perform each activity, and whether they perform the activity alone or in combination with the others. Second, we need a statistical procedure to test whether combinations in which two basic activities enter together yield more growth than combinations in which the two activities are performed separately.

We specify the growth function as a variant of equation (3):

$$G_t(\mathbf{STR}, G_{t-1}, \mathbf{Z_{t-1}}) = G_t(STR_0, STR_2, \ldots, STR_{15}, G_{t-1}, \mathbf{Z_{t-1}}), \quad (5)$$

9 Recall, also, that we tested longer lag structures, so that the absence of any effect estimated for most innovation variables cannot be explained by simply arguing that it takes longer than a year for innovation to affect growth.

10 While the estimates presented here capture the effects on the "average firm," we also performed a quantile regression analysis to detect asymmetries in the innovation–growth relation across the growth quantiles, in line with recent studies suggesting that innovation activities impact fast-growing firms differently. These results are presented and discussed in Appendix B.

where G is regressed against the vector **STR** of all the strategy dummies (defined in Table 4), its past G_{t-1} and the set $\mathbf{Z}$ of (lagged) controls.

Super-modularity of G with respect to the lattice of the strategies **STR** means having to check that, given two partitions $\mathbf{STR}'$ and $\mathbf{STR}''$, the following relationship holds:

$$G(STR' \vee STR'', \mathbf{Z}) + G(STR' \wedge STR'', \mathbf{Z}) \geq G(STR', \mathbf{Z}) + G(STR'', \mathbf{Z}). \quad (6)$$

The number of nontrivial inequalities to verify is $2^{(K-2)} \sum_{i=1}^{K-1} i$, where K is the number of basic categories for which we want to assess pairwise complementarity, and $i=2$ (binary choices) (see Topkis, 1998). In our case $K=4$, thus we have 24 inequality constraints to verify, four for each pairwise combination of basic innovation activities. Labeling as b_j the coefficient to be estimated on each strategy dummy STR_j in a linear regression of the growth function in equation (5), the relevant constraints can be compactly written as follows:

- INT-EXT complements if: $b_{8+s} + b_{4+s} \leq b_{0+s} + b_{12+s}$ with $s = 0, 1, 2, 3$
- INT-PROD complements if: $b_{8+s} + b_{2+s} \leq b_{0+s} + b_{10+s}$ with $s = 0, 1, 4, 5$
- INT-PROC complements if: $b_{8+s} + b_{1+s} \leq b_{0+s} + b_{9+s}$ with $s = 0, 2, 4, 6$
- EXT-PROD complements if: $b_{4+s} + b_{2+s} \leq b_{0+s} + b_{6+s}$ with $s = 0, 1, 8, 9$
- EXT-PROC complements if: $b_{4+s} + b_{1+s} \leq b_{0+s} + b_{5+s}$ with $s = 0, 2, 8, 10$
- PROD-PROC complements if: $b_{2+s} + b_{1+s} \leq b_{0+s} + b_{3+s}$ with $s = 0, 4, 8, 12$

For each pair, the associated inequalities must hold jointly. Tests of joint inequality constraints are not straightforward to implement. We apply the Wald-type statistic and the procedure derived by Kodde and Palm (1986). The test statistic is defined as:

$$D = (C\tilde{\mathbf{b}} - C\hat{\mathbf{b}})'(C' cov(\hat{\mathbf{b}})C)^{-1}(C\tilde{\mathbf{b}} - C\hat{\mathbf{b}}) \quad (7)$$

with

$$\tilde{\mathbf{b}} = \underset{\mathbf{b}}{\operatorname{argmin}}(C\mathbf{b} - C\widehat{\mathbf{b}})'(C' cov(\widehat{\mathbf{b}})C)^{-1}(C\mathbf{b} - C\widehat{\mathbf{b}}) \quad s.t. \quad C\mathbf{b} \leq 0, \quad (8)$$

where $\hat{\mathbf{b}}$ is the estimator of the coefficients $\boldsymbol{b}$ in the growth function and $cov(\hat{\mathbf{b}})$ the associated covariance matrix, while C is the matrix that maps the coefficients into the inequality constraints stated above. The set $\tilde{\mathbf{b}}$ is obtained as the closest value to the estimates of $\boldsymbol{b}$ under the restrictions imposed by the matrix C, and it can be computed via quadratic minimization under inequality constraints.

Notice that the D statistic does not have an exact distribution, but Kodde and Palm (1986) provide lower and upper bounds for different levels of significance. The null of complementarity is accepted for values of D below the lower bound, and it is rejected for values above the upper bound, whereas the test is inconclusive if the estimated D falls between the two bounds.

The main requirement for the whole procedure to be valid is that $\hat{\mathbf{b}}$ is a consistent estimator of the vector of strategy dummy coefficients $\boldsymbol{b}$. To get as close as possible to consistency, we apply, as before, a GMM-DIFF estimator, and so account for firm fixed-effects and the possible endogeneity of both innovation strategies and firm-level controls. Notice also that we use a 1-year lag of the strategy dummies.

The GMM-DIFF estimates of the growth function are presented in the left-hand panel of Table 7 (with STR_0 normalized to 0). The set of instruments includes lags of growth and controls, as well as lag-2 of the innovation strategy dummies. As such, the coefficients convey little information, as they do not provide a formal test of complementarity. In the right-hand panel, we show the estimated D statistics and report in bold the combinations of basic innovation activities where the null of complementarity cannot be rejected at the 10% level, which is the standard significance level employed in previous studies exploiting this methodology.

Our results support the presence of complementarity in just two cases. First, it is present between internal R&D (INT) and product innovation (PROD). Previously, internal R&D emerged as being beneficial to relative sales growth when its “separate” role was examined in the panel regressions in Section 5.1. The super-additive effect observed here implies that internal R&D exerts a stronger effect on growth when it is coupled with the introduction

Table 7. Estimation results and complementarity test

		Complementarity test	
Dependent variable is G_t	GMM estimates	Pair	Wald statistic
$STR_{1,t-1}$	0.0327	INT-EXT	2.5637
	(0.118)	**INT-PROD**	**0.9227**
$STR_{2,t-1}$	0.1751	INT-PROC	2.1074
	(0.339)	EXT-PROD	2.5533
$STR_{3,t-1}$	0.0104	EXT-PROC	5.9878
	(0.328)	**PROD-PROC**	**0.8102**
$STR_{4,t-1}$	0.5051		
	(0.379)		
$STR_{5,t-1}$	−0.1231		
	(0.163)		
$STR_{6,t-1}$	−0.0351		
	(0.823)		
$STR_{7,t-1}$	−0.0553		
	(0.265)		
$STR_{8,t-1}$	0.5152***		
	(0.179)		
$STR_{9,t-1}$	0.2201		
	(0.179)		
$STR_{10,t-1}$	0.2904		
	(0.234)		
$STR_{11,t-1}$	0.3336		
	(0.228)		
$STR_{12,t-1}$	0.2357		
	(0.259)		
$STR_{13,t-1}$	0.2562		
	(0.183)		
$STR_{14,t-1}$	0.5431**		
	(0.267)		
$STR_{15,t-1}$	0.2885		
	(0.203)		
G_{t-1}	−0.2990***		
	(0.104)		
$\ln Empl_{t-1}$	−0.1304		
	(0.195)		
$\ln Age_t$	−0.3154***		
	(0.076)		
$Export_{t-1}$	−0.3082**		
	(0.128)		
$PubFund_{t-1}$	0.0109		
	(0.022)		
$Group_{t-1}$	−0.0335		
	(0.033)		
$Techn_{t-1}$	−0.5488*		
	(0.294)		
AR(1)	0.000		
AR(2)	0.179		
Hansen	0.192		
Wald χ^2	99.58***		
Observation	21,291		

Notes: GMM-DIFF estimates of a linear panel specification of the growth function in equation (5). Regression includes a full set of year and sector dummies. Robust standard errors in parentheses, clustered at firm-level: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. We also report *P*-values of Arellano–Bond test for first- and second-order serial correlation, AR(1) and AR(2), together with the *P*-value of the robust Hansen test for overidentifying restrictions.

Complementarity test: Bold values indicate that the null of complementarity cannot be rejected at 10% significance level (lower bound = 1.642, upper bound = 7.094).

of new products. At the same time, while product innovation did not impact significantly on market share dynamics when considered alone in the panel estimates of Section 5.1, the INT-PROD complementarity observed here indicates that product innovation becomes beneficial to growth if undertaken jointly with internal R&D.

Second, we also find evidence of complementarity between process (PROC) and product (PROD) innovations. Much like in the case of the INT-PROD complementarity, this result confirms that introducing new products can in fact make a contribution to growth dynamics when coupled with another innovation activity. At the same time, we also identify a role for process innovation. The separate effect of process innovation was barely significant in the panel analysis, but we find that its contribution to growth increases when combined with product innovation.

The results of all the other complementarity tests are inconclusive. It is particularly noteworthy that we do not detect any complementarity between external sourcing and the other innovation activities. This finding adds to the negative result that emerged from the panel analysis of the separate effect of this innovation activity. The contribution of buying knowledge and technologies from outside the firm does not increase when these activities are performed in conjunction with other innovation activities. This confirms that combining external sources of innovation with other innovation activities may, in fact, result in an excessively high level of complexity. At the same time, performing other activities does not improve the ability of firms to absorb external knowledge and technologies in such a way that it eventually fosters growth and market share dynamics.

6. Conclusions

The relationship between innovation and firm growth has remained unfathomable to researchers for many years. While macroeconomic theories tend to predict a strong positive impact of innovation on growth performance of sectors and countries, the multifaceted, and uncertain nature of the innovation process, as described in the microeconomics of innovation, complicates the picture considerably. Indeed, empirical studies report extremely mixed results in terms of the effects that the innovation activities undertaken by firms have on sales growth and market share dynamics.

In this article, we have provided fresh insights into the relationship between innovation and market success in terms of sales growth, by examining the effects of four key innovation activities that firms may decide to perform, encompassing innovation inputs and outputs as well as different modes of sourcing new knowledge. After a preliminary, more standard investigation of the individual role played by such four innovation activities in relation to firm expansion in the market, we improve from existing studies by exploring whether it is a firm's ability to combine innovation activities into specific innovation strategies that matters for market success.

The overall picture emerging from the analysis points to interesting heterogeneities in the role played by different innovation activities and strategies in the growth process.

When we consider the four innovation activities separately, we find a strong positive effect of internal R&D; a mildly negative, and essentially insignificant, effect of process innovation; and no effect in the cases of external sourcing and product innovation. The negative result in the case of external sourcing lends support to the view that knowledge is inherently firm-specific, and so businesses may face considerable difficulties in integrating innovation generated outside the firm. Likewise, the absence of any effect in the case of process innovation is in line with predictions that new processes are designed primarily to enhance efficiency, and will only affect sales growth indirectly and, then, only in fairly late stages. Finally, the insignificant results associated with product innovation reflect the fact that product portfolio dynamics and market positioning may hamper a simplistic one-to-one mapping between the introduction of new goods and services and the expansion of market shares. All in all, we would wish to highlight that the different innovation activities should not be seen as imperfect, interchangeable proxies of a more complex, underlying process. Each activity seems to have its own specificities, which in turn result in quite distinct relations with firm growth.

The analysis of the pairwise complementarities between innovation activities enables us to add further insights. While we are able to confirm the importance of internal R&D as a driver of sales growth, we find that product and process innovations represent two sources of relevant complementarities, too. Indeed, we find that the beneficial effect of R&D on growth turns even stronger when R&D is coupled with product innovation. Moreover, growth is fostered when process and product innovation are carried out jointly. In short, combining R&D and product innovation, as well as jointly conducting process and product innovations emerge as the two most valuable strategies.

The research agenda, of course, remains open to a number of future developments, but above all to deepen the analysis of the interactions between the different innovation activities considered here. We foresee two possible interesting avenues for further research in this direction, both of which address some of the limitations of the present study. First, by taking advantage of data sets that cover a longer time period, the effects of the sequential adoption of basic innovation strategies could be studied. In this way, we could explore, for instance, whether a positive impact of external sourcing on growth might be restored for firms that systematically perform product and/or process innovations several years after having invested in external sources. Or, in the same vein, we might examine whether the complementarity observed here between product and process innovations arises from the fact that new processes are a prerequisite for product innovations, or, vice versa, whether new products lead to subsequent adjustments in production processes before they impact on market shares. Second, and notwithstanding the fact that our study of complementarities incorporates the notion that firms engage at the same time in a variety of innovation activities, the relationship between growth and the degree of "complexity" of the innovation strategies adopted by firms could be analyzed in greater depth. For instance, we might derive a taxonomy to characterize complexity in terms of the coherence between the different innovation activities performed within each firm and, on the basis of this, assess whether this translates into distinct patterns of growth. Our results to date suggest that strategies that simultaneously pursue internal R&D and process and product innovations might provide the most effective combination for spurring growth and greater market shares.

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Appendix

Appendix A—distributional analysis

In Figure 1 we report kernel estimates of the unconditional distribution of the relative growth rates G as defined in the main text, across firms that perform ("innovators") or do not perform ("non-innovators") a given innovation activity. "Non-innovators" are generally more concentrated to the left part of the distribution. Differences across the two groups are less clear-cut in the right tails, with the two distributions substantially overlapping, irrespective of the innovation variable considered. Visual inspection is complemented by a Fligner and Policello (1981) test of distributional equality (reported on the plots as FP), which allows us to assess which of the two distributions stochastically dominates the other, for each innovation variable considered. The null hypothesis of stochastic equality is always rejected, and the positive FP statistics imply that "innovators" present a higher probability of experiencing higher growth than "non-innovators" do.

Appendix B—quantile regressions

Motivated by the stylized fact that growth rates exhibit fat-tails, the literature on the innovation–firm growth nexus increasingly adopts quantile regression techniques to disentangle the effect of innovation proxies across the spectrum of the growth rates distribution (see Coad *et al.*, 2014, for a recent review). To uncover possible asymmetric effects across the growth quantiles in our data, we apply the fixed-effects quantile regression estimator developed in Canay (2011) and reestimate the full model specification of equation (3), that is, with all innovation variables entering at

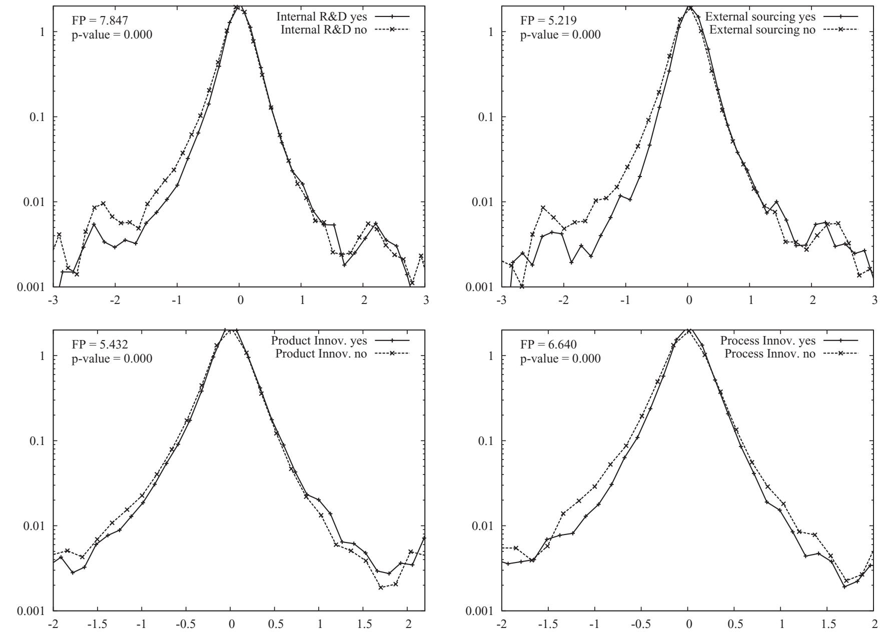

Figure 1. Kernel estimates (Epanechnikov kernel) of growth densities across "innovators" vs. "non-innovators," defined as firms that do (YES) or do not (NO) engage in each innovation activity. Innovation proxies are *Internal R&D* or *External sourcing* (top row), and *Product Innov*. or *Process Innov*. (bottom row). Figures also report a Fligner and Policello (1981) test of stochastic dominance: a positive and significant FP statistic indicates that "innovators" dominate "non-innovators." Results obtained by pooling the working sample—26,386 observations.

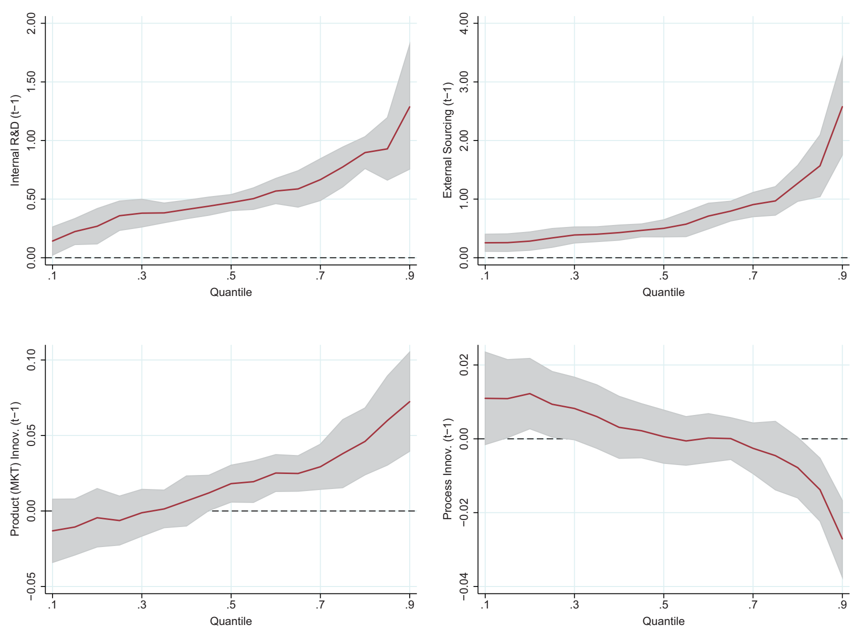

Figure 2. Fixed-effects quantile regression estimates of coefficient β from equation (3). Innovation variables are internal R&D (top left), external sourcing (top right), product innovation (bottom left), and process innovation (bottom right). The shaded areas represent 99% confidence bands, constructed via bootstrapped standard errors.

the same time (as in Column 5 of Table 6). Notice that we cannot include the autoregressive term G_{t-1}, since fixed-effects might exacerbate the bias due to the presence of the lagged dependent among the regressors, and there is no a GMM-equivalent solution for quantile estimates. Likewise, we cannot control for endogeneity of innovation activities and other regressors.

Figure 2 shows a graphical analysis of the variation of the innovation variable coefficients across the quantiles of the dependent variable G (full results reporting all coefficient estimates available upon request to the authors). A common pattern characterizes the two measures of innovation input, internal R&D and external sourcing. The estimates are positive and significantly different from 0 in practically all the quantiles, though coefficients are smaller in magnitude for shrinking or slow-growing firms. Product innovation shows a positive and statistically significant association with sales growth starting only from the median, and the estimates increase steadily while moving toward the top decile. Conversely, the coefficients are insignificant across shrinking firms. Finally, the relationship between sales growth and process innovation is very weak, if present at all.

Of course, a direct comparison with panel estimates cannot be made, stricto sensu, given the different specification (no lagged growth and no control for endogeneity). However, two finding emerge as interesting to complement the panel analysis presented in this article. First, R&D is confirmed as important for growth in all quantiles, but its role is particularly relevant for firms that experience large jumps in relative market growth. Second, product innovation and external sourcing, neither of which affects average growth in the panel estimates, do in fact have a positive and significant association with growth of high-growth firms, in the top quantiles of the relative growth rates distribution.