How Can Firms' Basic Research Turn Into Product Innovation? The Role of Absorptive Capacity and Industry Appropriability

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Abstract—**We explain why companies seeking superior product innovation should invest in basic research. Our arguments highlight the role of absorptive capacity and examine how industry appropriability influences these relations. Based on a rich dataset of 8 416 firms, we argue that basic research in firms increases their knowledge stock and flows, therefore improving their capacity to identify, assimilate, and exploit external knowledge, which allows them to enhance their product innovation performance. We also verify that strong appropriability regimes not only reduce the effect of basic research on absorptive capacity, but also affect the relation between absorptive capacity and product innovation in two ways. In businesses with a high absorptive capacity, strong appropriability regimes exert a negative influence by reducing product innovation; however, businesses with a low absorptive capacity see their level of product innovation increase. This evidence not only throws into question the attitude of many managers toward basic research; it also calls for open reflection on both the net effect of appropriability on innovative performance and the stages of the innovation process to which public resources should be allocated.**

Index Terms—**Absorptive capacity, appropriability, basic research, product innovation.**

I. Introduction

CURIOSITY-DRIVEN science mostly took place in universities practically throughout the 20th century, while the responsibility for taking new products to the market was left almost exclusively to firms. Things have started to change, however, in the beginning of the 21st century [1]. The gap between private and university basic research is narrowing in Europe and the USA, whereas in Japan basic research in firms is now even exceeding university research [2].

Manuscript received April 4, 2014; revised August 12, 2014 and September 12, 2014; accepted December 21, 2014. Date of publication January 16, 2015; date of current version April 15, 2015. This work was supported by the Program for the Consolidation and Structuring of Competitive Research Units, co-funded by the European Regional Development Fund (GRC2014/021), and in part from the support of the Spanish Ministry of Economy and Competitiveness through Project ECO2013-45706-R. Review of this manuscript was arranged by Department Editor Dr. M. Levesque

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Digital Object Identifier 10.1109/TEM.2014.2386614

This shift can be partially explained by the change in the budgetary focus of universities from the "creation of science" to the "business of science," which leads them to make greater efforts to utilize their intellectual property through licenses and spin-offs [3], [4]. A probably more important motive, however, could be the slowly growing conviction that basic research can improve research capabilities [5]–[7], productivity [8]–[11], and in general terms, business revenues [12].

In this context, there is a lack of empirical evidence linking basic research and product innovation, which is at the root of competitive advantage [13], [14]. As Rosenberg put it decades ago [5, p. 168], "the output of basic research is never some final product to which the market place can attach a price tag," so something apparently as "theoretical" and "abstract" as basic research does not match easily with something as "purposeful" and "practical" as product innovation. The fact is that the most widely cited studies on new product development [15] make no reference at all to the influence of basic research. Moreover, in the fullest metaanalysis on this subject, of the 24 variables for which sufficient correlations could be found in the literature ($n > 10$ correlations), not one refers explicitly to investment in basic research [16]. To cover this niche is, therefore, the basic aim of this paper.

Although several authors have emphasized the moderating role[1] of absorptive capacity between several inputs and innovation results [7], [17], [18]–[20], this might have a conceptually more relevant effect if its influence were not just over the sign and strength of the relation but over its actual existence. Accordingly, our study posits and tests a mediating role of absorptive capacity between basic research and product innovation. Furthermore, since this relation depends crucially on the ability of firms to appropriate at least part of the value of their basic research and absorptive capacity, we also explore the moderating role of industry appropriability. Considering that its influence on the background and results of absorptive capacity is still a matter of controversy [21], we analyze its effects on the relation between basic research and absorptive capacity [22], [23], on the one hand, and on the relation between absorptive capacity

[1] A variable (*Mo*) moderates the relation between two other variables *X* and *Y* ($X \xrightarrow{M_o} Y$) when it influences the magnitude of the effect (increasing it or decreasing it) that *X* exerts over *Y*. By contrast, a variable (*Me*) mediates between two other variables *X* and *Y* ($X \longrightarrow ME \longrightarrow Y$) when it explains how they are related, even determining the very existence of the relation. Finally, moderation and mediation may be combined—as in this paper—to yield a moderated mediation, in which a conventional mediation may be influenced by a fourth variable (*Mo*) in one or the two sides of the relation ($X \xrightarrow{M_o} ME \xrightarrow{M_o} Y$).

and product innovation [24], [25], on the other. In both cases, we find conflicting views in the literature and test them empirically.

This paper is structured as follows. Section II draws three hypotheses regarding the relations between basic research, absorptive capacity, and appropriability in the process of product innovation. Section III describes the sample of firms, the variables, and the methodology used. In Section IV, we cover the econometric analysis and discuss the results. Finally, we conclude with our main findings and their implications for product innovation theory, managerial practice, and public policy.

II. Theoretical Background and Hypotheses

According to the Oslo Manual [26, p.48], a product innovation refers to the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. The first studies about product innovation determinants took place in the field of industrial economics and were inspired by Schumpeter. It is now conventional wisdom that certain industry characteristics such as technological change [27], market opportunities [28], [29], and appropriability regimes [10], [11], [30] may influence the behavior and performance of firms regarding product innovation.

In parallel, studies carried out in the management field shared with industrial economics a certain concern about market characteristics (growth potential, rivalry, uncertainty) but focused on organizational determinants [31]. Building frequently on the resource-based view of the firm [32], [33], the literature stressed the need for distinctive competencies in order to implement a successful innovation strategy [16], [34]. These distinctive competencies could be linked to the generation of new technology [35]–[37], the development of creative, dynamic and committed personnel [38], the implementation of organizational routines associated with innovative management philosophies [39], [40], and the firm's absorptive capacity [41], [42]. The role of basic research, nevertheless, has been almost residual throughout this literature.

The Frascati Manual [43, p. 77] defines basic research as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view." Together with applied research and experimental development, it forms what is generally known as R&D, which was originally constrained to institutionally structured research in the natural sciences and engineering but has now expanded into the services industry [43, pp. 46–50]. Since the key characteristic of basic research is that it is curiosity driven with no regard for a particular application, it is hardly surprising that for years most managers saw little value in supporting it. This makes the contributions on the general benefits of basic research by Nelson [44], Mansfield [45], or Griliches [9] three especially commendable papers.

It was probably Rosenberg [5], however, who aroused interest in the link between basic research and product innovation. His theoretical reflection indicated that the new knowledge created by basic research is essential for making strategic decisions on future product lines and on process technologies. One year later, Pavitt [46] completed this point of view by emphasizing that basic research allowed firms to better exploit external scientific conclusions through the development of certain skills, methods, and networks of professional contacts. Somehow they were both suggesting implicitly that basic research improves absorptive capacity; i.e., firms' ability to "recognize the value of new information, assimilate it and apply it to commercial ends" [47, p. 128].

Perhaps because in 1990 the concept of absorptive capacity [48] was not yet widely known, Rosenberg's argument was initially tested as a direct relation between basic research and patents [49]. It soon became evident, however, that patents do not necessarily lead to product innovations, nor do all product innovations stem from patents. Hence, given the abstraction inherent in the results of basic research and the increasing importance of the absorptive capacity concept, it was not long before studies on basic research or product innovation started to consider the ability of firms to exploit novel knowledge. Generally speaking, we can classify these studies in two groups: those which study the influence of basic research on absorptive capacity, and those which focus on the relation between absorptive capacity and innovative performance. Both strands of the literature, therefore, implicitly consider that firms need potential and realized absorptive capacity [50], [51]. That is, they need to build a set of organizational practices that, on the one hand, facilitate the acquisition and assimilation of knowledge, and on the other, can transform them into real innovation opportunities that can be exploitated in the market.

The first group of studies [20], [52], [53] suggests that firms that carry out their own R&D—either basic or applied—are in a better position to use any available external and internal information. These results bring to mind the differentiation between external and internal absorptive capacity [54], [55], and its particular relevance for understanding the effects of basic research on human capital. In fact, several papers conceive basic research as a learning process which, although not directly linked to the market, increases the depth and breadth of the stock of stored knowledge [6], [12], [56], and consequently, allows more to be learnt from any freely available internal and external information [57]. These arguments tie in exactly with what was initially stated by Rosenberg [5] and Pavitt [46], and in addition, authors like Cassiman and Veugelers [58] saw such a close link between basic research and absorptive capacity that they use basic research as a measure of absorptive capacity.

Moreover, the literature on innovation performance has traditionally emphasized the capacity for using external knowledge sources as a key factor for innovation [59]–[61]. In particular, since new product development is a knowledge-intensive activity that benefits from the acquisition and use of external scientific, technological or market information, greater absorptive capacity can be expected to improve product innovation [41]. In fact, there is empirical evidence suggesting that firms with higher levels of absorptive capacity are more product innovative. For example, Stock *et al.* [41] suggested that this relation has an inverted U shape, whereas Fosfuri and Tribó [42] found that firms with greater absorptive capacity systematically obtain greater percentages of sales of new, or substantially improved products.

All these studies have, therefore, helped us to understand the potential link between basic research and absorptive capacity, on the one hand, and between absorptive capacity and product innovation, on the other. But there have not yet been any attempts to observe these relations as a single system testing whether basic research has a positive effect on product innovation through absorptive capacity. The study which comes closest to this idea was performed by Lim [7], who verified empirically that absorptive capacity moderates the relation between research activities (both basic and applied) and invention capacity (number of patents). However, as the life of B. Franklin illustrates clearly, capacity for invention is not the same as innovation. Furthermore, granting a moderating role to absorptive capacity requires the implicit assumption that there is a direct link between basic research and product innovation. This is somehow awkward, however, considering that basic research is defined as research that aims to further scientific knowledge without any specific marketable application.

Rather, the ability to develop and market new products depends on the firm's capacity for recognizing the value of new information inside and outside the firm, assimilating it and applying it to commercial purposes, and this is associated with the firm's prior scientific and technological knowledge stemming from investment in basic research. Hence, deductive reasoning based on existing theories can only suggest that absorptive capacity acts as a mediating variable between basic research and product innovation. Against this background, we pose the following hypothesis:

H_1: Basic research in firms increases product innovation by improving their absorptive capacity.

Industry appropriability may, however, affect the strength of the link between basic research and product innovation. Industry appropriability refers to the economic and technological conditions of a specific sector that influence the capability of firms to reap greater or smaller profits from their innovations. The appropriability regime of a particular industry [62], [63] is stronger when rivals can, one way or another, be prevented from selling imitations. Hence, industry appropriability may have two basic effects on the initial model proposed: a first effect on the link between basic research and absorptive capacity, and a second on the link between absorptive capacity and the innovation result. In both cases, the literature points to certain areas of controversy that should be clarified [21].

Little is known about how appropriability regimes that protect existing technologies affect the learning processes that transform basic research into absorptive capacity. We do know, however, that the purpose of strong protection is to prevent unwanted spillovers [47], which has been said to provoke two contradictory effects: a higher level of knowledge generation and disclosure [22], [64], and a reduction of the stock and flows of knowledge that enable cumulative research [23], [65].

The first perspective has been the conventional wisdom in economics at least since Nelson [44] and Arrow [66] explained why profit-motivated agents tend to underinvest in the generation of knowledge. Basically, both authors highlight that knowledge is not fully appropriable by those who generated it and can be used by other firms simultaneously. Hence, firms will have incentives to invest in generating it only when a strong appropriability regime—and stronger IPRs specifically—facilitate the creation of a market for ideas (thus, making knowledge resemble any other commodity). Accordingly, only when firms benefit from a strong appropriability regime will they invest heavily in knowledge generation and disclose their results to others, therefore, potentially augmenting not only the stock but also the flows of knowledge on which absorptive capacity hinges.

Several authors have challenged this perspective. Dosi *et al.* [23] denied the existence of a monotonically growing relation between the tightening of appropriability conditions and the level of innovative search. As stated by Cohen and Levinthal [47, p.147], spillovers can interact with absorptive capacity in a way that often provides a sufficient stimulus to offset the negative appropriability incentive. The pursuit of knowledge itself—and not only profit—might actually be motivating most transformative discoveries (DNA, transistors, lasers, the Internet), and although spillovers might reduce incentives, they diminish the effort required to achieve innovative results such as a given level of cost reduction [67]. Furthermore, contracting environments suffer transaction costs that might also make strong appropriability regimes hinder cumulative research. Particularly, information asymmetries discourage researchers from proceeding with their work due to rent-seeking suspicions and potential litigation costs [68]. For instance, in a recent study comparing the use of gene sequences patented by the private firm Celera with those sequenced by the public Human Genome Project, Williams [65] founded that Celera's IP stifled further research to the order of 20–30%. Williams [65] explicitly mentioned informal discussions with university scientists who claimed that, although Celera did not apparently place restrictions on academic use of its data, they felt discouraged to use them because of the litigation risks they perceived in the contractual terms.

The appropriability regime might, therefore, affect the learning processes triggered by basic research in two opposite directions. Accordingly, its effect on the potential of firms to identify and assimilate scientific and technological opportunities could be stated in two alternative hypotheses.

H_{2a}: Stronger appropriability regimes positively moderate the mediation between basic research and product innovation by augmenting the effect of basic research on absorptive capacity.

H_{2b}: Stronger appropriability regimes negatively moderate the mediation between basic research and product innovation by reducing the effect of basic research on absorptive capacity.

The level of appropriability of innovations may also affect the relation between absorptive capacity and product innovation. Again, the literature shows two opposing forces that cast doubt on the net influence of appropriability. On the one hand, authors like Zahra and George [51, p. 196] took up the incentive side of appropriability to suggest that, for a given level of R&D, the payoff from absorptive capacity will be higher in strong appropriability regimes because firms can protect their knowledge assets and continue to generate profits from such inventions. We could, therefore, expect a strong appropriability regime will make firms more interested in transforming their knowledge base into product innovation, instead of prioritizing other sources of competitive advantage such as

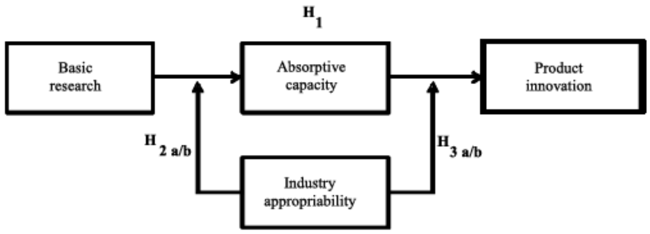

Fig. 1. Proposed model.

cost management, product reliability, process innovation, brand management, or manufacturing flexibility [69]. Due to the scope of the legal protection granted by IPRs, however, the effect of appropriability could also be the opposite. Strong appropriability regimes can hinder second-generation technologies, either because of the frequently overlapping search paths that infringe intellectual property, or because firms may need multiple and costly patented inputs to create a single useful product (Heller and Eisenberg's "anticommons" effects, [70]). Restrictions on knowledge spillovers might, therefore, explain why strong appropriability of results may reduce the effect of absorptive capacity on product innovation [25], [71]. We will, therefore, test the following two hypotheses.

H_{3a}: Stronger appropriability regimes positively moderate the mediation between basic research and product innovation by augmenting the effect of absorptive capacity on product innovation.

H_{3b}: Stronger appropriability regimes negatively moderate the mediation between basic research and product innovation by reducing the effect of absorptive capacity on product innovation.

Fig. 1 shows the conceptual model, which is obviously far from being exhaustive in terms of including all potentially relevant independent variables. Nevertheless, it does seem to be the best one that our insights allowed us to construct prior to this research, while sticking at the same time to the "keep it simple" rule. Our aim is not to explain basic research, absorptive capacity, industry appropriability, or product innovation, but to show there is a particular relation between them. Hence, hypothesis H_1 suggests that firms investing in basic research increase product innovation through the improvement of their absorptive capacity, whereas hypotheses H_2 and H_3 suggest how industry appropriability can change the intensity of these relations.

III. Data and Empirical Research

A. *Sample and Measurement of Variables*

Data comes from the Technological Innovation Panel (PITEC), which is based on the Community Innovation Survey carried out in Spain under the leadership of the Spanish National Statistics Institute (INE). Our reference year is 2007. Although 13 291 questionnaires were sent out and 95.99% replies were received (INE surveys are obligatory by law), we worked with a sample of 8 861 firms. The sample is composed of firms carrying out innovation activities (some of the firms answered they did not perform them) with a view to obtaining new products or processes during the period 2005–2007 (we cannot ignore firms performing basic research but yielding zero product innovations). After eliminating 445 observations with obvious outliers in the main variables, our sample resulted in a final database of 8 416 firms (65.96% of the PITEC population).

The sample, therefore, stems from the 2007 survey. However, some variables were taken from the innovation survey carried out by INE in 2004, 2005, and 2006 (http://www.ine.es/en/daco/daco42/daco4221/ite_cues_en.htm). Hence, product innovation, absorptive capacity, and industry appropriability are built from the 2007 survey asking about the period 2005–2007. In contrast, since the question in the survey on basic research refers to the survey year, we resorted to the surveys carried out in 2004, 2005, 2006, and 2007, in order to introduce lags.

Basic research is conceptualized in the survey following the definition of the Frascati Manual [43, p. 30]. The specific measure shows the importance of basic research for each firm in relation to its total expenditure on R&D. As noted previously, we introduced basic research for several years to examine the developmental and path-dependent characteristics of absorptive capacity [21], [72], which were not found.

With regard to absorptive capacity, although the seminal papers discussed in the theoretical section made significant advances in conceptualizing it, there has been no clear consensus on how to measure it.

In fact, there might even be a large gap between the proliferation of theoretical contributions and the ability of researchers to operationalize them empirically [55]. Thus, compared to its theoretical richness, measures of absorptive capacity have mainly been based on R&D activities [17], [73]. For the purposes of this paper, this is a rather problematic strategy given that all these variables are somehow correlated to basic research. Under these circumstances, we followed Fosfuri and Tribó [42], Vega-Jurado *et al.* [31], Murovec and Prodan [74], and Schmidt [75] to measure absorptive capacity as the relevance that external information sources have for innovation activities (note, therefore, that our proxy refers exclusively to external absorptive capacity and cannot differentiate between potential and realized absorptive capacity). Specifically, the proxy is built upon an index that summarizes the importance of ten external sources (suppliers, customers, competitors, consultants, universities, public research bodies, technology centers, conferences, scientific journals, and business associations) for innovation activities. Since firms rank the effects of these sources from 1 to 4 (1 if the source has not been used for its innovation activities, and 4 if it was considered of high importance), the index was built as the score for the first dimension derived from multiple correspondence analysis of the ten sources (Cronbach's alpha 0.89). It is, therefore, an ordinal variable with a mean of zero (it may take negative and positive values).

Regarding product innovation and following Murovec and Prodan [74], this was proxied by three effects that innovative activities may have on firms' products (we consider that all effects have the same relevance): a wider range of products and services, greater market penetration and higher quality goods or services [26, pp. 53–54]. Since firms ranked these effects on a scale from 1 to 4, with 1 if the effect is nonrelevant and 4 if it is marked, product innovation can take values from 3 to 12.

Additionally, in order to quantify the appropriability regime, for each industry, we built a measure that reflects the average utilization of different methods to protect intellectual property: patents, utility models, brands, and copyright [20]. Each firm was first assigned a value between 0 and 4 depending on the number of methods it uses, and we then calculate the industry average. We assume that the higher this industry average, the stronger the appropriability regime. Note that, given that we analyze firms of different sizes from industry and services, using proxies like the average number of patents per firm would lead to overestimation of sectors with larger companies or in which patents are especially relevant.

Finally, we included two control variables: firm size and industry. Some studies suggest that larger firms are more innovative because they benefit from economies of scale and scope [20], [76] and have more resources [77], [78], whereas others support the higher innovativeness of SMEs based on more flexible organizational structures and better communication flows [77], [79]. We also include industry as a control variable because it might determine the ease of producing innovations in terms of time and cost [80]–[82] since relevant scientific and technological know-how advances at different speeds and with different degrees of difficulty [83]. So, whereas firm size is proxied by turnover, industry is measured as a dummy variable that takes value 1 for medium and high-tech industries, and 0 for low-tech industries. We use the classification of the Spanish Institute for Statistics, which is based on the OECD classification for high-technology and medium-high technology in manufacturing industries, as well as on the Eurostat classification for highly innovative services.

Table I shows the main descriptive statistics, the average values of the variables for industry and firm size (the two control variables in the econometric model) and the three sectors with the highest and lowest levels of appropriability. We observe that firms in medium and high-tech industries exhibit higher values for all variables. By contrast, the variables achieve more heterogeneous values when we try to assess their behavior by size. In general terms, however, the most interesting fact lies in the evolution of R&D expenditure devoted to basic research. Thus, compared to what was suggested in the introduction regarding the cases of Europe, Japan, and USA, from 2004 to 2007 Spanish firms seem to have increasingly prioritized the type of research efforts that are closest to the market. This fact reflects the global evolution of basic research in Spain. According to the Spanish National Institute for Statistics (Science and Technology Indicators), although total basic research increased from 1 675€ million in 2004 to 2 186€ million in 2007, its share in total R&D expenditure decreased from 22.7% to 20.2%. Moreover, this reduction is likely to stem from a political-financial motive related to the origin of R&D funding. In fact, the Lisbon Strategy (designed in 2000 for the EU to stimulate its knowledge-based activities) resulted in a greater allocation of structural funds to R&D [84], which the Spanish authorities transferred to the business arena through public policies that mainly targeted applied research and the final stages of the innovation process. Competitive calls for pure basic research were, thus, essentially reserved for State Universities. Be that as it may, the fact that our model can be verified in a country with lower levels of private basic research makes our results even more generalizable to other contexts in which firms are more active in this field.

Additionally, Table II shows the correlations between the variables.

We can observe that the highest correlations occur between basic research each year and its interactions (product term) with sector appropriability. This is a rather common problem: if *XZ* is highly correlated with either *X*, *Z*, or both, the concern is that evaluation of the interaction effect will be undermined due to classic problems of multicollinearity. This will not generally be the case, however, unless the multicollinearity with the product term is so high (correlation 0.98 or greater) that it disrupts the algorithm designed to isolate the relevant standard errors [85], [86].

B. Analytical Models

In order to test the existence of mediation as suggested in hypothesis H_1, the following regressions are necessary [87], [88]:

$$\text{PRODINNOV} = \beta_{10} + \beta_{11}\text{BR7} + \beta_{12}\text{BR6} + \beta_{13}\text{BR5} + \beta_{14}\text{BR4} + \beta_{15}\text{SECTOR} + \beta_{16}\text{SALES} + \varepsilon_1 \quad (1)$$

$$\text{AC} = \alpha_{20} + \alpha_{21}\text{BR7} + \alpha_{22}\text{BR6} + \alpha_{23}\text{BR5} + \alpha_{24}\text{BR4} + \alpha_{25}\text{SECTOR} + \alpha_{26}\text{SALES} + \varepsilon_2 \quad (2)$$

$$\text{PRODINNOV} = \beta_{30} + \beta_{31}\text{BR7} + \beta_{32}\text{BR6} + \beta_{33}\text{BR5} + \beta_{34}\text{BR4} + \beta_{35}\text{AC} + +\beta_{36}\text{SECTOR} + \beta_{37}\text{SALES} + \varepsilon_3 \quad (3)$$

where PRODINNOV is the firm's product innovation; BR7, BR6, BR5, and BR4 represent the basic research that firms carried out, respectively, in 2007, 2006, 2005 and 2004; AC is absorptive capacity and the variable that mediates between basic research and production innovation; and SECTOR and SALES are the control variables in the model.

In order for absorptive capacity to mediate between basic research and product innovation, four conditions are necessary [87], [88]. Since we include investment in basic research over several years in the three equations (BR7, BR6, BR5, and BR4), we have to check whether these conditions apply in the basic research carried out every year, just some years, or not at all.

1) The total effect of basic research on product innovation should be significant; that is, the following parameters should be significant in (1): β_{11} for basic research in 2007, and β_{12}, β_{13}, and β_{14} for 2006, 2005, and 2004, respectively.
2) The effect of basic research on absorptive capacity (the mediating variable) should be significant; that is, the following parameters should be significant in (2): α_{21}, α_{22}, α_{23}, and α_{24}.
3) The effect of absorptive capacity (mediating variable) on product innovation should be significant, that is, β_{35} in (3) should not be zero.
4) The residual effect of basic research on product innovation (i.e., the effect after discounting the indirect mediating effect) should be lower in absolute value than the total

TABLE I
DESCRIPTIVE STATISTICS

Variable	Mean (% of fims)	Standard deviation	Minimum	Maximum	Mean by sector: Other sectors	Mean by sector: High and medium technology	Mean by size: SMEs	Mean by size: Others
Basic research 2004	5.25 (12.8%)	14.634	0	95	4.53	6.37	5.83	3.29
Basic research 2005	2.87 (10.5%)	10.726	0	90	2.18	3.92	2.96	2.54
Basic research 2006	1.35 (6.2%)	6.382	0	90	1.07	1.78	1.31	1.51
Basic research 2007	1.32 (5.8%)	6.451	0	80	0.97	1.88	1.33	1.32
Absorptive capacity	0.0	1	–1.69	1.4	–0.092	0.23	–0.0015	0.16
Industry appropriability	0.395	0.160	0	0.833	0.325	0.503	0.407	0.357
Sectors with highest appropriability:								
R&D services	0.80							
Pharmaceutical products	0.75							
Medical, precision, optical instruments	0.63							
Sectors with lowest appropriability:								
Tobacco	0.00							
Recycling	0.07							
Transport-related activities, travel agencies	0.10							
Product innovation	8.31	2.93	3	12	7.87	8.98	8.31	8.33
Sector	0.395	0.489	0	1				
Sales	1.03e8	5.303e8	1963	11899477040				

TABLE II
CORRELATION MATRIX

	Basic research 2004	Basic research 2005	Basic research 2006	Basic research 2007	Industry approp.	Basic research 2004 * Industry approp.	Basic research 2005 * Industry approp.	Basic research 2006 * Industry approp.	Basic research 2007 * Industry approp.	Absorptive capacity	Absorptive capacity * Industry approp.	Sector	Sales	Product innovation
Basic research 2004	1													
Basic research 2005	0.471***	1												
Basic research 2006	0.219***	0.279***	1											
Basic research 2007	0.214***	0.218***	0.321***	1										
Industry appropriability	0.105***	0.085***	0.087***	0.081***	1									
Basic research 2004 * Industry appropriability	0.930***	0.452***	0.246***	0.231***	0.228***	1								
Basic research 2005 * Industry appropriability	0.449***	0.926***	0.300***	0.236***	0.186***	0.505***	1							
Basic research 2006 * Industry appropriability	0.220***	0.275***	0.921***	0.321***	0.167***	0.285***	0.357***	1						
Basic research 2007 * Industry appropriability	0.206***	0.213***	0.318***	0.918***	0.162***	0.265***	0.278***	0.384***	1					
Absorptive capacity	0.042***	0.055***	0.071***	0.083***	0.140***	0.050***	0.063***	0.072***	0.075***	1				
Absorptive capacity * Industry appropriability	0.033***	0.056***	0.075***	0.081***	0.175***	0.059***	0.079***	0.094***	0.090***	0.923***	1			
Sector	0.065***	0.073***	0.039***	0.059***	0.540***	0.133***	0.125***	0.082***	0.100***	0.126***	0.147***	1		
Sales	-0.027**	-0.003	0.024**	0.006	-0.044***	-0.027**	-0.002	0.018	-0.008	0.051***	0.037***	-0.039***	1	
Product innovation	0.077***	0.076***	0.046***	0.063***	0.167***	0.082***	0.075***	0.046***	0.060***	0.469***	0.421***	0.173***	0.016	1

***p<0.01; **p<0.05.

effect, that is, $|\beta_{31}| < |\beta_{11}|$ in 2007; $|\beta_{32}| < |\beta_{12}|$ in 2006; $|\beta_{33}| < |\beta_{13}|$ in 2005; and $|\beta_{34}| < |\beta_{14}|$ in 2004.

To test the role played by appropriability in H_{2a}/H_{2b} (the relation between basic research and absorptive capacity) and H_{3a}/H_{3b} (the relation between absorptive capacity and production innovation), we need to consider the following equations [89]:

$$\begin{aligned} \mathrm{AC} &= \alpha_{40} + \alpha_{41}\mathrm{BR7} + \alpha_{42}\mathrm{BR6} + \alpha_{43}\mathrm{BR5} + \alpha_{44}\mathrm{BR4} \\ &+\alpha_{45}\mathrm{APPROP} + \alpha_{46}\mathrm{APPROP} * \mathrm{BR7} \\ &+\alpha_{47}\mathrm{APPROP} * \mathrm{BR6} + \alpha_{48}\mathrm{APPROP} * \mathrm{BR5} \\ &+\alpha_{49}\mathrm{APPROP} * \mathrm{BR4} + \alpha_{410}\mathrm{SECTOR} \\ &+\alpha_{411}\mathrm{SALES} + \varepsilon_4 \end{aligned} \tag{4}$$

$$\begin{aligned} \mathrm{PRODINNOV} &= \beta_{50} + \beta_{51}\mathrm{BR7} + \beta_{52}\mathrm{BR6} + \beta_{53}\mathrm{BR5} \\ &+\beta_{54}\mathrm{BR4} + \beta_{55}\mathrm{APPROP} + \beta_{56}\mathrm{APPROP} * \mathrm{BR7} \\ &+\beta_{57}\mathrm{APPROP} * \mathrm{BR6} + \beta_{58}\mathrm{APPROP} * BR5 + \beta_{59} \\ &\mathrm{APPROP} * \mathrm{BR4} + \beta_{510}\mathrm{AC} + \beta_{511}\mathrm{APPROP} * \mathrm{AC} \\ &+\beta_{512}\mathrm{SECTOR} + \beta_{513}\mathrm{SALES} + \varepsilon_5 \end{aligned} \tag{5}$$

where in addition to the variables introduced previously, APPROP refers to industry appropriability and its interaction with basic research on the one hand, and with absorptive capacity on

TABLE III
DIRECT AND INDIRECT EFFECTS OF BASIC RESEARCH AND MEDIATION BY ABSORPTIVE CAPACITY

Variable	Absorptive capacity (Mediating)		Product Innovation			
	**Equation (2)	VIF	Equation (1)	VIF	Equation (3)	VIF
Basic research 2004	0.0007	1.315	0.008***	1.315	0.0071***	1.315
Basic research 2005	0.002*	1.380	0.01***	1.380	0.0064**	1.381
Basic research 2006	0.006***	1.253	0.01*	1.253	0.0019	1.254
Basic research 2007	0.009***	1.218	0.017***	1.218	0.0043	1.222
Absorptive capacity					1.359***	1.052
Sector	0.339***	1.028	1.113***	1.028	0.652***	1.057
LogSales	0.061***	1.027	0.093***	1.027	0.011	1.043
Constant	0.007		8.275***		8.265***	
R^2	0.05		0.047		0.254	
F (p value)	58.3049 (0.000)		55.0984 (0.000)		315.0259 (0.000)	

*** $p<0.01$; ** $p<0.05$; *$p<0.10$.

the other. Note also that, following the recommendations given by Muller *et al.* [89], we center all variables at their mean except the outcome (ProdInnov). So in order to verify moderated mediation by appropriability, at least one of the two following conditions must be present.

1) *Condition 1:* The following parameters in (4) must be significant: α_{46}, α_{47}, α_{48}, and α_{49}, as well as parameter β_{510} in (5).
2) *Condition 2:* The following parameters in (4) must be significant: α_{41}, α_{42}, α_{43}, and α_{44}, as well as parameter β_{511} in (5).

IV. RESULTS

This section shows the results of (1)–(5). We checked that our model fulfills the basic requirements to yield a robust OLS estimation. The high number of observations [6 237 in (1)–(3); and 8 295 in (4) and (5)] facilitates normality in the error distribution. We also addressed possible heteroskedasticity problems by estimating the White heteroskedasticity-consistent covariance matrix [90]. Finally, analysis of the correlations and the variance inflation factors (VIF) suggest multicollinearity should not be a concern.

Table III, which shows the coefficients resulting from estimating (1)–(3), also indicates that the four conditions to verify the mediation of absorptive capacity are met.

1) There is a direct, significant, and positive effect of basic research in each year (2007, 2006, 2005, and 2004) on product innovation [see (1)].
2) There is a positive significant effect of basic research in 2007, 2006, and 2005 on absorptive capacity [see (2)].
3) There is an important, positive, and significant effect of absorptive capacity (mediating variable) on product innovation [see (3)].
4) The direct residual effect of basic research in 2007, 2006, and 2005 (the variables that influenced absorptive capacity) on product innovation [see (3)] is lower in absolute value than the direct effect [see (1)]. In fact, basic research in 2007 and basic research in 2006 are no longer significant; there is, therefore, total mediation by absorptive capacity between them and product innovation.

We performed the Sobel test to verify the mediation in 2007, 2006, and 2005. The results confirm the full mediation of absorptive capacity between basic research (2007 and 2006) and product innovation. This test also helped us to refute partial mediation between absorptive capacity in 2005 and product innovation.

The aforementioned results confirm that the basic research carried out in 2007 and 2006 had a positive effect on product innovation via the absorptive capacity generated in the period 2005–2007. Accordingly, our data not only support hypothesis H_1 but also suggest that basic research has short-term effects on product innovation.

However, the results also show an interesting effect in (3), since basic research in 2004 and 2005 appear to have a direct effect on product innovation. Perhaps recent basic research is closely linked to absorptive capacity because it allows researchers to be in the front line of knowledge. By contrast, basic research in 2004 and 2005 might yield product innovation results in 2007 because sometimes potential applications are only discovered some years later [5], [46].

With regard to the control variables, we observe that the technological dynamism of industries is positively associated with absorptive capacity and product innovation. Previous studies have actually confirmed the positive association of high-tech industries with absorptive capacity [91] and product innovation [92], [93]. As for the size variable, our results support that larger firms show higher levels of product innovation.

In order to test the moderated mediation of appropriability regimes (hypotheses H_{2a}/H_{2b} and H_{3a}/H_{3b}), we use the coefficients for (4) and (5), which are given in Table IV.

For the sake of simplicity, we focus on the most recent years, those in which absorptive capacity mediates between basic research and product innovation. The results confirm the moderated mediation of appropriability regimes with regard to the relation between basic research and absorptive capacity (H_{2b}), as well as with regard to absorptive capacity and product innovation (H_{3a}/H_{3b}).

We can affirm that appropriability influences the relation between basic research and absorptive capacity because the model verifies the first condition of Muller *et al.* [89] for basic research in 2007; i.e., we find significant coefficients for the interaction between basic research in 2007 and industry appropriability in

TABLE IV
MODERATED MEDIATION BY THE APPROPRIABILITY OF RESULTS

Variable	Absorptive capacity (Mediating)		Product innovation	
	Equation (4)	VIF	Equation (5)	VIF
Basic research 2006	0.006	7.926	0.02	7.955
Basic research 2007	0.020***	7.577	0.012	7.616
Industry appropriability	0.688***	1.499	1.27***	1.519
Basic research 2006 * industry appropriability	0.001	8.427	–0.041	8.467
Basic research 2007 * industry appropriability	–0.025***	8.063	–.010	8.092
Absorptive capacity			1.611***	6.883
Absorptive capacity * industry appropriability			–0.783***	6.958
Sector	0.172***	1.423	0.525***	1.431
LogSales	0.062***	1.024	0.019	1.043
Constant	0.001		8.310***	
R^2	0.048		0.237	
F (p value)	64.168 (0.000)		299.045 (0.000)	

*** $p<0.01$; ** $p<0.05$; *$p<0.10$.

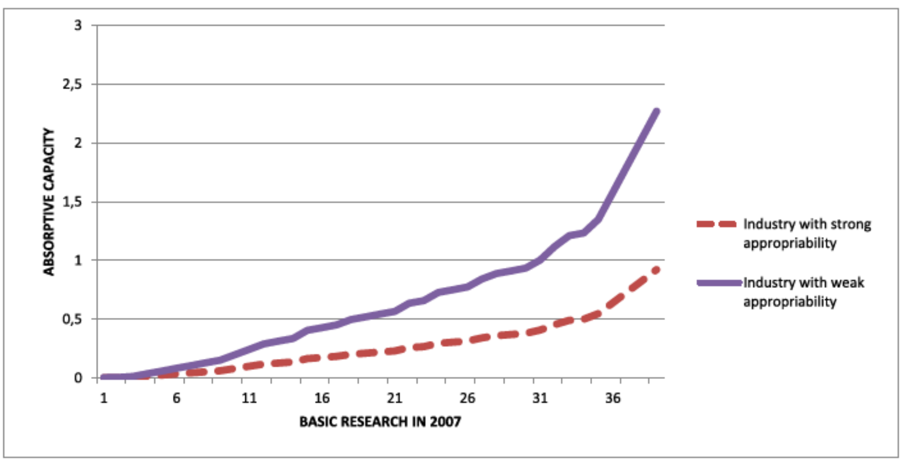

Fig. 2. Effects of the industry appropriability regime on the relation between basic research and absorptive capacity

(4), as well as for absorptive capacity in (5). In order to clarify whether appropriability increases (H_{2a}) or reduces (H_{2b}) the effect of basic research on absorptive capacity, Fig. 2 shows a complementary graphical analysis. We calculate the slope of the curve from (4) as the derivative of absorptive capacity with respect to basic research ($\partial AC/\partial BR$). The value of this derivative depends on the level of appropriability that each sector shows, so we can assume there are as many curves as levels of appropriability. For the sake of simplicity, we represent the most extreme cases: maximum and minimum appropriability.

We can, thus, observe that the effect of basic research on absorptive capacity is lower when a firm is in a strong appropriability regime; H_{2b} can, thus, be confirmed. Strong appropriability regimes might, therefore, be deterring learning processes that would otherwise enhance the capacity of firms to identify and assimilate new knowledge. The fact that appropriability regimes do not influence this relation for basic research in 2006 [the coefficient of the interaction between basic research in 2006 and industry appropriability is not significant in (4)] may indicate that greater knowledge in 2006 generated by spillovers in weak appropriability regimes is no longer so relevant. Because of the speed and dissemination of technological change, such knowledge, which is available to all, may have become outdated; it would thus be of limited usefulness in 2007 for firms' human capital, for their relation with other agents and for identifying new business opportunities.

With regard to hypotheses H_{3a} and H_{3b}, the results suggest that both could be accepted. We verify the second condition proposed by Muller *et al.* [89] and find significant coefficients for basic research in 2007 in (4), as well as for the interaction between absorptive capacity and industry appropriability in (5). This means that the level of appropriability moderates the mediation between basic research and product innovation by changing the effect of absorptive capacity on product innovation. Again, in order to address the positive (H_{3a}) or negative (H_{3b}) effect of appropriability regimes, Fig. 3 shows graphically the relation among absorptive capacity, product innovation, and appropriability.

We calculate the slope of the curve from (5) as the derivative of product innovation with respect to absorptive capacity ($\partial ProdInnov/\partial AC$). Analogously to Fig. 2 and for the sake of simplicity, each of the curves represents two extreme cases: maximum and minimum appropriability. There could be infinite curves in between. Fig. 3 thus shows that H_{3a} and H_{3b} can

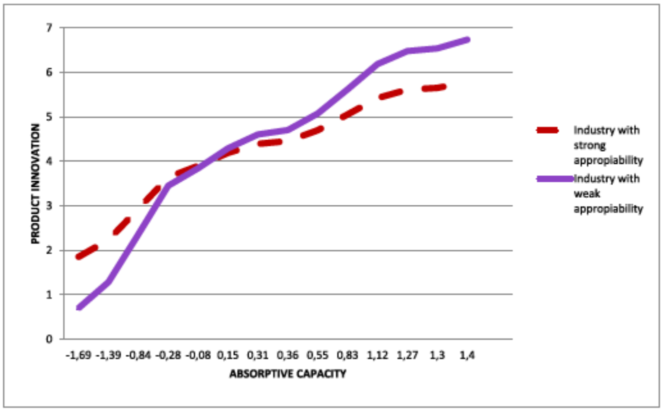

Fig. 3. Effects of industry appropriability on the relation between absorptive capacity and product innovation

be confirmed simultaneously because the net effect of appropriability depends on the level of absorptive capacity. Strong appropriability regimes increase the effect of absorptive capacity on product innovation (H_{3a}) for firms with low absorptive capacity; however, strong appropriability regimes have the opposite effect for firms with high absorptive capacity (H_{3b}).

V. Conclusion

Our results confirm that basic research improves product innovation in the short term through the enhancement of absorptive capacity. The reason is that even though basic research by definition does not seek a specific marketable application, it does increase the stock and flow of knowledge needed to extract, assimilate, and exploit the latest scientific and technological developments. This in turn stimulates the development of new or improved products.

Nevertheless, the effect of basic research on absorptive capacity, and therefore, on product innovation, has a time limit. However, much a firm invests in basic research during any given year, the effect on its absorptive capacity will have a limited duration unless it perseveres. If its effort is not systematic, fast-moving scientific and technological change will lead the knowledge generated by the investment to quickly become outdated.

We also verified that the effect of basic research on absorptive capacity is weaker in firms that belong to sectors with stronger appropriability regimes. As explained earlier, strong appropriability regimes may be deterring the learning processes triggered by basic research, and thus, hinder the identification of new scientific and technological opportunities. Additionally, the level of appropriability also affects the relation between absorptive capacity and product innovation. Firms with high absorptive capacity obtain better results in weak appropriability regimes, whereas firms with low absorptive capacity apparently enhance product innovation in strong appropriability regimes.

A question to address in future research is whether our analysis on absorptive capacity would also hold if we could differentiate empirically between potential and realized absorptive capacity. It would be interesting to verify, for instance, whether the skills and competences that basic research stimulates in the firm are as important for assimilating new internal and external knowledge as for producing new marketable products.

With regard to the implications of our results, managers should abandon their traditional prejudices about basic research. The short-sightedness inherent in focusing exclusively on market-based R&D means that the generation of human capital among technical staff is neglected, which can only bring about a gradual loss of capacity to support substantial product innovations. Clearly, therefore, private basic research would somehow stimulate a firm's ambidexterity to pursue both explorative and exploitative capabilities [94]. Compared to the variable and long-term returns usually attached to explorative capabilities, however, we show that basic research carried out by firms in 2006 and 2007 affected absorptive capacity and product innovation during that same period. Furthermore, given that our analysis has been performed with firms from all sectors and of all sizes, the contribution of basic research to ambidexterity does not apparently depend on resource endowment [95] or environmental dynamism [96]. Finally, on a more general basis, our results question one of the most important drawbacks seen by managers when investing in basic research: i.e., its low appropriability becomes a less severe problem when the arguments behind it have more to do with its influence on absorptive capacity than its specific, immediate and exclusive returns. On the other hand, if managers are concerned that the results of basic research might generate spillovers to other firms, then they might wish to resort to industrial secrecy, a method being adopted by a growing number of firms to protect the results of their applied research [97], [98]. After all, firms' researchers do not need academic publications to gain promotion.

Concerning public policy, our results reinforce the well-known arguments about the inefficiency of allocating public funding to projects that are too close to the market [66]. Since such projects are of interest *per se* for firms, public intervention often ends up reducing costs at the expense of distorting competition. By contrast, knowledge-intensive projects like those associated with basic research are often affected by market failures, making public support efficient [44]. We are not, of course, suggesting that public policies should aim to promote only basic research in firms, but, just as public administrations appreciate universities coming closer to the market, the designers of public policies should do everything possible to ensure that firms generate knowledge amongst their technical staff. Otherwise, not only will regions find that their technologists become increasingly good in increasingly obsolescent areas and techniques, but they will also miss opportunities to generate intra- and intersector spillovers by providing the only human capital that can solve problems at the forefront of knowledge [99]. Public policies that stimulate the incorporation of young postdoctorate scholars into the private sector should, therefore, be welcomed, especially in low-tech regions where cooperation between universities and firms is often weak [100]. Finally, our results are partially coherent with the criticisms to the outright and oversimplified support that international institutions have given to the strengthening of IPRs [101]. Thus, while the strength of appropriability regimes may have opposite effects on product innovation depending on the level of absorptive capacity that each firm shows, we have also verified that strong appropriability regimes reduce the influence of a given level of basic research on absorptive capacity. Irrespective of how important appropriability incentives really are for fostering R&D in many industries [23], policy makers should consider the warnings regarding increasing privatization of the scientific commons because of the consequences for the freedom of researchers to address what they see as the most challenging scientific problems [102].

Acknowledgment

The authors would like to thank the Editor and both referees for their time and comments, and are also grateful to the participants at ACEDE 2011 for several useful suggestions to an initial draft of this paper published in *Spanish in Cuadernos de Economía y Dirección de la Empresa*.

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