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External knowledge search, absorptive capacity and radical innovation in high-technology firms

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ABSTRACT

Open innovation and absorptive capacity are two concepts based on the idea that companies can leverage the knowledge generated externally to improve their innovation performance. The aim of this paper is to analyse the joint effect of open innovation and absorptive capacity on a firm's radical innovation. Open innovation is expressed in terms of external search breadth and depth strategies and absorptive capacity is described by distinguishing between potential and realized absorptive capacity. In order to test our hypotheses, we carried out empirical research in firms operating in high-technology industries. The results indicate that internal routines and processes for absorbing external knowledge help explain radical innovation as they show a significant effect of potential and realized absorptive capacity. Also, there is a moderating effect of absorptive capacity on open innovation. Specifically, potential absorptive capacity exerts a positive effect on the relationship between external search breadth and depth and radical innovation. Realized absorptive capacity moderates the influence of external search breadth. These findings confirm the complementary nature of absorptive capacity and open innovation search strategies on radical innovation.

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1. Introduction

The concept of open innovation (OI) stresses the notion of leveraging external knowledge and has become increasingly popular both in academic research and industry practice (Chesbrough & Bogers, 2014). The basic premise of OI is opening up the innovation process (Huizingh, 2011). Nevertheless, the presence of valuable external sources of knowledge does not imply that the flow of external new ideas and knowledge into firms is an automatic or easy process (Vanhaverbeke & Cloodt, 2014). Implicitly, external knowledge is considered to be 'out there' ready to be harnessed by firms, but we have a limited understanding of the process of sourcing and bringing this into corporations (Dahlander & Gann, 2010). The ability to exploit external knowledge is, thus, a critical component of innovative capabilities (Cohen & Levinthal, 1990).

Despite its popularity, many firms still struggle to manage OI properly, and the internal organization challenges perceived are the

most difficult to manage (Vanhaverbeke, Chesbrough, & West, 2014). For instance, results of a survey among large firms in Europe and the United States suggest that it is not easy to implement an OI program and there are a range of challenges and constraints that limit firms' ability to make use of OI, the management of external relationships being an important challenge (Chesbrough & Brunswicker, 2014). In this work, we suggest that the fact that the firm possesses absorptive capacity (AC) facilitates external knowledge identification and exploitation and can be helpful to attenuate some of the challenges posed by OI. AC has been defined as the capacity to learn and solve problems, allowing a firm to assimilate external knowledge and create new knowledge (Kim, 1998; Lane, Koka, & Pathak, 2006; Zahra & George, 2002). It is not only a matter of searching and accessing external ideas and knowledge, but also of being able to generate internally innovative outputs by combining external insights with the firm's internal capabilities. Accordingly, external knowledge does not equally benefit all firms, as the firm's own resources and actions determine the extent to which it will be able to take advantage of it (Fabrizio, 2009). As with OI, the notion of AC is based on the idea that companies can leverage the knowledge generated externally. More particularly, since AC focuses on acquiring and utilizing external knowledge

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inside the firm, it is a concept at the heart of the outside-in dimension of OI (Vanhaverbeke & Cloudt, 2014).

Radical innovations incorporate a large amount of new knowledge since they encompass revolutionary changes in technology and clear departures from existing practice (Dewar & Dutton, 1986) and also may involve new knowledge about existing or emerging markets (Zhou, Yim, & Tse, 2005). Hence, radical innovations require new insight that is distant from a firm's existing competences and practices and, even, its own internal processes, since there is a gap between the firm's knowledge and the knowledge needed to innovate. In doing so, the firm must bring external knowledge inside, or develop the required knowledge in order to innovate successfully (Green, Gavin, & Aiman-Smith, 1995). Thus, external knowledge may complement internal efforts to develop radical innovations. In this context, radical innovation can be fostered in companies with highly developed OI processes and increased AC, since these firms span larger technological distances and are better equipped to explore new technological areas that are not directly related to their core technology (Nooteboom, Vanhaverbeke, Duysters, Gilsing, & van den Oord, 2007; Vanhaverbeke & Cloudt, 2014).

In addition to their direct effects on radical innovation, we propose that there is a complementary positive effect of OI and AC on it. Previous research has explored the relationship between OI and AC by adopting different approaches. Referring to literature on AC and learning, some works rely on the notion that AC is determined primarily by prior related knowledge, suggesting that OI represents an antecedent of a firm's AC (e.g. Ferreras-Méndez, Newell, Fernández-Mesa, & Alegre, 2015; Ferreras-Méndez, Fernández-Mesa, & Alegre, 2016; Fosfuri & Tribó, 2008; Sun & Anderson, 2010). Their reasoning is that firms connect with their external environments in pursuing diverse knowledge across organizational boundaries to increase their AC, this being one of their reasons to propose that AC has a mediation role in the firm's openness-innovation performance relationship. A moderating approach is followed by a second group of scholars who draw on Cohen and Levinthal's (1990) model of sources of a firm's technical knowledge, the central feature of which is that the firm's AC determines the extent to which extramural knowledge is utilized, examining the moderating role of AC in the relationship between OI and innovation performance (e.g. Clausen, 2013; Escribano, Fosfuri, & Tribó, 2009; Fabrizio, 2009; Ghisetti, Marzucchi, & Montresor, 2015; Huang & Rice, 2012; Laursen & Salter, 2006; Rothaermel & Alexandre, 2009). This view can be especially relevant for explaining radical innovation, as "to integrate certain classes of complex and sophisticated technological knowledge successfully into the firm's activities, the firm requires an existing internal staff of technologists and scientists who are both competent in their fields and familiar with (...) extramural relationships" (Cohen & Levinthal, 1990, p. 135). Although Cohen and Levinthal (1990) focused on the role of R&D in enhancing the firm's ability to assimilate and exploit external knowledge, it fits with the idea that AC creates opportunities for interorganizational combinations of knowledge within an OI model (Vanhaverbeke & Cloudt, 2014). Finally, drawing on arguments from both approaches, recent contributions propose conceptual frameworks that embrace relationships between the two concepts by focusing on different types of OI and the components of AC (e.g., Kim, Kim, & Foss, 2016; Xia & Roper, 2016).

This paper adopts a moderating approach to study the influence of both OI and AC on a firm's radical innovation and examine their complementarity by analysing the effect of AC on the relationship between OI and radical innovation. In order to do so, we describe OI in terms of external search breadth and depth strategies (Laursen & Salter, 2006) and focus on both components of AC, potential and

realized AC (Zahra & George, 2002). Our research links to the literature on OI that examines the influence of external knowledge search strategies and the presence of moderators (e.g., Chen, Chen, & Vanhaverbeke, 2011; Chiang & Hung, 2010; Clausen, 2013; Cruz-Gonzalez, López-Sáez, Navas-López, & Delgado-Verde, 2015; Huang & Rice, 2012; Laursen & Salter, 2006; Sofka & Grimpe, 2010). While previous studies examined the moderating effect of AC on external search strategies, most research on the relationship between external search and AC has considered AC as a whole and relied on R&D-related proxies to represent it (e.g., Laursen & Salter, 2006; Rothaermel & Alexandre, 2009). To represent AC, we follow Zahra and George's (2002) reconceptualization of AC and focus on the routines and processes that form potential and realized AC, which organizations use to acquire, assimilate, transform and exploit knowledge. The theoretical distinction between potential and realized AC helps us identify which abilities matter more to the external linkages and radical innovation of firms (Xia & Roper, 2016). Although firms' OI activities need both, the link between two components of AC in the context of various types of OI has not received much attention (Kim et al., 2016). Hence, this research contributes to recent literature examining the specific relationship between OI types and potential and realized AC.

Our study is developed on high-technology firms, since, as they need a great deal of relevant knowledge in their innovation processes, they frequently try to find it outside their boundaries. Firms in high-tech industries have the highest levels of external search breadth and depth, with high levels of R&D and rates of innovation (Laursen & Salter, 2006). Thus, external knowledge flows become important and the ability to benefit from these flows plays a crucial role in securing competitive advantage (Escribano et al., 2009). In addition, one of the most widely cited motives for explorative external collaborations is the acquisition of new technical skills or capabilities from partner firms (Xia & Roper, 2016).

This work both contributes to OI research on the external search for innovation by considering that OI strategies' effectiveness can be enhanced through a firm's internal AC processes in shaping the ability to leverage external knowledge sources. Specifically, examining how each AC component can interact with external search breadth and depth is a distinctive contribution that can enhance understanding about how both concepts relate to radical innovation.

This paper proceeds as follows: in the next section, we provide the theoretical background of this study and formulate the research hypotheses. Section 3 presents the data and the methodology. Section 4 shows the results of the data analysis and Section 5 discusses the results. Section 6 summarizes key conclusions, implications and limitations of the work.

2. Literature review and hypotheses development

2.1. Radical innovation

Radical innovation has been conceptualized in terms of substantial changes in technology that advance the price/performance frontier by much more than the existing rate of progress (e.g., Dewar & Dutton, 1986; Gatignon, Tushman, Smith, & Anderson, 2002). Thus, radical innovations have often been conceived as (Green et al., 1995): 1) incorporation of an embryonic technology rapidly developing in the general scientific community; 2) incorporation of a technology that is new to a firm, but may be well understood by others; 3) departure from the firm's existing management or business practices; 4) requirement of a sizable financial risk. Hence, technology can be new to the adopting firm and to the referent group of organizations, or require important transformations in an organization since it introduces such throughput

and output modifications in an organization that entail substantial internal changes (Ettlie, Bridges, & O'Keefe, 1984). Radical innovation is also characterized by a market dimension or perspective, which determines the extent to which the new product fulfills key customer needs better than existing products (Chandy & Tellis, 1998; Danneels & Kleinschmidt, 2001). Innovations characterized as radical from this market dimension are designed for new or emerging markets and customers, and offer new benefits, or they may be targeted at existing customers and offer radically different benefits (Zhou et al., 2005).

Radicalness depends on the familiarity and amount of experience people in the organization have with the innovation they are adopting or developing (Dewar & Dutton, 1986). Thus, if an innovation takes the firm into areas where there is little knowledge about the new technology or novel routines are demanded of the organization, the innovation is likely to be seen as more radical (Green et al., 1995). Also, from the market perspective, radicalness refers to innovations that are characterized according to the difficulty in evaluating potential customers' reactions *ex ante* (Sainio, Ritala, & Hurmelinna-Laukkanen, 2012). In this context, in addition to the possession of robust internal innovative capabilities, knowledge on insights and expertise developed externally can be determinants in developing successful radical innovations.

2.2. External knowledge search and radical innovation

The OI literature can be viewed as an instance of how firms make decisions whether to develop innovations internally or partner with external actors (Dahlander & Gann, 2010). Although for decades the literature has recognized the importance of external sources of knowledge in the company's innovation process, Henry Chesbrough's contributions on OI were decisive in giving equal or even greater emphasis to its role compared with firms' internal activities in their pursuit of breakthrough results (Barge-Gil, 2010). Openness to external sources allows firms to draw in ideas from outsiders to deepen their pool of available technological opportunities and, hence, can contribute to enhance their innovation results (Laursen & Salter, 2006).

A way of examining the influence of OI on innovation results is by focusing on the role of external search for new innovative opportunities. Laursen and Salter (2006), drawing on research by Katila and Ahuja (2002) on the relationship between search strategies and innovative performance, developed the concepts of breadth and depth as two components of the openness of individual firms' external search strategies. External search breadth is defined as the number of external sources or search channels that firms rely upon in their innovative activities. External search depth represents the extent to which firms draw deeply from the different external sources or search channels. Searching widely and deeply across a variety of channels can provide ideas and resources that help firms gain and exploit innovative opportunities (Laursen & Salter, 2006).

Specifically, firms that access knowledge from a large number of external sources conduct broader and more general knowledge searches (Chiang & Hung, 2010). Access to a broad knowledge base facilitates understanding of new information and potential changes, which enhances the firm's ability to detect remote technological or market opportunities and gives flexibility to adapt to unpredictable changes and to expand the company's knowledge pool for its radical innovation (Chesbrough, 2003; Ferreras-Méndez et al., 2015; Zhou & Li, 2012). Thus, more remote environmental areas can help firms to find new market opportunities to enter new strategic domains since a wider exposure can increase managers' chances of finding technological solutions that meet the needs of new customers (Chiang & Hung, 2010; Hargadon & Sutton, 1997).

Also, as radical innovation often results from knowledge recombination, having a greater number of complementary sources of knowledge could improve innovation success (Leiponen & Helfat, 2010). Based on the above, we argue that accessing knowledge from a large number of external sources (open search breadth) will positively relate to the company's radical innovation, leading us to propose the following:

H1. Open search breadth will exert a positive effect on a firm's radical innovation.

Radical innovations are often related to the incorporation within the firm of technologies where new practices, kinds of knowledge, and skills are demanded, either because technologies are embryonic or because, although the technology is well understood by others, it is new to a firm (Green et al., 1995). In this context, the process for radical innovation requires solutions that rely on external knowledge expertise, as it may involve technologies in which the firm's technical experience is not high. More intense links with a variety of sources enable companies to deepen their understanding of the knowledge possessed by the different external parties (Cruz-Gonzalez et al., 2015). These deep relationships are built on the basis of a continuous interplay that enables a common approach when working together. Thus, search depth reflects the importance of an intense use of key external sources (e.g. lead users, suppliers, universities) to the internal innovation process and facilitates understanding of how these external sources are integrated into internal innovative efforts (Laursen & Salter, 2006). Furthermore, radical innovations can be developed as a consequence of a firm trying to enhance satisfaction of mainstream customers and can involve exploring whether new technologies might offer them superior benefits (Govindarajan, Kopalle, & Danneels, 2011). Also, having in-depth knowledge of current and potential customers may help in terms of finding new ways of reaching customers and fulfilling their expectations efficiently (Sainio et al., 2012). Here, a firm's effort to understand its customers in great depth leads to uncovering expressed as well as latent needs, and how new technologies might satisfy them (Slater & Narver, 1998). Therefore, companies following this open search strategy are better placed to acquire a range of novel pieces of knowledge and combine them with the firm's current knowledge base, thereby acting as a seedbed for developing radical innovations (Cruz-Gonzalez et al., 2015). Accordingly, a close relationship with external partners will be fundamental in providing the required technical or market knowledge that complements the internal efforts for effective radical innovation. Based on the above, we propose that:

H2. Open search depth will exert a positive effect on a firm's radical innovation.

2.3. Absorptive capacity and radical innovation

AC is one of a firm's fundamental learning processes as it reflects its ability to identify, assimilate and exploit knowledge from its environment (Lane et al., 2006). Thus, AC facilitates the creation of radical innovations by enabling the exchange of existing knowledge and learning, and combining it with new sources of knowledge (Ritala & Hurmelinna-Laukkanen, 2013).

Zahra and George (2002) conceptualize AC as a dynamic capability formed by a set of organizational routines and processes, and distinguish between potential and realized AC. Whereas potential AC represents the knowledge-seeking capacities a firm has developed, but which may or may not be used to produce innovations, realized AC represents its ability to develop products and services

based on this stock of knowledge.

Potential AC consists of the processes of external knowledge acquisition and assimilation. It helps firms track changes in their industries more effectively and, therefore, facilitates the timely deployment of necessary capabilities, such as production and technological competencies (Zahra & George, 2002). Since more radical innovations are based on distant knowledge and capability reconfiguration, it is expected that external knowledge acquisition by organizations contributes to the development of innovations incorporating a higher degree of novelty (Cruz-González, Navas-López, López-Sáez, & Delgado-Verde, 2012). Also, since radical technological advances may originate outside the firm (Green et al., 1995), the ability to identify and understand external knowledge is crucial in order to facilitate the transmission of knowledge. In addition, firms with well-developed acquisition and assimilation capabilities are likely to be more adept at continually renewing their knowledge stock by detecting trends in their external environment and internalizing this knowledge. For example, these opportunities can help firms to maintain and sustain better performance through strategic advantages such as first-mover advantages and receptiveness towards customers (Zahra & George, 2002). In other words, potential AC precludes firms from becoming locked into a specific area of expertise and running the risk of failing to seek out alternative technologies by providing them with the strategic flexibility to adapt within various industry contexts (Enkel & Heil, 2014). Bearing this in mind, we put forward the following hypothesis:

H3. Potential AC will exert a positive effect on a firm's radical innovation.

Being able to transfer external knowledge back to the organization to apply it to knowledge creation activities is a process vital to the effectiveness of external AC routines (Lewin, Massini, & Peeters, 2011). Although potential AC is necessary to identify, filter and internalize relevant external knowledge, a competitive advantage in innovation only materializes if the firm also possesses realized AC (Fosfuri & Tribó, 2008). Realized AC results from processes of transformation and exploitation (Zahra & George, 2002). Indeed, once the knowledge is inside the organization, it must be shared across the firm's members and integrated with internally-generated knowledge. Success in radical product innovation requires managers to combine aspects of technological and customer knowledge and competence in completely new ways (Henderson & Clark, 1990). Whereas transformation helps firms to develop new perceptual schema or changes to existing processes, exploitation converts knowledge into new products (Kogut & Zander, 1992). The transformation and exploitation capabilities that make up AC are, therefore, likely to influence firm performance through product and process innovation (Zahra & George, 2002). Thus, we propose the following hypothesis:

H4. Realized AC will exert a positive effect on a firm's radical innovation.

2.4. External knowledge search, absorptive capacity, and radical innovation

External knowledge search is not costless (Cruz-Gonzalez et al., 2015). As Tether and Tajar (2008) indicate, a key challenge is who to access and how. In addition, it is often not simply a matter of identifying the basic competence of the partner for cooperation, but ensuring that the partner is sufficiently committed to the task. Although there are many benefits from being able to buy-in or source ideas external to the organization, internal expertise is

required to search for and evaluate them (Dahlander & Gann, 2010). That is, an innovating firm needs to engage in continuous learning opportunities with the objective to detect market and technology trends and translate them into pre-emptive actions (Sofka & Grimpe, 2010). Here, the presence of AC may reduce the costs of openness, and increase profits by better application of external knowledge to in-house activities (Barge-Gil, 2010). Therefore, the fact that the firm has developed AC can be a key determinant in fostering the positive effects of a broad and intense use of external sources.

As highlighted previously, a wider set of knowledge sources provides the firm with more options for approaching problems from different perspectives and will facilitate radical innovation by offering new insights that complement internal efforts. But, also, a broader degree of external search may imply significant costs (Cruz-Gonzalez et al., 2015), such as those associated with information search and partnering (Sisodiya, Johnson, & Grégoire, 2013) or with the range of management skills required to deal with diverse external sources (Faems, de Visser, Andries, & Van Looy, 2010).

Specifically, some of the costs associated with adopting a broad external search can be minimised if the firm has a strong potential AC. For instance, gatekeeping is particularly relevant when the external information is not directly related to the organization's core activities and requires contextual interpretation to be considered useful by other members of the organization (Lewin et al., 2011). Indeed, a network of gatekeepers devoted to monitoring and connecting the firm with external agents will diminish information search costs associated with recognition of external sources and facilitate acquisition of valuable information from a variety of sources (Cruz-Gonzalez et al., 2015). Also, processes and routines aimed at understanding and evaluating the contribution of external sources to internal innovation efforts allow for a more accurate identification of innovation opportunities and possible constraints (Comacchio & Bonesso, 2011, pp. 15–17). Thus, the fact that there are internal capabilities related to where and how to search, i. e., potential AC, will make the breadth search strategy more effective.

Even though searching deeply may rely on a small number of external sources, this may be highly costly, as firms need to sustain a pattern of interaction over time for each of these sources (Laursen & Salter, 2006). In this context, selecting the most convenient organizations to learn from (or generate knowledge with) on a continuous basis becomes crucial. Thus, as far as the firm possesses internal abilities to recognize and understand the specific knowledge source which best meets their needs, errors in partners identification may be reduced, diminishing eventual costs associated with mismatches to external partners. Also, since close cooperation involves access to the partner's knowledge base, and, therefore, constitutes an effective way to access external knowledge not publicly available (Lewin et al., 2011), firms' internal abilities to unravel and interpret it, will be drawn upon intensively in order to obtain valuable knowledge for radical innovation. Based on the above, we propose the following:

H5. Potential AC will exert a positive effect on the relationship between open search breadth and depth and radical innovation.

Being more involved in OI can create tensions with other practices within the organization since the capabilities required to work as a 'broker', recombining ideas from inside and outside the firm, are likely to be different from those found in traditional internal R&D settings (Dahlander & Gann, 2010). As the knowledge breadth expands in a firm, the firm may encounter higher marginal costs due to the increased complexity of managing the variety of the knowledge (Leiponen & Helfat, 2010). Due to the limited cognitive

capacity, accumulation of knowledge in different areas may diminish the management's ability to integrate effectively the new information for innovation purposes (Fleming & Sorenson, 2001). Extensive resources are required to effectively achieve internal coordination, facilitate knowledge transfer and make new insights compatible with existing ones. In this context, since sufficient integration and full utilization of the knowledge acquired become fundamental to the development of true breakthroughs (Katz & Du Preez, 2008; Zhou & Li, 2012), the firm's abilities for combining and exploiting external knowledge source will enhance the benefits of external knowledge breadth search strategies in its internal innovation process.

When the firm searches deeply for specific knowledge, many resources must be applied to tap this knowledge (Garriga, von Krogh, & Spaeth, 2013). Organizations often have to go through a period of trial and error to learn how to gain knowledge from an external source and it requires extensive effort and time to build up an understanding of the norms, habits, and routines of different external knowledge channels (Laursen & Salter, 2006). Development and maintenance of close relations with external partners implies an ongoing relationship, which is not always easy, and may be very demanding for the firm. It is not only about selecting the most adequate sources and establishing the principles of the cooperation, but also about preserving them, which implies being committed in terms of resources and attention (Laursen & Salter, 2006). Also, in the case of radical innovations, the innovation process may require extra involvement and additional shared work, to adapt and integrate effectively the newly acquired knowledge. Firms must be able to create the proper context for individuals to feel motivated and committed to learning, articulating and sharing the knowledge they have, and for them to be willing to apply it to the creation of new products and processes (Díaz-Díaz & de Saá-Pérez, 2014). In these cases, a way of succeeding with managing close cooperation is facilitated by developing stable patterns of collaboration between the two partners (Zollo, Reuer, & Singh, 2002), where processes to help both parties in applying new knowledge in their own contexts facilitate learning. For instance, as illustrated by Lewin et al. (2011), actions such as Cisco's implementation of a web-based system for collaborating with suppliers where the intensity of collaboration and mutual obligations vary with the collaborative status of suppliers, may become a source of learning if close relationships built on mutual trust develop over time. Hence, to benefit better from an external knowledge depth strategy, realized AC can contribute positively to the effectiveness of a depth search strategy. Accordingly, the above considerations let us suggest that:

H6. Realized AC will exert a positive effect on the relationship between open search breadth and depth and radical innovation.

Fig. 1 provides a representation of the concepts and relationships posited in the hypotheses. The model includes external knowledge breadth and depth search as OI dimensions. Absorptive capacity is expressed in terms of potential and realized AC. Radical innovation is the dependent variable. It depicts a direct effect of external breadth and depth on radical innovation and the direct effect of potential AC and realized AC on radical innovation. Also, the moderating effect of AC components is represented.

3. Methodology

The empirical research was conducted in Spanish medium-sized and large industrial firms (with 50 or more employees) in high-technology industries. We used the threshold of 50 employees because smaller companies find it more difficult to draw on a high number of external sources of knowledge (Cruz-Gonzalez et al.,

2015). Specifically, the population was formed by firms operating in the following sectors: pharmaceutical; office, accounting and computing machinery; radio, TV and communications equipment; medical, precision and optical instruments; and aircrafts and spacecraft. We chose these sectors as they are the ones with the highest R&D intensity, according to the OECD's classification of R&D intensity. Data about the number of firms in each industry was obtained from the Central Business Register of the Spanish National Statistics Institute and 365 firms formed the total population. The sample size was determined in such a way that the results were statistically significant in relation to the population considered and calculated by stratifying according to sector and size and the final sample consisted of 172 firms. Table 1 shows the sample composition by sectors.

Information on firms was drawn from the Analysis System of Iberian Balances (SABI) database. Firms were selected randomly and data were gathered by means of a telephone survey. To limit common method bias, we interviewed two respondents from each firm using two different structured questionnaires. Data on AC dimensions were provided by the R&D Manager, while data on radical innovation and open search strategies came from a second respondent, the General Manager (when not available, the Marketing Manager was interviewed instead). R&D Managers were also asked about innovation performance and this information was used to validate further the data.

Measurement of variables was based on previous published scales. For radical innovation, we draw on the scale proposed by Gatignon et al. (2002). The items were answered by the second respondent in each firm. Respondents were asked to assess, on a 7-point scale, how far they agreed with the following statements: (1) the innovation was a minor improvement on the previous technology (reverse coded); (2) the innovation was based on a revolutionary change in technology (breakthrough innovation); (3) the innovation led to products that were difficult to replace using older technology; (4) the innovation represented a major technological advance in a subsystem, part or product component. To test the reliability of the resulting scale (from which the first item was subsequently deleted), Cronbach's alpha was used, resulting in a value of 0.730. Also, correlation of the scale with data from R&D managers on the same scale ($\rho = 0.629$, $p < 0.001$) contributed to give additional support to its validity.

We relied on Laursen and Salter (2006) measures to represent OI search breadth and depth. Breadth was constructed by combining 10 possible sources of knowledge for information: (1) suppliers; (2) customers; (3) competitors; (4) consultants, commercial laboratories or R&D institutes; (5) universities or other higher education institutes; (6) government research institutes; (7) technological centres; (8) conferences, commercial fairs and expositions; (9) scientific publications and technical or commercial journals; and (10) professional and sectoral associations. Each of the 10 sources was coded as a binary variable, 0 being no use and 1 being use of the knowledge source. Next, the sources were added up so that each firm received a score of 0 when no external knowledge sources were used and 10 if they were all used. Cronbach's alpha coefficient of the measure was 0.735.

External search depth, defined as the extent to which firms draw intensively from different search channels or sources of innovative ideas, was constructed using the same 10 sources of external knowledge. Each of the sources was coded with 1 when the firm said it had been very important for its innovation activities and 0 in the case the given source had no, low or medium importance. The 10 sources were subsequently added up so that each firm received a score of 0 when no knowledge sources were important to a high degree, while the firm had the value of 10 when all knowledge sources were highly important. Reliability of this measure was also

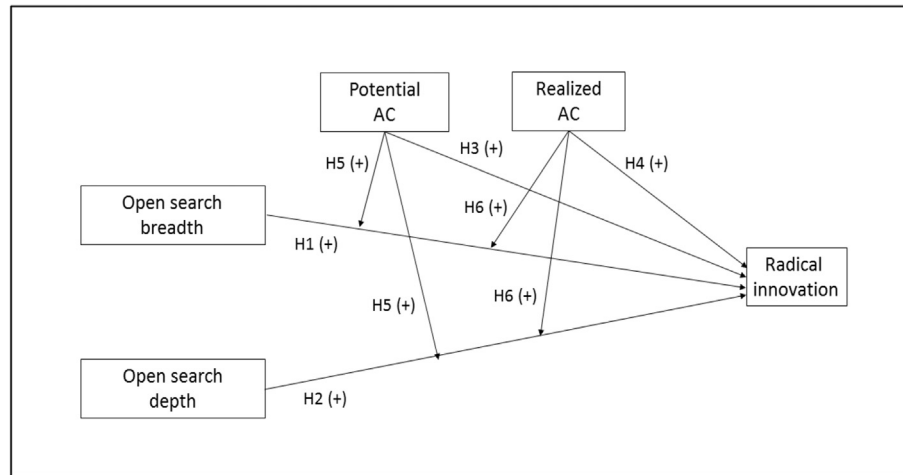


Fig. 1. The conceptual model.

Table 1
Sample composition.

Sector	Population	Sample
Pharmaceuticals	135	61
Office, accounting and computing machinery	10	6
Radio, TV and communications equipment	86	38
Medical, precision and optical instruments	99	48
Aircrafts and spacecraft	35	19
Total	365	172

confirmed, as the Cronbach's alpha coefficient was 0.725.

Also, following Laursen and Salter (2006), as a test of robustness of the results for the measure of external search depth, an alternative measure was calculated by considering whether or not the firm had formal collaboration links with different external partners, including (1) suppliers; (2) customers; (3) competitors; (4) consultants, commercial laboratories or R&D institutes; (5) universities or other higher education institutes; (6) government research institutes; and (7) technological centres. Each of the seven possible forms of cooperation was coded as a binary variable, 0 being no collaborating and 1 being collaboration with the given partner. Subsequently, the seven sources were added so that each firm received a 0 when no partners were used, while the firm had the value of 7 when all the potential collaboration partners were used. Correlation of this indicator with external search depth measure ($\rho = 0.394$, $p < 0.01$) confirmed the robustness of the measure.

To reflect potential and realized AC, we essentially adapted the items used by Jansen, Van den Bosch, and Volberda (2005), which, in turn, were based on Zahra and George (2002) and Szulansky (1996). The items were assessed by each R&D Manager on a 7-point disagree-agree scale. Potential AC was measured by the items: (1) new opportunities to serve our clients are understood rapidly; (2) we analyse and interpret changing market demands promptly; (3) employees record and store newly acquired knowledge for future reference; (4) we quickly recognize the usefulness of new external knowledge to existing knowledge. Realized AC was measured with the items: (1) we incorporate external technological knowledge into our firm; (2) we thoroughly grasp the opportunities new external knowledge offers our company; (3) we periodically meet to discuss consequences of market trends and new product development; (4) employees are clearly aware of how the firm's innovation activities should be performed; (5) we are constantly reviewing how to better exploit external knowledge; (6) employees

share a common language to refer to our products and services. Following previous studies (Bou-Lluisar, Escrig-Tena, Roca-Puig, & Beltrán-Martín, 2009; Ferreras-Méndez et al., 2016), we performed confirmatory factor analysis (CFA) to validate potential and realized AC scales. In doing so, we used EQS 6.3. Dimensionality was analyzed executing a CFA model for each construct. The goodness-of-fit indicators of the proposed models were all above the recommended values, showing the existence of a single dimension for both scales (Table 2). Cronbach's alpha and composite reliability were used to test the reliability of the scales. The values obtained were higher than 0.7, the threshold level suggested as a reference of acceptable reliability. Convergent validity was evaluated using the following indicators: the Bentler-Bonett normed and not normed fit index (Bentler & Bonett, 1980), GFI and AGFI (Table 3). In both scales, the values were greater than 0.90, which indicates strong convergent validity (Ahire, Golhar, & Waller, 1996). Discriminant validity was assessed by different approaches (Bagozzi & Phillips, 1982; Bou-Lluisar et al., 2009) (Table 3). First, for the two scales, Cronbach's alpha was higher than the average interscale correlation (AVISC). Second, the average correlation between the scale and non-scale items was lower than between the scale items. We also conducted a pair-wise test (Bagozzi & Phillips, 1982) to analyse whether a model with two correlated factors fits the data significantly better than an alternative model in which the correlation between the factors are fixed to one (i.e., equivalent to a single-factor model). The scaled chi-square difference values were found to be statistically significant at 5% level (S-B scale difference = 22.15; d. f. = 1) (Satorra & Bentler, 2001), rejecting thus the perfectly correlated two-factor model.

We also included as control variables firm age, expressed in years at the time of data collection, firm size, measured by the number of employees; R&D intensity, measured by the percentage of R&D personnel as a share of all employees; and dummies representative of the sectors examined, since previous research suggests these variables can exert an influence on a firm's radical innovation (e.g. Chen et al., 2011; Hurmelinna-Laukkanen, 2012; Zhou & Li, 2012). Logarithmic transformations were used in age, size and R&D intensity measures.

4. Results

Table 4 presents descriptive statistics and correlations for the study variables. The correlations indicate that potential and realized AC are positively related and that external search depth is

Table 2

AC scales dimensionality and reliability analysis.

	Unidimensionality			Comparative Factor Index (CFI)	Reliability	
	Satorra-Bentler Chi-square	df	p-Value		Cronbach's α	Composite reliability
Potential AC	4.951	2	0.084	0.976	0.748	0.866
Realized AC	14.844	14	0.388	0.996	0.736	0.742

Table 3

AC scales convergent and discriminant validity analysis.

	Convergent validity				Discriminant validity		
	BBNFI	BB-NNFI	GFI	AGFI	Average interscale correlation (AVISC)	Average item-to-scale correlations with	
						Scale items	Non-scale items
Potential AC	0.961	0.927	0.985	0.924	0.260	0.758	0.369
Realized AC	0.940	0.994	0.973	0.947		0.714	0.395

positively related to both dimensions of AC. They also show that radical innovation is correlated with potential and realized AC and with external depth. Hypotheses were tested using multiple linear regression analysis. We followed a hierarchical procedure and estimated different models where the dependent variable was radical innovation (Table 5). First, we analysed the impact of control variables (Model 1). Next, in Model 2, we included the main effects variables. Finally, in order to test the moderating effects, we defined four models that, together with the main effects, included an interaction term of each OI strategy and each AC component. Models 3 and 4 include the interaction terms for potential AC and external search breadth and depth respectively. The moderating effect of realized AC on the OI search strategies is tested in Models 5 and 6. Although examination of the VIF values did not reveal any problem, to minimize potential multicollinearity, we standardized the variables for the interaction terms prior to creating the respective cross products.

Results indicate that there is a positive effect of external knowledge sources on radical innovation as the regression equation for Model 2 is statistically significant ($F = 6.738$, $p < 0.001$). Model 1 shows that neither open search breadth nor open search depth exert a significant direct effect on radical innovation, hence our Hypotheses 1 and 2 cannot be confirmed. With regard to the influence of AC on radical innovation, Model 2 lets us confirm Hypotheses 3 and 4, since it shows a positive significant effect of both potential AC ($\beta = 0.304$, $p < 0.001$) and realized AC ($\beta = 0.252$, $p < 0.001$). As for the moderating effect of AC on OI, results corroborate the moderating effect of potential AC on open breadth and depth strategies (Model 3 and Model 4, respectively), as in both cases there is a significant change in the explained variance of the

models (Model 3: $\Delta R^2 = 0.021$, $p < 0.05$; Model 4: $\Delta R^2 = 0.021$, $p < 0.05$). These findings support Hypothesis 5, showing that there is a significant moderating effect for potential AC and external search breadth ($\beta = 0.158$, $p < 0.05$) and external search depth ($\beta = 0.156$, $p < 0.05$). With regard to Hypothesis 6, inclusion of the interaction terms in Model 5 and Model 6 indicate that, although there is also an increase in the explanatory power of both models, the moderating effect of realized AC is only significant for the case of open search breadth ($\beta = 0.141$, $p < 0.1$), thus giving partial support to hypothesis 6.

5. Discussion

The empirical results in this work indicate that internal routines and processes for absorbing external knowledge exert a direct influence on radical innovation and determine the effectiveness of OI search strategies. We discuss our findings in detail below. First of all, neither external search breadth nor depth had a significant direct effect on radical innovation, thus we cannot confirm Hypotheses 1 and 2. These findings echo evidence from Cruz-Gonzalez et al. (2015), who found that none of the two open search strategies had a significant direct effect on overall firm performance and posited the need to take into account the downsides associated with openness. More specifically, with respect to radical innovation, our findings regarding the non-significance of external search breadth are similar to results reported by Ferreras-Méndez et al. (2015) and are consistent with those described by Laursen and Salter (2006), who found that the more radical the innovation, the less impact the number of external knowledge sources has on innovative performance. Concerning the non-significant effect of

Table 4

Means, standard deviations and correlations.

	Mean	S.D.	1	2	3	4	5	6	7
1. Radical innovation	4.5349	0.7877							
2. Age	30.2038	21.7769	−0.012						
3. Size	262.89	354.848	0.062	0.102					
4. R&D intensity	7.7708	7.9649	−0.057	−0.119	−0.181 ^a				
5. Search breadth	9.7326	0.8436	0.005	−0.105	0.191 ^a	0.217 ^b			
6. Search depth	3.5407	2.5139	0.165 ^a	0.026	0.185 ^a	0.028	0.093		
7. Potential AC	4.4655	0.8994	0.479 ^b	−0.126	−0.022	−0.086	−0.077	0.205 ^b	
8. Realized AC	4.8735	0.5891	0.406 ^b	−0.004	0.081	0.015	0.095	0.174 ^a	0.557 ^b

Variables 2, 3 and 4 describe actual values for descriptive statistics. Logarithmic transformations of these variables were used in regression analysis.

^a Correlation significant at the 0.1 level.

^b Correlation significant at the 0.05 level.

Table 5
Results of regression analysis. Standardized coefficients (β).

	Model 1		Model 2			Model 3		Model 4		Model 5		Model 6	
	Beta	t	Beta	t	VIF	Beta	t	Beta	t	Beta	t	Beta	t
Age	–0.060	–0.693	–0.006	–0.077	1.379	0.008	0.099	0.005	0.063	0.008	0.103	–0.002	–0.031
Size	0.079	0.996	0.065	0.898	1.212	0.074	1.056	0.088	1.230	0.064	0.897	0.057	0.792
R&D intensity	–0.044	–0.559	–0.024	–0.341	1.187	–0.023	–0.349	0.002	0.035	–0.030	–0.424	–0.007	–0.095
Pharmaceutical	–0.01	–0.075	0.009	0.079	3.302	0.022	0.237	0.033	0.283	0.031	0.265	0.012	0.102
Office and computing machinery	0.206 ^b	2.193	0.164 ^a	1.965	1.624	0.160 ^a	2.232	0.171 ^b	2.078	0.164 ^b	1.982	0.162 ^a	1.958
TV and communications equipment	0.194	1.641	0.222 ^b	2.118	2.574	0.242 ^b	2.399	0.249 ^b	2.388	0.255 ^b	2.415	0.242 ^b	2.296
Medical and precision instruments	0.045	0.360	0.086	0.768	2.918	0.113	1.088	0.098	0.891	0.119	1.057	0.089	0.802
Search breadth			0.001	0.015	1.175	–0.016	–0.232	–0.004	–0.057	0.043	0.581	0.019	0.269
Search depth			0.032	0.460	1.139	0.026	0.376	–0.013	–0.186	0.030	0.438	0.005	0.072
Potential AC			0.304 ^c	3.600	1.664	0.295 ^c	3.598	0.314 ^c	3.764	0.311 ^c	3.713	0.298 ^c	3.550
Realized AC			0.252 ^c	3.026	1.624	0.316 ^c	3.669	0.240 ^c	2.912	0.301 ^c	3.469	0.257 ^c	3.100
Potential AC search breadth						0.158 ^b	2.250						
Potential AC search depth								0.156 ^b	2.250				
Realized AC search breadth										0.141 ^a	1.867		
Realized AC search depth												0.107	0.518
R ²	0.074		0.317			0.338		0.338		0.331		0.326	
Adj. R ²	0.034		0.270			0.288		0.288		0.281		0.276	
Change R ²			0.243			0.021		0.021		0.015		0.010	
F	1.856 ^a		6.738 ^c			6.752 ^c		6.756 ^c		6.563 ^c		6.419 ^c	

^a The relationship is significant at the 0.1 level.

^b The relationship is significant at the 0.05 level.

^c The relationship is significant at the 0.001 level.

external search depth, our results are consistent with those of [Chiang and Hung \(2010\)](#) and [Garriga et al. \(2013\)](#), who found no effect on radical innovation of depth of search for knowledge. A possible explanation for these results can be related to the high-technology nature of firms examined in this study and the complexity of the technologies involved. In these type of industries with high levels of technological opportunities and extensive investments in search activities by other firms, a firm will often need to search more widely and deeply in order to identify and gain access to critical knowledge sources. Thus, in our study, the fact that participating firms belong to high-technology industries can contribute to explaining why most of them adopt open search strategies. Additionally, the complexity of technological knowledge bases can help explain the fact that certain industries show broader patterns of innovative search but have low rates of innovation, as opposed to industries where there are simple technologies but high levels of innovation and patterns of search may be narrower ([Laursen & Salter, 2006](#)). In this sense, developing external search strategies can be seen as an activity developed by most firms operating in these industries, and a necessary condition to compete in such competitive settings, but it is not a distinctive characteristic when explaining higher radical innovation.

Examination of the direct effect of AC on innovation performance in Hypotheses 3 and 4 confirms that internal routines and processes for absorbing external knowledge contribute to explaining radical innovation. These results are similar to those reported in previous research, which, in general terms, found a positive effect of AC on innovation performance (e.g., [Escrignano et al., 2009](#); [Nitzsche, Wirtz, & Göttel, 2016](#)). More specifically, with regards to [Hypothesis 3](#) on the influence of potential AC, results confirm its positive effect, suggesting that it is worth investing in processes and routines that facilitate greater recognition and assimilation of external knowledge to enhance radical innovation. There is mixed evidence in previous research on this point. [Ritala and Hurmelinna-Laukkanen \(2013\)](#) did not find any significant direct effect on radical innovation emerging from cooperation with competitors. [Fosfuri and Tribó \(2008\)](#) found that firms with higher levels of potential AC capability systematically obtain larger shares of their sales from new or substantially improved products, giving

additional support to [Zahra and George's \(2002\)](#) argument that potential absorptive capacity is a necessary condition for achieving competitive advantage in innovation. Also, our results regarding [Hypothesis 4](#) indicate that realized AC is relevant for radical innovation, findings in line with those of [Hurmelinna-Laukkanen \(2012\)](#). This author observed that the knowledge application side of AC in particular was influencing the innovation performance of the firm, suggesting that, without the ability actually to utilize the internally-generated and externally-acquired knowledge, new combinations of knowledge and innovation rarely emerge. Although OI strategies may have a number of advantages that lead firms to pursue them extensively, there are also costs associated with engaging in OI. When sourcing external knowledge, there are a number of aspects that make the process difficult, such as the preference to develop the firm's own organizational knowledge or uncertainty regarding the validity and reliability of knowledge provided by others ([Díaz-Díaz & de Saá-Pérez, 2014](#)). It may imply that benefits of OI are not fully achieved unless certain internal conditions which favour the effectiveness of external search strategies in the firm are present. Hence, the existence of internal processes and routines aimed at developing acquisition, assimilation, transformation and exploitation capabilities can help to counterbalance the costs of open search and extract the best returns from interacting with a wide range of channels and getting into close relationships with key external agents. Accordingly, Hypotheses 5 and 6 examined the moderating effect of potential and realized AC on the influence of open search strategies. Our findings for [Hypothesis 5](#) validate a positive influence of potential AC on the relationship between open search breadth and depth and radical innovation. With regard to the moderating effect of potential AC on search breadth strategy, the positive results are consistent with those of [Clausen \(2013\)](#), who reported that firms with better developed AC are more able to source external knowledge from cooperation with a breadth of different types of external actors. Additionally, although not directly comparable, our results share common elements with those of [Enkel and Heil \(2014\)](#). These authors found that firms that apply a wide search scope make regular use of a broad range of mechanisms for recognizing and assimilating distant knowledge, since this approach can result in more

exploratory innovation. Thus, potential AC can be a determinant for firms to achieve the full benefits of managing a broad set of knowledge sources by establishing processes aimed at identifying, examining and evaluating the contribution of prospective sources and partners. Potential AC also contributes positively to the effect of open search depth on radical innovation. Similarly, Zhou and Li (2012) found that a firm with a deep knowledge base is more capable of developing radical innovation through market knowledge acquisition. Additionally, the fact that we are examining firms in high-technology industries can also help us explain these results. High-technology industries are characterized by fast-changing technologies and, even the largest firms, cannot keep pace with all technological developments by themselves (Chen et al., 2011). Since there are high levels of technological opportunities and knowledge spill-overs, firms in these industries with adequate AC capacities to evaluate, assimilate and integrate valuable knowledge from external sources can benefit to a greater extent from a close interaction with external sources.

In Hypothesis 6, we posited a positive influence of realized AC on OI breadth and depth search strategies. Although in both cases the coefficient of the interaction term is positive, we only found a significant moderating effect of realized AC on the relationship between external search breadth and radical innovation. Developing a radical innovation implies a high degree of departure both from the state of knowledge prior to its introduction and from the existing internal practices, and requires that the firm successfully integrates the new market or technological knowledge (Chandy & Tellis, 1998; Dewar & Dutton, 1986; Green et al., 1995). The broader the firm's external search strategy, the higher might be the possibilities to combine different and distinct knowledge fields that are suitable for radical innovations. Nevertheless, it is not only a matter of identifying and assimilating this broad array of opportunities; the full exploitation of external breadth search advantages only becomes effective if external knowledge is incorporated into the firm's internal innovation processes. It means that costs associated with managing a diverse knowledge base should be considered and also that integration of the varied new information should be achieved in order to attain coordination for innovation purposes (Fleming & Sorenson, 2001). Our findings confirm that the abilities that the firm possesses for integrating, combining and exploiting external knowledge sources together with internal knowledge become fundamental to deploying effectively the benefits of external knowledge breadth search strategies into radical innovations. Indeed, the fact that the positive effect of accessing a broad variety of knowledge sources is fostered by realized AC is a reflection of the relevance of internal capabilities related to connecting external insights with internal knowledge and sharing this external knowledge internally, in order to achieve radical innovation. Finally, our results cannot confirm that transformation and exploitation abilities contribute to foster the influence of external search depth on radical innovation. These findings contradict the results by Hsieh and Tidd (2012), who identified a positive relationship between project novelty, intensity of interaction between actors and the use of more rich mechanisms for knowledge sharing in new service development projects in chain convenience stores. Although direct comparison of works is difficult due to the fact that this research was carried out in a very different sectoral setting, this dissimilar industrial context may help explain why our results are not consistent with theirs. Additionally, in our case, the non-significant moderating effect of realized AC might be explained because, for the examined firms, the fact of possessing abilities to combine external knowledge with internal knowledge and exploit it, is not enough to achieve a higher degree of innovation stemming from the implementation of an external depth search strategy. That is, although more intense links with external sources enable

companies to deepen their knowledge of what is possessed by different external parties, effective exploitation of that knowledge in order to get a radical innovation may be accompanied of significant difficulties, that require extensive efforts and abilities which go beyond those forming realized AC. This viewpoint is reinforced by previous research (Cruz-Gonzalez et al., 2015; Garriga et al., 2013), which indicates that when the firm needs to search deeply, costs are exacerbated, many resources must be applied and individuals need to be highly devoted to the search. Hence, an external depth search strategy can be so demanding in terms of effort and resources that, even in the presence of strong internal transformation and exploitation abilities, it will not be effective in delivering radical innovations. Particularly, in the case of high-technology industries, Cohen and Levinthal (1990) stress that those who are attempting to encourage cooperative research ventures in rapidly advancing fields should recognize that direct participation in the venture should represent only a portion of the resources that it will take to benefit from the venture. Participating firms must also be prepared to invest internally in the AC that will permit effective exploitation of the venture's knowledge output.

6. Conclusions

This study analyses the influence of open external search strategies and AC on radical innovation in high-technology firms. Also, the moderating effect of AC is examined by focusing on the relationships between potential and realized AC and external breadth and depth strategies.

Regarding the relationship between open breadth and depth and radical innovation, our findings did not find a significant direct effect and do not corroborate the results of previous research where a positive effect on radical innovation of external breadth (e.g., Chiang & Hung, 2010) and external depth (e.g., Ferreras-Méndez et al., 2015) has been found. These results can be justified in the context of the type of firms being analysed, i.e., high-technology firms. Thus, although searching widely and deeply across external sources can provide ideas and resources which help firms gain and exploit innovative opportunities, in these kinds of industries it can be considered a requirement to compete, but on its own, it is not sufficient to achieve a competitive advantage through radical innovation. We found that both potential and realized AC exert an influence on radical innovation. Our findings suggest the value of devoting resources and efforts to intensify awareness of potential partners and developing capabilities that facilitate the transformation and exploitation of external knowledge as the role of both components of AC, i.e. search-based capabilities related to knowledge acquisition and assimilation, and knowledge-application capabilities, are shown to foster innovation radicalness. Although there is previous empirical research that studied and verified the effect of AC, it mostly used proxy variables to represent AC, with no identification of the processes and abilities that form AC. Therefore, the way AC is conceptualized in this research should be highlighted, as the distinction between both components of AC, based on Zahra and George's (2002), allows a deeper understanding of the role of AC.

Only when linked to AC can the positive effects of external search be achieved. Especially revealing is the finding regarding the complementary effect of potential AC and external knowledge search breadth and depth, which corroborates previous research on moderating effects of AC and OI (e.g., Clausen, 2013). Also, our research gives support to Barge-Gil's (2010) assertion that AC reduces the costs of openness, by reducing search and assimilation costs, and increases profits by a better application of external knowledge to in-house activities. In summary, our results stress the importance of developing processes and routines to identify,

acquire and assimilate external knowledge in order to take effective advantage of external breadth and depth search strategies. With regard to the moderating effect of realized AC, the fact that the positive effect of accessing a broad variety of knowledge is fostered by transformation and exploitation abilities is a reflection of the relevance of internal capabilities related to sharing and integrating internally this diverse external knowledge in order to achieve radical innovation. Finally, the fact that we could not confirm the moderating effect of realized AC can be an indicator of how demanding implementing an external depth search strategy in high-technology industries may be to obtain radical innovations since possession of abilities to combine external knowledge with internal knowledge and exploit it is not enough to render a positive result.

This study contributes to the OI literature by examining the effects of open search on radical innovation and by investigating the relevance of AC as an internal moderator that affects effectiveness of open search strategies. In doing so, we draw on previous research on OI and AC, jointly examining two theoretical approaches which are complementary (Vanhaverbeke & Cloodt, 2014). Also, a notable contribution in this research is the distinction between potential and realized AC and the examination of how each of these dimensions interacts with OI breadth and depth search strategies. Although previous studies have connected AC and OI (e.g. Clausen, 2013; Escribano et al., 2009; Huang & Rice, 2012; Rothaermel & Alexandre, 2009), examination of the two components of AC in the context of various types of OI has been scarce (Kim et al., 2016). The fact that we have differentiated between the abilities to identify and assimilate external knowledge from the abilities to transform and exploit it, give a better understanding of how managers can modulate their efforts to leverage the impact of external knowledge on a firm's radical innovation.

This study presents several implications for practitioners as it highlights the relevance of internal capabilities and external search strategies to take full advantage of external knowledge when pursuing radical innovation. External search strategies should be assessed not only in terms of benefits but also their costs, both in terms of searching and managing diverse knowledge sources and also in terms of seeking the best partners, investing and maintaining continuous relationships when adopting depth search strategies. In this sense, particularly relevant are the processes and routines that form AC, as they not only contribute positively to radical innovation, but also increase the effectiveness of open search strategies. Specifically, managers should foster activities aimed at seeking and understanding external knowledge. With regard to leveraging external breadth search strategies, they should support activities oriented at identifying a broader range of external sources of knowledge and interact with external agents, by considering not only technology sources but also market-related sources. Gatekeeping is a regular practice to acquire knowledge in many high-technology firms, but it should be complemented with activities directed at identifying new market trends and also by following the evolution of more remote knowledge domains. Instruments such as industry trade magazines, participation in events and fairs that are not specific to the firm's sector, the development of personal networks or the creation of links with external experts and the use of social media can contribute to enhance external knowledge recognition. Assimilation can be promoted through practices such as mapping of new knowledge domains (as a potential solution) with existing problems in the firm; by means of codification, recording and storage of new knowledge to facilitate its ulterior use; or by promoting informal communication and interactions to foster dissemination of knowledge within the firm (Comacchio & Bonesso, 2011, pp. 15–17). Managers should also facilitate proactively external

knowledge transformation and exploitation processes. To implement incorporation of the new external knowledge, firms can develop periodic meetings in order to examine the consequences of external facts and discuss potential ways of using the externally acquired and assimilated knowledge in new product development. Also, they can explicitly support and reward new ideas where individuals apply the new knowledge in radical innovations, in such a way that employees are clearly aware about the relevance of these activities in the firm. These implications can also be extended to the case of external depth strategies. Although our results were not strong enough to support the moderating effect of realized AC on depth search, we are convinced that implementation of processes that facilitate learning and new knowledge application from partners can help attenuate costs associated with the development of stable patterns of collaboration.

This study is subject to a number of limitations and some of them create paths for future research. First, our research is focused on high-technology Spanish firms. It may be that the relationships examined in this study do not hold in other industrial settings such as low- and medium-technology industries. The complexity of technological knowledge bases in different industries may determine the appropriate level of external search breadth and depth and also the relevance of potential and realized AC. For instance, according to Laursen and Salter (2006), medium-technology firms search widely. By contrast, those in low-technology sectors exhibit the lowest levels in breadth and depth. Regarding AC, activities such as knowledge intelligence and knowledge dissemination are, in some cases, even more important than pure knowledge development in traditional industries. (Spithoven et al., 2010). Hence, future studies should explore how these relationships hold in different industrial contexts. Second, we only considered firms' external search strategies in terms of breadth and depth, without taking into account that there are differences in what insights firms might gain from interacting with different types of external sources and it might be that they exert an unequal effect on radical innovation. Depending on their needs, different firms may have different external knowledge links and a different search strategy for accelerating internal innovation (Chen et al., 2011). In this sense, exploration of the contribution of different types of partners and the moderating effect of AC on each one constitutes a direction for future research. Third, although we draw on previous studies to represent the variables in the study, checked for validity and reliability issues, and relied on two informants in each firm, this study is based on the assessment of managers, so there is a risk of potential subjective bias. Development of more refined scales and, specially, inclusion of objective data when possible, could help overcome this limitation.

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