Absorptive capacity and ambidexterity in R&D: linking technology alliance diversity and firm innovation

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ABSTRACT

The aim of this study is to examine how firms realize the benefits associated with a diverse range of technology alliances. We propose and test the hypothesis that firms' knowledge combination capabilities mediate the relationship between technology alliance diversity innovation. Using panel data for Spanish manufacturing companies during the period 2004-2011, we provide evidence that firms' absorptive capacity and ambidexterity in R&D serve as mediating mechanisms between technology alliance diversity and innovative performance Our study advances the literature on technology alliances by showing how firms use their portfolios of technology alliances to form their combination capabilities, and subsequently, to enhance innovation outcomes.

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INTRODUCTION

Innovation is the process through which firms find solutions which meet market needs through knowledge search (Katila and Ahuja 2002). The generation of solutions in this process depends critically on firms' ability to combine existing knowledge in new ways and/or reconfigure how new and existing knowledge is combined (Henderson and Clark 1990). As shown by prior studies, technology partnerships play a potentially important role in enhancing firms' knowledge recombination capabilities (Rosenkopf and Almeida 2003, Grant and Baden-Fuller 2004). Involvement in technology alliances enables firms to extend their knowledge search activities outside their organizational boundaries, encouraging the formation of novel combinations of knowledge (Rothaermel and Alexandre 2009, Rosenkopf and McGrath 2011). Recent studies have identified the *diversity* of firms' technology alliances as an important factor in shaping innovative performance by enhancing the opportunities for new knowledge combinations (Faems *et al.* 2005, Sampson 2007, Oerlemans *et al.* 2013, Wuyts and Dutta 2014). Diversity in this context refers to the degree of differentiation – defined in terms of a given trait – among the set of alliances formed by a firm. This may relate, for instance, to the presence of different partner types along the innovation value chain (e.g., upstream, downstream, horizontal links), or across distinct geographic contexts (e.g., regional, national, international) (Powell *et al.* 1996, Nieto and Santamaria 2007, Duysters and Lokshin 2011, Faems *et al.* 2012, van Beers and Zand 2014).

Empirical studies on technology alliance diversity confirm that new knowledge combinations resulting from links with different partner types shape firms' innovation outcomes. Some studies find evidence indicating the presence of positive innovation performance effects linked to technological alliance diversity (Nieto and Santamaria 2007, van Beers and Zand 2014, Wuyts and Dutta 2014). Other studies report that the effects of technology alliance diversity are significant, but limited by the presence of important liabilities, such as the learning difficulties and management costs associated with highly diverse alliance portfolios (Sampson 2007, Duysters and Lokshin 2011, de Leeuw *et al.* 2014). More recently, studies have suggested the potential value of a contingency perspective to uncover the factors that influence the technology alliance diversity – innovation relationship (Faems *et al.* 2012). Firms' technology management capabilities (Oerlemans *et al.* 2013), the configuration of the firm's internal knowledge bases (Wuyts and Dutta 2014), and firms' experience in managing diverse external knowledge sources (Love *et al.* 2013) have all been identified as potentially important factors in moderating the impact of technology alliance diversity on innovative performance.

Prior studies postulate a direct relationship between technology alliance diversity and firms' innovation outcomes. Knowledge recombination and its associated complementarities are widely recognized as the predominant mechanism driving this relationship. Yet, previous research tends to conceive of knowledge recombination as a *black box process*, in which the focus is on determining the connection between inputs (technology alliance diversity) and outputs (innovation outcomes) rather than explaining how firms actually undertake knowledge recombination. More research is therefore needed to uncover the mechanisms through which technology alliance diversity shapes firms' innovative performance.

In this paper, we aim to fill this gap by proposing a theoretical framework for how firms' knowledge combination capabilities *mediate* the connection between technology alliance diversity and innovative outputs. Our goal is to determine whether the relationship between technology alliance diversity and innovation outcomes occurs indirectly through the development of these capabilities. We define technology alliance diversity as the combination of two attributes: the position of firms' partnerships across the innovation value chain and the geographic scope of their partnerships. We also focus on the mediating role played by two specific knowledge combination capabilities: firms' absorptive capacity (ACAP) and their ambidexterity in research and technological development (R&D). Using rich panel data on Spanish manufacturing companies for the period 2004-2011, our evidence shows greater technology alliance diversity helps firms to improve their ACAP and ambidexterity in R&D. This increases firms' ability to take advantage of both internally and externally based knowledge and knowledge generated by different learning processes (exploration vs. exploitation). We then provide evidence indicating that, by influencing firms' knowledge combination capabilities, technology alliance diversity enhances innovative performance.

Our research extends the previous literature in the following respects. To the best of our knowledge, this is the first study that integrates research on ACAP and ambidexterity to explain how firms create value from their technology alliances. Compared to other studies on alliance diversity (Faems *et al.* 2005, Sampson 2007, Duysters and Lokshin 2011, de Leeuw *et al.* 2014, van Beers and Zand 2014) our research demonstrates that ACAP and ambidexterity in R&D are important in enabling firms to realize the benefits of diverse technology alliances. Some studies have started to consider mediating mechanisms to link alliance formation and firm innovation. For instance, Fosfuri and Tribó (2008) analyze how alliance formation drives a firm's potential ACAP, and then, its innovative performance. However, they ignore the role of alliance diversity as an influence on firms' knowledge combination capabilities. Simsek (2009) proposes a model in which network diversity impacts firms' organizational ambidexterity, and subsequently, its performance but does not empirically validate these relationships. Together, these contributions provide only a fragmented view of the relationship between alliance diversity and firm performance and the potential mediating role of both ACAP and ambidexterity.

Our study identifies technology alliance diversity as a new antecedent of firms' ambidexterity extending previous studies which have focused on intra-organizational characteristics and environmental conditions as the main determinants of ambidexterity in exploration and exploitation (Gupta *et al.* 2006, Jansen *et al.* 2006, Raisch and Birkinshaw 2008). Our study also offers new evidence to indicate that technology alliance diversity can contribute to ACAP. Several prior studies have theorized about this linkage (Cohen and Levinthal 1990, Nicholls-Nixon 1995, Zahra and George 2002) but very few have actually provided empirical evidence about the impact of technology alliance diversity on ACAP (George *et al.* 2001).

Our study is not only the first to assess the indirect effects of technology alliance diversity on firms' innovative performance through its ACAP and ambidexterity in R&D, but we also conduct this assessment using panel data. Thus, compared to other studies (George *et al.* 2001, Fosfuri and Tribó 2008) we are able to establish causality and to avoid problems, such as the presence of common method bias, which might affect the validity of the reported results. In addition, our research exploits rich data on firms' alliance portfolios that allows an examination of the effects of diversity arising not only from R&D collaboration but also from market-based agreements. In doing so, this study generates new evidence about the impact of alliance diversity arising from market-based agreements on innovation outcomes.

The paper is organized as follows. The next section presents the theoretical foundations for studying the links between technology alliance diversity, knowledge combination capabilities and innovation. In subsequent sections, data, methods and results of the study are described and concluding remarks are discussed in detail.

THEORETICAL BACKGROUND

Explaining the Links Between Technology Alliance Diversity and Success In Innovation

We postulate that firms realize the benefits of technology alliance diversity when diversity contributes to the development of their knowledge combinationcombination capabilities, defined according to Kogut and Zander (1992) as the abilities that lead a firm to 'synthesize' and 'apply' current and new knowledge sources. An implication of this idea is that these combination capabilities act as the mechanisms that *mediate* the link between technology alliance diversity and firms' innovative performance. To see how this mediation might occur we develop the arguments of earlier studies on organizational learning (Cohen and Levinthal 1990, March 1991, Kogut and Zander 1992, Tushman and O'Reilly 1996) to propose two effects linking technology alliance diversity and firms' knowledge combination capabilities. The first is a *knowledge-provision effect*, viewed here as the increase in a firm's knowledge combination capabilities made possible by better access to new knowledge resources from a varied range of partnerships. The second is a *learning-experience effect* that occurs when the experience gained by the firm in managing diverse technology alliances reduces the presence of behaviors that could impair knowledge recombination in the innovation process. As explained below, when these effects are present, a firm is better able to achieve knowledge recombination and successful innovation.

In this study, two specific knowledge combination capabilities are proposed as mechanisms linking technology alliance diversity and innovations: (i) a firm's ACAP, and (ii) its ambidexterity in R&D. A firm's ACAP is the set of knowledge processing capabilities related to the identification, assimilation, and application of external knowledge (Cohen and Levinthal 1990). ACAP enhances a firm's innovative performance by enabling the utilization of external knowledge in innovation (van Beers and Zand 2014). Ambidexterity is a capability that allows firms to perform highly incompatible activities simultaneously (Duncan 1976, Tushman and O'Reilly 1996). Here, the focus is on ambidexterity occurring in exploration and exploitation, because of the critical role of these activities in enhancing firms' innovative performance (Katila and Ahuja 2002, He and Wong 2004, Rothaermel and Alexandre 2009). A manifestation of ambidexterity in exploration and exploitation occurs when firms make an effort at balancing their focus on exploratory and exploitative activities. As shown by previous studies on R&D management, these activities are highly complementary, but at the same time they involve different operating logics and organizational requirements (DeSanctis *et al.* 2002, Mudambi and Swift 2011, Davila *et al.* 2012). Thus, ambidexterity in R&D involves the development of capabilities that allow firms to combine exploration and exploitation in R&D through the innovation process.

In Figure 1, we present a mediated model that describes the channels through which we argue that technology alliance diversity can influence innovative performance. To clarify the contribution of our research, Table 1 compares our approach with previous contributions in the field.

[Insert Figure 1 here]
[Insert Table 1 here]

Technology Alliance Diversity and Firms' Knowledge Combination Capabilities

First, the influence of technology alliance diversity on building the firm's ACAP is considered. ACAP is a combination capability because it allows firms to combine external and internal knowledge needed for innovation (Lewin *et al.* 2011). A relevant attribute of ACAP is that its formation is path-dependent, since prior experience in conducting knowledge processing activities determines firms' current abilities to learn from external knowledge (Lane and Lubatkin 1998, Roberts *et al.* 2012). For example, several studies indicate that there is a positive feedback between "experience" and "competence" that makes learning easier from technologies where there has been prior knowledge accumulation (Kogut and Zander 1992, Leonard-Barton 1992, Ahuja and Lampert 2001). Hence, firms tend to form competences in processing knowledge related to areas where prior experience exists, and these competences ease the share and transfer of knowledge across firms' sub-units, thereby supporting their capacity to assimilate and utilize internally generated knowledge, or what is called *inward-looking ACAP* (Cohen and Levinthal 1990, Lewin *et al.* 2011). However, the development of competences grounded in previous experience may also reduce the diversity of the firm's knowledge. This may incline the firm to become more myopic reducing its interest in external technologies. This may impair its capacity to recognize and acquire externally produced knowledge, or what is called *outward-looking ACAP* (Cohen and Levinthal 1990, Rothaermel and Alexandre 2009).

In this study, diverse technology alliances are viewed as sources of knowledge-provision and learning experiences effects that offset this trade-off. First, the role of the knowledge-provision effect is considered. This effect occurs when knowledge resources generated by the firm's participation in diverse technology alliances enhance their ACAP. These resources may improve the way a firm monitors and assesses the evolution of new technological fields. For instance, participation in upstream and/or international technology alliances may help a firm's employees be aware of new technical advances in diverse technological fields (Cohen and Levinthal 1994, Fosfuri and Tribó 2008, Lavie and Miller 2008). In this way, the firm may expand its capacity to screen technological opportunities in areas unrelated to prior knowledge accumulation, thus increasing its abilities to recognize the importance of emerging external technologies (i.e. outward-looking ACAP). In this regard, Cockburn and Henderson (1998) suggest that the level of 'connectedness' to the scientific community is a key factor that enables pharmaceutical companies to advance their abilities in recognizing the value of upstream developments. Alternatively, other knowledge resources may help the firm better utilize its internal sources of information. For instance, engagement in alliances with competitors, suppliers or clients, or with local partners, may facilitate the benchmarking of managerial practices, strategies and routines, which could improve knowledge sharing and utilization within the firm (i.e. inward-looking ACAP). As suggested by Lenox and King (2004), the way knowledge is shared across a firm's functional areas plays an important role in enhancing the inward-component of ACAP.

A learning-experience effect also contributes to shaping a firm's ACAP. This effect arises when technology alliance diversity leads firms to gain experience in knowledge processing that favors a balance between the inward- and outward-looking components of their ACAP. For instance, connections with diverse partners make it more likely that a firm is exposed to varied learning experiences, increasing its capabilities to recognize and acquire external knowledge (Rosenkopf and Almeida 2003, Lavie and Miller 2008). In doing so, technology alliance diversity helps firms prevent the emergence of behaviors, such as those related to the *Not-invented here syndrome* that over-emphasizes internal search and reduces the perceived value of new external knowledge (Laursen and Salter 2006).

By balancing the inward- and outward-looking components of their ACAP, firms gain experience in managing external and internal searches simultaneously. In doing so, they are better able to recognize underlying differences in learning from external and internal sources, which facilitates the management and subsequent integration of these learning modes (Rothaermel and Alexandre 2009, Duysters *et al.* 2012). An implication is that a balanced ACAP profile leads firms to develop capabilities, which improve organizational learning. That is, firms are better able to reconfigure their internal knowledge searches to neutralize technological inertia, or the tendency to learn mainly from technologies rooted in familiar knowledge (Lavie and Rosenkopf 2006). Thus, they are better able to change their knowledge search behavior in response to external knowledge sources. Taken together these arguments lead us to suggest that:

Hypothesis 1a: A diverse portfolio of technology alliances enhances the firm's ACAP.

Ambidexterity in R&D is a combination capability that enables the firm to combine research and technological development activities involving exploration and exploitation. To examine the effects of technology alliance diversity on the formation of this combination capability, we focus here on the R&D behavior of firms, because it provides useful signals for inferring the presence of ambidexterity in knowledge search. In fact, received research shows that R&D investments can lead the firm to different types of knowledge search (Hoang and Rothaermel 2010, Mudambi and Swift 2011, Rosenkopf and McGrath 2011). Whereas research – the '*R*' in the R&D process – includes activities intended to discover and use new knowledge sources over the innovation process, technological development – the '*D*' in the R&D process – includes activities that allow firms to utilize existing knowledge for improving their current portfolios of products and technologies. Since the use of "new" or "existing" knowledge is conventionally adopted as a rule to distinguish exploration and exploitation (Levinthal and March 1993, Lavie *et al.* 2010, Rosenkopf and McGrath 2011), we assume here that firms' effort in research is directed to the pursuing of exploration, while effort invested in technological development is addressed to the undertaking of exploitation. With this assumption, we then propose that a diverse range of technology alliances shapes a firm's incentives to implement ambidextrous models of knowledge search, reflected in the balance it reaches in the '*R*' and '*D*' processes. We further posit that the knowledge-provision and learning-experience effects serve as mechanisms that explain the link between technology alliance diversity and the presence of ambidexterity.

First, the role of the knowledge-provision effect is analyzed. This effect is produced when connections with diverse partner types provide knowledge that encourages the firm to undertake exploration and exploitation internally enhancing ambidexterity. Technology alliance diversity obliges firms to handle sources of information resulting from both upstream and downstream activities along the innovation value chain (Hoang and Rothaermel 2010), or from activities rooted in different geographical contexts (Lavie and Miller 2008). While some of these sources comprise a pool of new ideas, others form a pool of well-established ideas. In both cases, firms face will benefit from balancing their search effort to harness the inputs provided by these pools and potential cross-fertilization from combining diverse ideas (Quintana-García and Benavides-Velasco 2008, Faems *et al.* 2012). In the case of the pool of new ideas, firms receive inputs that lead them to reinforce their internal exploration activities. In the case of the pool of well-established ideas, firms receive inputs that reinforce their internal exploitation activities. From this pool, they can learn how to adjust, improve and leverage their current knowledge bases and competences. In addition, the pool of new ideas may also lead firms to engage in more intensive exploitation in an attempt to transform these ideas product and/or technology development process (Holmqvist 2004, Rothaermel and Deeds 2004). Similarly, well-established ideas may also lead firms to undertake more exploration, especially in cases in which technological exhaustion caused by these ideas is imminent (Ahuja and Katila 2004, Holmqvist 2004).

A learning-experience effect also explains how technology alliance diversity shapes firms' ambidexterity in R&D. In this case, this effect appears when the exposure to diverse types of partners helps firms balance exploration and exploitation internally, thereby avoiding search behaviors that might impede the presence of ambidexterity. Diverse portfolios of technology alliances enable a firm to allocate specific search activities to specific network patterns. For instance, whereas exploratory search occurs at upstream stages of the innovation value chain and/or in distant geographic contexts, exploitation search arises at downstream stages and/or in local geographic contexts (Rosenkopf and Almeida 2003, Faems *et al.* 2012). By buffering these search activities, a firm is able to mitigate incompatibilities existing between them in terms of differing operating logics. As a result, firms connected to diverse partner types are better positioned to experience differing learning activities without any crowding out.

Just as firms can blend diverse external search types they may also learn how to blend similar internal search processes rooted in exploration and exploitation. Our argument is that, when recognizing differences in learning processes associated with diverse partnerships, firms gain valuable experience in identifying and managing comparable differences in the learning process adopted in their internal '*R*' and '*D*'. This helps firms accommodate the '*R*' and '*D*' processes favoring the presence of ambidexterity. As postulated by Parkhe (1991), the recognition of differences in the attributes of a given process is the first step toward making sense of them, which in turn, facilitates their subsequent organization.

Because the experience of handling diverse alliances helps a firm shape capabilities in managing different search types, less polarization in either exploration or exploitation is expected in the organization of its intramural R&D activities. This claim is coherent with the suggestion of Simsek (2009) that network diversity assists firms in avoiding familiarity and propinquity traps that impede a balance in exploration and exploitation. Altogether, these aruguments lead us to suggest that:

Hypothesis 1b: A diverse portfolio of technology alliances enhances the degree of ambidexterity in a firm's R&D.

Knowledge Combination Capabilities and Firm Innovative Performance

Here, we posit that firms' knowledge combination capabilities contribute to shaping their innovative performance by improving the integration of knowledge differing in their *loci* (internal vs. externally-based) and *generating processes* (exploration vs. exploitation). First, the role of the firm's ACAP in improving innovation outcomes is considered. High levels of ACAP mean firms are able to learn from external knowledge, making further technological renewal more likely (Lavie and Rosenkopf 2006). As a result, new knowledge recombination opportunities are created as firms are enabled to embrace external sources of knowledge differing from those in their own technological background (van Beers and Zand 2014). High levels of ACAP also help firms utilize external knowledge in creating and capturing value from resulting innovations (George *et al.* 2001). This suggests:

Hypothesis 2a: ACAP is positively related to the likelihood that firms will successfully commercialize innovative products.

The presence of ambidexterity in R&D allows firms to integrate exploration and exploitation and to use knowledge generated from these activities to increase the impact of their innovations. From the '*R*', firms explore new technological opportunities, thereby expanding the possibilities for knowledge re-combination. From the '*D*', firms exploit existing knowledge and capabilities to adjust their product lines with the aim of meeting customer needs. Ambidexterity in R&D assists firms in transforming knowledge from research activities into new product designs with the capacity to add value. Thus, a balanced combination of '*R*' and '*D*' activities allow firms to avoid the risks of over-exploring and over-exploiting knowledge. The benefits of ambidexterity in knowledge search have been documented by several studies. For instance, Katila and Ahuja (2002) provide evidence for a sample of robotics companies about the benefits of balancing exploration and exploitation on their abilities to make new product introductions. Likewise, Rothaermel and Alexandre (2009) demonstrate that balanced combinations of technological sourcing strategies aligned with exploration and exploitation lead firms to increase their innovativeness. He and Wong (2004) also show that ambidextrous firms are better placed to increase their sales through the generation of more product and process innovations [1]. Together this leads us to hypothesize that:

Hypothesis 2b: The degree of ambidexterity in R&D is positively associated with the likelihood that firms will successfully commercialize innovative products.

The Mediating Role of Knowledge Combination Capabilities

As the degree of technology alliance diversity increases, firms are exposed to a wider range of knowledge resources and experiences that improve their abilities to integrate internal and external knowledge bases and exploration and exploitation searches. This leads firms not only to build ACAP, but also to develop ambidexterity in R&D. With enhanced knowledge combination capabilities, firms increase the chance of generating new product lines with a high commercial value. We therefore hypothesize that:

Hypothesis 3: Firms' knowledge combination capabilities mediate the relationship between technology alliance diversity and the likelihood of successfully commercializing innovative products.

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[1] In the field of technological innovation, several studies define ambidexterity by using the dichotomy between product and process innovation (Benner and Tushman 2003) and between incremental and radical innovation (Greve 2007). In line with He and Wong (2004), our interpretation here is that exploration and exploitation are *ex-ante* strategies aimed to the production of innovation outcomes.

EMPIRICAL ANALYSIS

Data

Our analysis makes use of data from the "Panel of Technological Innovation" (henceforth PITEC). The PITEC is gathered by the Spanish National Statistical Institute (INE), in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The PITEC is built from data collected annually by the Innovation in Companies Survey, which provides information on firms' technological innovation activities for all the main industries of the Spanish economy. Information is available from the year 2003 in a set of annual files[2]. In line with the EU Community Innovation Survey (CIS), the PITEC applies the methodological rules and the type of questions defined by the Organization for Economic Cooperation and Development's (OECD) Oslo Manual (2005). In order to maintain representativeness, the PITEC comprises four samples that aim to characterize different firm populations. The first includes data for large firms (with more than 200 employees). This sample covers 73% of all large firms that are listed by the Spanish Central Company Directory (DIRCE). The second sampleincludes information on firms with intramural R&D expenditures, which accounts for 56% of all firms involved in in-house R&D activities, according to data from the Research Business Directory (DIRID) (Vega-Jurado *et al.* 2009). In 2004, two new samples were incorporated to improve the coverage of small companies. The first of these samples represents firms with fewer than 200 employees that report external R&D, but no intramural R&D expenditures, while the second sample includes information on firms with fewer than 200 employees that report no innovation expenditures.

[2] This dataset is freely available at: http://icono.fecyt.es/PITEC/Paginas/descarga_bbdd.aspx

In this study, we focus on manufacturing companies across 24 industries, based on the Spanish National Classification of Economic Activities (CNAE-2009)[3]. Due to data limitations, we built a sample that covers a time frame from 2004 to 2011. The effective sample size ranged between 2,933 and 3,517 firms because of both the lag structure needed in the study of mediation models and the presence of missing values. Classifying industries as low- or high-tech intensive according to the OECD taxonomy (2005)[4], suggests that nearly a quarter of the companies in the sample operate in low-tech industries, while, on average, the share of companies in the sub-sample of high-tech industries is around 12.7%. On average, companies in the sample have 199 employees. Companies in high-tech industries are on average larger than those in low-tech sectors, as indicated by the average number of employees, which for the former group reaches 194 while for the second group is equal to 178 employees.

Our sample has some characteristics that are relevant for the purpose of this study. First, the tracking of information on the same companies over time is necessary to conduct mediation analysis. Since a correctly defined mediation model sets out causal relationships among variables, temporal precedence of causal factors is required (MacKinnon *et al.* 2007, Ndofor *et al.* 2011, Lejarraga and Martinez-Ros 2013). In our sample, information for characterizing "technology alliance diversity", "knowledge combination capabilities" and "innovation outcomes" is available at different points in time, so causality can be established. Second, a multi-industry sample of companies allows us to account for the presence of well-documented industry-idiosyncratic effects that can influence the formation of firms' knowledge combination capabilities and their abilities to produce innovation (Malerba 2007, Vega-Jurado *et al.* 2009).

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[3] The CNAE-2009 used in the PITEC is equivalent to the 2-digit SIC classification.
[4] The group of high-tech intensive includes: pharmaceutical and chemicals, electrical machinery and apparatus manufacturing, electronics, computers and office equipment, medical optical and scientific instruments, aerospace transportation equipment. The group of low-tech intensive comprises: food, beverage and tobacco, textile, clothing and leather, paper and publishing, rubber, plastics and synthetic material, glass, pottery, and related products, base metals and fabricated metal products, furniture and wood products.

Measures

Dependent variable

Innovative performance: Our theory suggests that, by shaping knowledge combination capabilities, technology alliance diversity increases firms' chances of successfully commercializing new products. Elaborating on Nieto and Santamaria (2007), we characterize innovative performance using two binary variables, which indicate whether a firm had sales in year *t* attributable to new products introduced between *t-2* and *t*. The first variable indicates whether sales at *t* were due to "new-to-the-market" product introduction, regarded here as a proxy for the presence of radical innovation. The second variable specifies whether sales at *t* were attributable to any "new-to-the-firm" product introduction, viewed as a proxy for incremental innovation[5]. The use of these indicators allows us to examine the existence of differences in the way in which knowledge combination capabilities translate technology alliance diversity into enhanced probabilities to commercialize innovative products with varying degrees of novelty.

Mediator variables

ACAP: Firms' ACAP is largely recognized to be multidimensional construct (Zahra and George 2002, Jansen *et al.* 2005, Lewin *et al.* 2011, Roberts *et al.* 2012). To capture this feature in our operationalization, we chose several indicators to represent the main dimensions of ACAP. First, in line with Cohen and Levinthal (1990), we take into account firms' R&D expenditure to capture the learning dimension of the construct. Second, we

[5] We opted for binary variables to represent innovation outcomes for the following reason. The use of measures like total sales due to new products requires the treatment of censored outcome variables in the assessment of the mediation effects of technology alliance diversity. Then, Tobit regression analysis is required. But, since Tobit estimation assumes non-linearity, the assessment of mediation may become difficult. Ignoring the censoring problem of the outcome variable might generate misspecification concerns. Other options allow the assessment of mediation effects for the case of binary outcome variables. Although estimation of models with binary outcome variable assumes non-linearity, some methods have been developed to treat this issue while testing for mediation. For a discussion on this topic, see Kenny (2008) and Mackinnon et al (2007).

take into consideration the fact that ACAP is formed from related prior knowledge (Cassiman and Veugelers 2006, Escribano *et al.* 2009, Xia and Roper 2014). To do so, we add a dummy variable that takes the value of 1 when a firm claims that its R&D engagement is continuous. Third, along the line of prior literature on organizational learning, we incorporate the human capital dimension of ACAP (Leiponen 2005, Xia and Roper 2014). To do so, we consider two indicators: training for R&D personnel and employee skills. The first indicator is a continuous variable measuring the level of firms' investment in scientific and technical training. With this variable, we aim to capture the fact that training helps firms develop multi-skilled employees (Lazear 1998). This type of training facilitates job rotation, communication and flexibility, attributes that greatly favor knowledge sharing and its utilization within firms (Jansen *et al.* 2005). The second indicator is a continuous variable that reflects the percentage of employees with at least an undergraduate degree in any subject. In line with earlier studies, we assume that well-educated employees enhance both the capacity for the assimilation and application of new external knowledge and knowledge sharing within firms (Xia and Roper 2014).

In order to form a composite measure that represents the multidimensionality of ACAP, we proceeded as follow. Drawing on Escribano et al. (2009), we built a measure of ACAP that is the principal component of the variables described above. Hence, ACAP is represented by a linear combination of the indicators previously defined, so that each of these indicators was weighted by its corresponding factor loading[6]. Formally, firms' ACAP is defined as follows: $\sum_i \omega_i \upsilon_i$, where υ_i represents the standardized values of the observed variable *i*, whereas ω_i is the corresponding factor loading of *i*. There are two benefits associated with the use of our measure of ACAP. First, the use of composite measures

[6] Factor loadings are defined as the correlations existing among a range of observable variables and its corresponding principal component. They are estimated during the process by which principal components are extracted from the observable variables (Hair *et al.* 2010). So, if a given observable variable is highly correlated to the extracted principal component, the resultant factor loading will be high as well. Results of the factor analysis used for building the ACAP are available upon request.

provides a means of mitigating the presence of measurement errors inherent in all measured variables (Hair *et al.* 2010). Second, the use of composite measures tends to produce more suitably complex constructs than single base indicators (Lejarraga and Martinez-Ros 2013).

Ambidexterity in R&D: In our framework, ambidexterity in exploration and exploitation takes place through the balancing of '*R*' and '*D*' activities. To measure this capability, we used the PITEC information about the type of R&D performed by the surveyed firms. Specifically, we analyzed data where firms indicate how they distributed their R&D expenditures between "research" and "technological development". In the PITEC, expenditures on research refer to those explicitly addressed to the generation of *new knowledge* (i.e. basic and applied research). Alternatively, the PITEC distinguishes expenditures on technological development, which are defined as those dedicated to the search for new applications of *existing knowledge sources* that improve current materials, products, and/or technologies.

To measure the presence of ambidexterity in R&D, we calculated the degree of diversification of firms' R&D expenditures by applying the Blau's (1977) index: $1-\sum_{i=1}^{2}(K_i)^2$. In this context, K_i represents the percentage of internal R&D expenditures dedicated to the objective *i*, where *i* = *research*, *technological development*. This index ranges between 0 and 0.5, where high values suggest firms equally distribute their R&D expenditures between research and technological development, while low values indicate a resource allocation in which firms tend to focus on either research or technological development. This operationalization captures the balance dimension of ambidexterity proposed by Cao et al. (2009). Hence, ambidexterity takes place when firms tend to allocate resources to research and development around the ideal balance point of 50%-50%.

It is worthwhile to note that our measure of ambidexterity rests on the assumption that distributions of resources for '*R*' and '*D*' reveal information about how knowledge search is conducted within firms. For instance, because R&D spending primarily covers labor costs, a distribution of resources around the balance point of 50%-50% should be reflective of the time and energy invested by researchers (i.e. effort in exploration) and engineers-managers (i.e. effort in exploitation) within firms as part of the knowledge search process. This distribution shows how firms deploy their resources to obtain blends of exploration and exploitation activities, (March 1991, Gupta *et al.* 2006, Lavie *et al.* 2010). This isconsistent with the definition of a firm's capability viewed as a set of decision rules, routines and processes whereby the firm allocates and mobilises resources to accomplish its strategic objectives (Teece and Pisano 1994, Langlois and Robertson 2002, Jansen *et al.* 2009). Our position is that decisions on how firms allocate resources between research and technological development are encoded in their competences and capabilities, so these decisions are informative about how firms organize their knowledge searches.

Independent variables

Diversity arising from alternative forms of technology alliances – R&D collaboration or market-based arrangements – may have a differentiated impact on firms' knowledge combination capabilities, and subsequently on innovation outcomes. This may arise as technology alliances can differ from each other in terms of their purposes, interaction modes, and learning requirements (Lane and Lubatkin 1998, Anand and Khanna 2000, Lucena 2011). To take this issue into account, we distinguished portfolios formed by R&D collaboration from those containing R&D outsourcing deals[7].

R&D cooperation portfolio diversity: In the PITEC, firms are asked about the set of R&D collaboration agreements in which they participated during the period between *t-2* and *t*. These agreements include domestic and international links with eight different partner types[8]. From this information, we build a measure of diversity based on the combinations formed by

[7] R&D collaboration includes intentional links formed by firms and external actors with the aim of co-developing innovation activities, while R&D outsourcing refers to projects and R&D services contracted by firms in the markets for technology.
[8] Partner types include: other companies of the firm's business group, clients, suppliers, competitors, consulting firms/commercial laboratories, universities, public research centers, and technological centers.

varied partner types across alternative geographic contexts. This variable is calculated as follows: $\frac{1}{NxL}\sum_j \sum_i c_{ij}$, where *N* stands for the number of partner types with whom a firm can co-develop R&D activities, *L* represents the number of geographic locations corresponding to its partners, and c_{ij} is an indicator variable that takes the value of 1 when the firm is linked to a partner of type *i* that operates in the region *j*. This indicator ranges from 0 to 1; with high values indicating the presence of diversity, whereas low values indicating the occurrence of specialization in a portfolio of R&D collaboration agreements.

R&D outsourcing portfolio diversity: The PITEC also examines the sources from which firms acquired R&D services in the markets for technology during the period between *t-2* and *t*. These sources comprise domestic and international deals with six alternative seller types[9]. Similar to the previous case, we build a measure of diversity based on the combinations of diverse R&D seller types across different geographic contexts. This indicator is calculated as follow: $\frac{1}{MxL}\sum_j \sum_i o_{ij}$, where *M* represents the number of R&D seller types from which a firm can acquire external R&D services, *L* stands for the number of geographic origins where R&D sellers operate, and o_{ij} is an indicator variable that awards the value of 1 if the firm acquired R&D services from a seller of type *i* and origin *j*. This variable ranges between 0 and 1, where high values indicate the presence of diversity, and low values reveal the presence of focused portfolios of R&D outsourcing deals.

Control variables

We include in our study the following control variables. First, we control for firms' affiliation to other companies, since these connections may provide access to valuable resources for the development of combination capabilities and the promotion of innovation. Business affiliation was measured by two binary variables: *Parent company* and *Subsidiary*. These

[9] Sellers of R&D services include: other companies of the firm's business group, other firms, universities, public agencies, research associations, and other institutions.

variables indicate whether a firm is either a group parent company or a subsidiary of a larger corporation. Second, we included the variable *Firm size* because larger companies might have richer endowments of resources that enable them to enhance their combination capabilities and innovative performance. Firm size was measured as the logarithm of the number of employees. Third, we control for whether firms decentralized their R&D activities by establishing R&D-units in alternative locations within Spain. We expect that decentralized models of R&D will influence the organization of knowledge search, and subsequently the development of firms' combination capabilities. Furthermore, decentralization also might improve the access to diverse knowledge sources, influencing firms' prospect to make innovations. To control for this issue, we introduce the variable *R&D decentralization*, which measures the number R&D units the firm allocates across different location within Spain. Fourth, we control for firms' export propensity because of its influence in stimulating knowledge search and innovation. Firms with a high propensity to export are expected to develop their combination capabilities and increase innovative performance to compete effectively in international markets. We measured exporting by the binary variable *Export propensity*, which takes the value of 1 if the firm reported exports outside the European Union. Fifth, we include the indicator *Public support for R&D* to control for the effect that technology policy may have on the organization of the firm's knowledge search activities and on its innovation behavior. Public support for R&D was measured by the percentage of a firm's internal R&D expenditures that were financed with public funds.

Finally, we accounted for the following issues. First, to control for the presence of persistence in the formation of firms' combination capabilities and in their propensity to innovate, we included one-period lagged values of the dependent variables corresponding to mediators and innovation outcomes. Second, to control for differences across industries in terms of factors, such as technological opportunities, and appropriability, we adopted the Pavitt's (1984) taxonomy of patterns of technological regimes, which classifies industries as S*upplier-dominated, Scale intensive, Specialized supplier and Science-based*. By considering the two digit-level

CNAE-2009 industry classification, we created four binary variables–one for each of the prior categories– and classified surveyed firms accordingly.

Methods

To test our hypotheses we proceed as follows. First, we estimate two sets of models, one for the determinants of firms' knowledge combination capabilities and the other for their innovative performance. The nature of the dependent variable used in each situation determined the types of models finally implemented. In the first case, we used Generalized Linear Square (GLS) regression analysis because our proxies for firms' knowledge combination capabilities are continuous variables. In the second case, we used probit analysis to model firms' likelihood of commercialising innovative products. To conduct the empirical study, we took advantage of the panel design of our data. First, we treated the presence of unobserved heterogeneity by using random-effect specifications. Second, with the inclusion of the first lag of the dependent variables in each model, we accounted not only for the presence of persistence effects, but also for sources of unobserved heterogeneity (Rothaermel and Alexandre 2009, Leiponen and Helfat 2011). This mitigates potential problems derived from specification errors, such as the presence of omitted variables (Jacobson 1990).

Subsequently, we examined the mediation hypothesis proposed by our framework in two ways. First, we implemented the *causal-step method* developed by Baron and Kenny (1986) to verify the conditions required for mediation, taking into account temporal precedence among variables. We started the analysis by confirming the presence of a direct relationship between technology alliance diversity (*t-2*) and firm innovation (*t*). Then, we verified the presence of an indirect-type relationship by examining if: (i) technology alliance diversity (*t-1*) shapes firms' combination capabilities (*t*); and, (ii) these capabilities (*t-1*) determine their prospects to make innovations (*t*). We also verified if technology alliance diversity (*t-2*) affects firms' propensity to generate innovations (*t*), once the effects of their combination capabilities is controlled (*t-1*). Second, we complemented previous analysis by using the *product-coefficient method* (Preacher and Hayes 2004, 2008) to assess the indirect effects of technology alliance diversity on the firm innovation. In this case, we tested for the statistical significance of the direct and indirect effects attributable to technology alliance diversity.

Results

Table 2 lists descriptive statistics and bivariate correlations for the variables under consideration. Given the presence of moderately high correlations for some pairs of covariates, we evaluated the presence of multi-collinearity by estimating the "variance inflation factor" (VIF). In most cases, we found average VIFs to be under 1.35, with a maximum of 1.73. Since VIF scores were below the conservative ceiling of 5, we conclude that the threat of multi-collinearity is limited (Cohen *et al.* 2003).

[Insert Table 2 here]

Results from the causal-step method

Table 3 reports the estimates from the random effect GLS regression analysis used to explain firms' knowledge combination capabilities. Hypotheses 1a-1b predicted that technology alliance diversity will positively affect the formation of these capabilities. Models1 and 2 show that increases in the degree of diversity coming from both R&D collaboration and R&D outsourcing deals have statistically significant effects on ACAP and ambidexterity in R&D adopted by firms. The impact of technology alliance diversity on firms' ACAP is stronger than that on their ambidexterity in R&D. These findings provide support for Hypotheses 1a and 1b, confirming that a diverse range of connections with external agents enhances firms' knowledge combination capabilities, as measured by ACAP and ambidexterity in R&D.

[Insert Table 3 here]

Table 4 reports the results relevant for Hypothesis 2a-2b. Since innovation outcomes in these models are binary variables, estimations were derived from probit analysis with random effects. To treat the dynamic panel structure in this context, we included the initial dependent variable values in each time to account for the initial conditions problem emerging in the estimations of dynamic probit models (Wooldridge 2005). Models 3a-3b report the results when predicting firms' likelihood of to successfully commercialising product that are new to the market (radical innovations), whereas Models 4a-4b show the results for product introductions that are new to the firm (incremental innovations).

In regard to radical innovation effects, Model 3a shows that technology alliance diversity positively influences firms' likelihood of successfully commercialising this type of innovative product. This confirms the existence of a direct relationship between diversity in firms' external links and the presence of highly novel product introductions. Alternatively, Model 3b shows that firms' ACAP and ambidexterity in R&D have a positive and statistically significant impact on their probability of commercialising radical innovations, thereby providing support to Hypotheses 2a-2b. With regards to incremental innovation effects, Model 4a indicates that diversity coming from R&D outsourcing has a positive and statistically significant effect on firms' probability of successfully commercialising this type of innovative product, revealing the presence of a direct relationship. However, diversity from R&D collaboration fails to explain the likelihood of commercializing incremental innovation. Likewise, Model 4b shows that ambidexterity in R&D explains the probability of commercialising incremental innovation. However, it is also observed that the impact of the firm's ACAP is not statistically significant in driving the prospects incremental innovation. Taken together, results from Models 2 and 4 partially confirm Hypothesis 2a that a firm's ACAP shapes the likelihood of successfully commercialising innovative products, and gives strong support to Hypothesis 2b that ambidexterity in R&D does drive such possibilities.

[Insert Table 4 here]

Hypothesis 3 predicted that firms' knowledge combination capabilities mediate the relationship between technology alliance diversity and innovative performance. Examination of the conditions established by the causal-step method uncovers the following results. As regards radical innovation, the findings in Models 1-3 meet the conditions for mediation. First, they show that sources of technology alliance diversity positively determine firms' knowledge combination capabilities (Hypotheses 1a-1b), and that these capabilities have a positive effect on firms' propensity to make radical innovations (Hypotheses 2a-2b). Second, Model 3b shows that the influence of R&D outsourcing is no longer statistically significant after accounting for the effect of firms' combination capabilities, which reveals the presence of "total mediation". Alternatively, the results suggest that the influence of R&D collaboration diversity reduces, but remains statistically significant once we control for firms' knowledge combination capabilities suggesting the presence of "partial mediation". These results are consistent with the premise that R&D outsourcing diversity affects firms' likelihood of commercialising radical innovations exclusively through shaping their knowledge combination capabilities. In contrast, R&D collaboration diversity not only has a direct effect on making this type of commercialization more likely, but also has an indirect effect running through the development of firms' knowledge combination capabilities.

As regards incremental innovation, the conditions for mediations are met particularly when ambidexterity in R&D serves as a mediator. As indicated by Table 3, the sources of technology alliance diversity positively determine the degree of ambidexterity in R&D, while, as shown by Table 4, this combination capability has a positive and statistically significant effect on the probability of commercialising incremental innovations. Alternatively, although technology alliance diversity influences the firm's ACAP, as shown by Table 3, this combination capability does not have a statistically significant effect on firms' likelihood commercialising incremental innovations. Therefore, ACAP does not transform the effect of technology alliance diversity into enhanced incremental innovative performance. Diversity from R&D outsourcing, however, has a direct effect on incremental innovative performance, and an indirect effect running through the formation of ambidexterity in R&D[10]. Interestingly, the results of Model 4a in Table 4 reveal that the effect of diversity from R&D collaboration is not statistically significant in driving incremental innovation. Compared to Baron and Kenny's (1986) framework, studies on mediation by MacKinnon et al. (2002) and Zhao et al. (2010) recently recognize that a significant direct relationship between independent and dependent variables is not a necessary condition in order for mediation to be present. For these scholars, mediation just requires the existence of significant relationships between independent variables and mediators, and between mediators and dependent variables[11]. When this is the case, total mediation can be claimed. According to this criterion, our study shows that ambidexterity in R&D appears as the only link connecting R&D collaboration diversity and firms' incremental innovation performance. Since R&D collaboration diversity and innovative performance in this case are not directly related, one can state that ambidexterity in R&D totally mediates this link.

Results from the product-coefficient method

To further examine the mediating role of firms' knowledge combination capabilities, the product coefficient method[12] was adopted to estimate the direct and indirect effects of technology alliance diversity (Preacher and Hayes 2004). According to this method, the indirect effect of *X* on *Y* mediated by M_1 and M_2 can be calculated by: $\sum_i \alpha_i \beta_i$, where α_i is the estimated effect of *X* on M_i, while β_i stands for the estimated effect of M_i on *Y*. The Stata routine for *Binary Mediation Analysis* was implemented to obtain the estimates for α_i and β_i. Pooled Ordinary Least Squares (OLS) and pooled probit regression analysis were used in the estimation,

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[10] Slightly changes in the coefficient in the independent variables once mediators are included are founded by the Heimeriks and Duysters (2007) in their study of the mediating role of alliance capability in the link between experience and alliance performance.
[11] Tiwana (2008) illustrates a case in which this criterion is used when testing for mediation in the context of the causal-step method.
[12] The use of Structural Equation Modelling (SEM) represents another alternative to assess the presence of mediation. However, SEM assumes the presence of linearity, which is incompatible with the use of binary variables as measures of innovation outcome.

depending on the nature of the dependent variable under consideration[13]. From this estimation, we generated bootstraps standard errors and 95% confidence intervals for the indirect and direct effects[14]. A given effect is then statistically significant when the corresponding confidence interval does not contain zero. If a zero is included, an insignificant effect is claimed.

Table 5 contains the results from the product coefficient method. These findings strongly support Hypothesis 3 that technology alliance diversity has an indirect effect on firms' innovative performance, which runs through increases in their knowledge combination capabilities. Indeed, the direct effects reported in Table 5a and 5b fail to be statistically significant, as evidenced by the fact that the corresponding confidence intervals include zero. In the case of radical innovation (Table 5a), one can observe that knowledge combination capability appears as a valid mediation mechanism between technology alliance diversity and innovative performance, as confidence intervals for the indirect effects in each case contain only positive values. On the other hand, Table 5b confirms the conclusion drawn from the causal step method that ambidexterity in R&D is the only valid mechanism that mediates the link between technology alliance diversity and firms' incremental innovation.

[Insert Table 5 here]

Control variable and robustness checks

Results for control variables in Table 3 and 4 show interesting insights. As regards results from Table 3, positive and statistically significant coefficients on the lagged dependent variables show the path-dependent nature of firms' combination capabilities. Having a business affiliation to

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[13] Given differences in their scales, these parameter estimates were previously standardized according to the procedures discussed by preceding studies on mediation (MacKinnon *et al.* 2007).

[14] Compared to other procedures (e.g., Sobel test), bootstrapping is advantageous because it does not impose any requirement on the distribution of indirect effects (Preacher and Hayes 2008).

other companies, receiving public support for R&D, and allocating the innovation activities across Spanish regions are distinctive factors enhancing firms' ACAP, while having a strong propensity to export outside the European Union is a significant influence on the degree of ambidexterity in R&D. As regards results in Table 4, positive coefficients on the lagged dependent variables indicate that the innovation behavior of firms is persistent across time. Additionally, firm size and the tendency to decentralize the R&D functions appear as important drivers for explaining firm innovative performance both radical and incremental. A technological regime characterized by the presence of specialized suppliers also favors the development and commercialization of innovative products in Spain.

Two important robustness checks were conducted. First, we tested the presence of moderation, but we found no significant interaction effects between the sources of technology alliance diversity and our indicators of firms' combination capabilities. This reinforces our arguments about the mediating role of firms' knowledge combination capabilities developed in the study. Second, we accounted for the presence of potential correlations among the error terms in the models used for the mediation analysis (Shaver 2005). To do so, we estimated the predicted values of our mediator variables from Models 1-2, which were used as instruments in the estimation of Models 3-4. In both settings, we obtained results consistent with those presented above.

DISCUSSION AND CONCLUSIONS

Our objective in this paper has been to provide an explanation on how technology alliance diversity shapes firms' likelihood to introduce innovative products. We develope a theoretical framework in which two distinctive knowledge combination capabilities – the firms' ACAP and ambidexterity in R&D – are proposed as mechanisms that explain the links between technology alliance diversity and innovative performance. Using panel data from Spanish manufacturing companies for the period 2004-2011, this research is among the first in estimating a mediated model to examine the causal relationship existing between technology alliance diversity, firms' knowledge combination capabilities, and their innovation consequences.

Our results provide strong support for the hypothesis that a firm's ACAP and ambidexterity in R&D mediate the relationship between technology alliance diversity and innovation. As a result, this research demonstrates that these capabilities explain part of the process through which firms transform the benefits of technology alliance diversity into enhanced innovative performances. Specifically, this study describes alternative paths that allow firms to create value from a diverse range of technology partnerships. For instance, consistent with the presence of total mediation, our results indicate that R&D outsourcing diversity influences firms' radical innovation exclusively by shaping their knowledge combination capabilities. Similarly, R&D collaboration diversity has an impact on firms' incremental innovation, which runs totally through the formation of firms' ambidexterity in R&D. In line with the presence of partial mediation, our conclusions also reveal that R&D collaboration diversity has a direct effect on firms' propensity for radical innovation as well as an indirect effect that operates through its influence on their knowledge combination capabilities. Likewise, R&D outsourcing diversity has not only a direct effect on firms' incremental innovation, but also an indirect effect running through the formation of their ambidexterity in R&D. Altogether, these findings uncover new ways through which different types of technology alliance diversity drive firm innovative performance.

Differences in the mediation patterns previously reported could depend on the presence of alternative interaction modes in collaboration and market-based agreements. As indicated by other studies on inter-organizational learning, strong interactions prevail among partners in R&D collaboration links, which facilitates learning from tacit knowledge sources. On the contrary, interactions in market-based agreements are limited to successive exchanges of standard and highly codified knowledge sources (Lane and Lubatkin 1998, Anand and Khanna 2000, Gomes-Casseres *et al.* 2006). Since tacit and codified knowledge sources differ from one another in their capacity to induce radical and incremental innovations, these differences could explain why R&D collaboration and R&D

outsourcing diversity have correspondingly dominant effects on radical and incremental innovative performance.

Our results also reveal differences in the way firms' knowledge combination capabilities mediate technology alliance diversity and their innovative performances. Ambidexterity in R&D appears as a critical factor in transforming the benefits of technology alliance diversity into both types of innovative performance. This finding confirms that ambidexterity in knowledge search contributes to the production of innovation streams, defined by Tushman et al. (2010) as the ability of firms to produce and commercialize incremental and radical innovations simultaneously. However, contrary to our expectations, ACAP appears to be critical only to enhancing firms' radical innovation. This finding supports the idea that ACAP fundamentally favors the utilization of external knowledge for the innovation process that is essentially unrelated to firms' knowledge background (Lavie and Rosenkopf 2006).

Implications for Research

The results of this study have relevance for several research areas. For instance, they uncover an understudied role of R&D outsourcing as a driver of innovative performance. Traditionally, studies on inter-organizational learning consider that market-based agreements have a reduced capacity to produce learning effects because they give access to codified knowledge (Anand and Khanna 2000, Lucena 2011). However, our results point to the diversity of this type of arrangement as important in driving firms' knowledge combination capabilities, and subsequently, innovation outcomes. However, this indirect effect has been rarely assessed in prior studies on inter-organizational learning. To the best of our knowledge, only the works of George et al. (2001) and Fosfuri and Tribó (2008) examine the mediating role of ACAP, but for the link between the adoption of R&D alliances – including market-based arrangements – and firm innovation. Our study advances these contributions by uncovering the role of diversity as an important attribute of market-based agreements in forming firms' ACAP, and in shaping innovative performance. Our research also extends prior contributions by assessing the mediating role of ambidexterity in R&D as an alternative knowledge combination capability that explains the impact of R&D outsourcing diversity on innovation outcomes.

Our results also have relevance for the literature that examines firm innovation from the perspective of the resource-based view. In this stream of research, access to partners' resources is commonly considered as a driver of innovation (Lavie 2006). However, much less attention has been paid to the internal processes needed to orchestrate these resources in the production of innovations. In line with studies on resource management (Ndofor *et al.* 2011, Sirmon *et al.* 2011), our research shows that ACAP and ambidexterity in R&D are factors that help transform external resources emanating from technology alliances into innovation. In terms of Sirmon et al. (2011), this is a process in which firms "structure", "build", and "leverage" their capabilities to use technology partnerships for creating and capturing value. Orchestration of external resources through firms' combination capabilities is also relevant to understand how firms create sustainable competitive advantages. For instance, our research suggests that the link between technology alliance diversity and knowledge combination capabilities is a valuable source of competitive advantage. The combination of these elements not only is difficult to replicate, but also constitutes a driving force enhancing the impact of firms' innovation.

Finally, our results have implications for the alliance management literature. Our study indicates that technology alliance diversity impacts firms' likelihood of innovations, depending on whether partial or total mediation is involved. From these results, two alternative models can be inferred to describe how firms generate value from their technology alliance portfolios. In the case of total mediation, firms create value by *learning from* their R&D partners. That is, firms internalize diverse knowledge and learning experiences that in form their knowledge combination capabilities, and subsequently, the prospects for innovation. In the case of partial mediation, the existence of both direct and indirect effects suggests that firms create value through a two-fold process –namely, they *learn from* and *along* with their partners. Firms learn from their partners by acquiring knowledge and gaining experience that molds their knowledge combination capabilities. Alternatively, technology alliance diversity has a direct effect on firms' likelihood of innovating. This fact indicates that firms learn along with their partners, by co-developing innovation activities that are embedded in their connections. This is consistent with the idea that a diverse network of technology partnerships serves as a basis for building relational capabilities (Dyer and Singh 1998) and social capital (Powell *et al.* 1996), factors which widely contribute to firms' innovative performance (van Beers and Zand 2014).

Managerial Implications

Our results have also implications for management actions. First, they show that decisions on the configuration of a firm's portfolio of technology alliances has wider strategic relevance. Our findings indicate that managers should choose a technology alliance portfolio design by taking into account the firm's innovation targets. For instance, managers should emphasize R&D collaboration diversity where their aim is radical innovation, and portfolio designs with diverse market-based relationships deals when the target is more incremental innovation. Second, given the reported effects of diverse technology partnerships, it is clear that managers should promote strategies that improve interconnections between research and business units, inside and outside their firm. For instance, the adoption of *innovation platforms*, or networks that bring together different organizations' members to diagnose common problems and identify solutions, constitutes an example of how companies could boost bpimdaru-spanning interactions (Davila *et al.* 2012). The use of these platforms may increase the effectiveness with which firms boost technology alliance diversity to develop their knowledge combination capabilities. In line with this suggestion, managerial actions stimulating the use of open innovation models, namely, the establishment of independent open innovation business units, the use of information technologies, and incentives based on open-orientated metrics (Chiaroni *et al.* 2010), may further help companies channel the knowledge obtained from their technology partnerships into the formation of ACAP and ambidexterity in

R&D.

Limitations and Future Research

The results of this research are subject to limitations, which at the same time, open new avenues for future research. First, our measures of firms' knowledge combination capabilities are based on the outcomes associated with the presence of these capabilities. We are not able to detect specific organizational routines embedded in these combination capabilities that are affected by technology alliance diversity. For instance, we cannot identify whether the presence of alliance diversity leads firms to buffer research and development activities in specialized sub-units with the purpose of achieving structural ambidexterity. Similarly, we cannot identify whether alliance diversity leads firms to use gatekeepers or cross-functional knowledge sharing practices to develop their ACAP. In line with the work of Lewin et al., (2011) and Jansen et al., (2009), we acknowledge that more research is needed to identify the emergence and evolution of specific organizational routines resulting from firms' exposures to diverse alliances and that might shape their knowledge combination capabilities.

Second, our mediated model is necessarily incomplete, because it does not take into account the effects of innovation outcomes on other indicators of firm performance, such as market value and sales growth. In line with Faems et al. (2010), future research is needed to assess the causal relationships between technology alliance diversity, knowledge combination capabilities, innovation outcomes, and firm performance. Third, we recognize that our results may be affected by the lag structure used among independent, mediators and outcome variables. A post hoc analysis in which a greater lag between mediators and outcome variables was allowed revealed that the main conclusions of the study hold, but with smaller indirect effects, particularly for incremental innovation. A deeper analysis is needed to identify the time span over which the impact of technology alliance diversity on both knowledge combination capabilities and innovation occurs.

Additional suggestions for future research include the following. First, the study and examination of the costs that diversity in technology alliances may have on the formation of firms' knowledge combination capabilities is a promising avenue for future research. In the context of this study, a post hoc analysis uncovered the presence of an inverted U-shape relationship between technology alliance diversity and our indicator of ACAP[15]. This finding is intriguing because it seems to indicate that, once a given threshold is reached, increases in technology alliance diversity impair the formation of firms' ACAP. The analysis of the causes of this effect deserves more attention. Second, the study of other countries could generate valuable knowledge to assess how different contexts influence the links between technology alliance diversity, firms' combination capabilities and innovation outcomes. Spain is a "technology-follower", as suggested by some of the indicators traditionally used to monitor developments (Vega-Jurado *et al.* 2009). For instance, data from the 4th Community Innovation Survey (CIS-4) reveal that the rate of technological cooperation in Spain was below the European Union average. Despite these facts, the results show that technology alliance diversity has a relevant role in promoting innovation outcomes. Examinations of countries with better and worse technological performance could be insightful to uncover the influence of alternative national innovation systems on the relationships between technology alliance diversity and innovative performance. In addition, the comparison of the mediation role of knowledge combination capabilities between service and manufacturing companies could be helpful to identify industry-idiosyncratic factors with potential effects on determining how companies in different industries realize the benefits of technology alliance diversity.

[15] It is worthwhile to mention that the main results of the study hold once this curvilinear effect is controlled. We thank one of the anonymous reviewers for raising this issue.

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Figure 1. Model explaining the links between technology alliance diversity and firm innovation

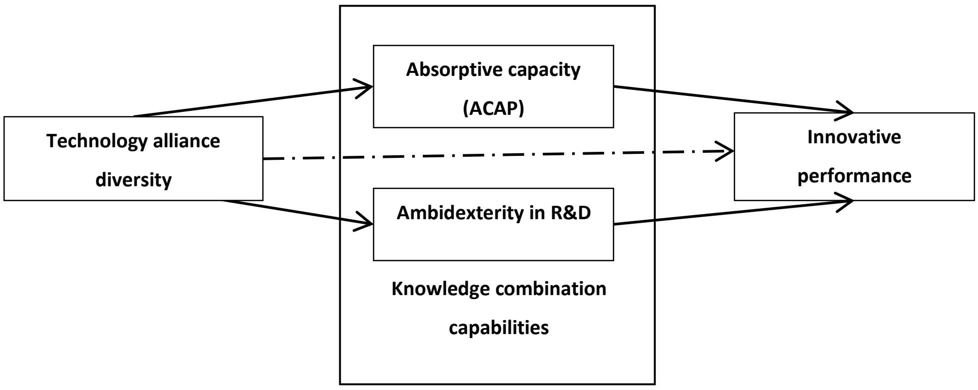

Table 1. Overview of studies on alliance diversity

Authors and year	Research focus	Methodology	Main conclusions	Our contribution
de Leeuw et al. (2014)	Innovation consequences of alliance diversity	Panel data and large-scale sample of Dutch manufacturing firms	Alliance portfolio diversity has an inverted U-shape relationship with productivity and radical innovation, and a positive and linear relationship with incremental innovation. Different levels of diversity are needed to induce productivity and innovations with alternative degrees of novelty	• Identification of mechanisms (i.e. ACAP and ambidexterity in R&D) to explain the relationship between technology alliance diversity and firm innovative performance • Analysis of the innovative performance effects of diversity coming not only from R&D collaboration diversity, but also from market-based link diversity
Duysters and Lokshin (2011)	Innovation consequences of alliance diversity	Cross-section and large-scale sample of Dutch manufacturing firms	Innovators compared to imitators form alliance portfolios with higher degrees of diversity. Innovators benefits more from exploration and imitators from exploitation. Alliance complexity has an inverted-U shape relationship with firm innovative performance	
Faems et al. (2005)	Innovation consequences of alliance diversity	Cross-section sample of Belgian manufacturing firms	Diverse alliance portfolios positively affect firms' radical innovation performance. Exploratory and exploitative alliances increase radical innovative performance, while exploitative alliances increase incremental innovative performance	
Faems et al. (2012)	Innovation consequences of alliance portfolio attributes	Theoretical paper	Propositions defining combinations between "structural" and "managerial" attributes of alliance portfolios that better drive firm innovation	
Lavie and Miller (2008)	Performance effects of alliance portfolio internationalization	Archival data from a panel of 330 US-based firms in the software industry	The degree of internationalization of a firm's alliance portfolio shapes its performance. Evidence indicates that as the level of internationalization increases, firm performance declines, then improves, and then declines again.	
Love et al. (2013)	Innovation consequences of alliance diversity and moderator factors	Panel data and large-scale sample of Irish manufacturing plants	Evidence indicating that experience in collaborations in previous periods positively moderates the link between openness and firm innovation	
Nieto and Santamaria (2007)	Innovation consequences of alliance diversity	Panel data and large-scale sample of Spanish manufacturing firms	High degrees of novelty are associated with alliance portfolios comprising several partner types. Cooperation with suppliers, clients and research centers are particularly useful to increase the novelty of innovations.	
Oerlemans et al. (2013)	Innovation consequences of alliance diversity and moderator	Cross-section and large-scale sample of South African manufacturing firms	Evidence indicating an inverted-U relationship between alliance diversity and firm innovative performances (radical and incremental). The use of technology management tools positively moderates the link between alliance diversity and	

Table 1. Overview of studies on alliance diversity-continued

	factors		innovation outcomes	
Sampson (2007)	Innovation consequences of alliance diversity	Archival data on 463 R&D alliances in the telecommunications equipment industry	Evidence supporting an inverted-U relationship between technological diversity in alliances and firm innovation. Equity joint ventures help companies harness the benefits of alliance diversity	
Wuyts and Dutta (2014)	Innovation consequences of alliance diversity and moderator factors	Archival data from a panel of 52 pharmaceutical companies	Alliance portfolio diversity has a positive effect on firms' prospects for having superior innovation. Internal knowledge attributes moderate the link between alliance diversity and firm innovation	
Fosfuri and Tribó (2008)	Antecedents and innovation consequences of potential ACAP	Cross-section and large-scale sample of Spanish manufacturing firms	Participation in R&D cooperation and external knowledge acquisitions are drivers for firms' potential ACAP. Potential ACAP shapes innovation	• Use of an integrative framework that considers the role of ACAP and ambidexterity in R&D as mechanisms explaining the link between alliance diversity and innovative performance • Evaluation of the role of alliance diversity in the formation of ACAP • Use of a panel data design that improves the assessment of causal relationships
George et al. (2001)	Antecedents and performance consequences of ACAP	Archival data of 143 biopharmaceutical companies	The numbers of alliances (horizontal/vertical), the number of market-based links, along with proxies for firms' ACAP, determine their performance. Firms' ACAP mediates the link between number of alliances and firm performance	• Use of an integrative framework that shows how a firm's ACAP and ambidexterity in R&D mediate the link between alliance diversity and firm innovative performance • A better characterization of alliance diversity in which information about partner types, rather than information about the number of links, is used for the analysis
Simsek (2009)	Antecedents and consequences of organizational ambidexterity	Theoretical paper	Propositions indicating that network alliance characteristics, organizational attributes and environmental conditions affect firm performance through driving its organizational ambidexterity	• Use of an integrative framework that examines firms' capabilities to combine not only internal and external knowledge, but also exploration and exploitation searches • Empirical evaluation that proves the connection between alliance diversity and firm innovative performance running through the firm's ACAP and ambidexterity in R&D

Table 2. Descriptive Statistics

Variables	Mean	S.D	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. New to the firm	0.63	0.48	0.00	1.00	1.00															
2. New to the market	0.49	0.50	0.00	1.00	0.02*	1.00														
3. Firm's ACAP	-0.10	1.11	-6.19	2.30	0.06*	0.11*	1.00													
4. Ambidexterity in R&D	0.16	0.20	0.00	0.50	0.08*	0.13*	0.12*	1.00												
5. R&D collaboration diversity	0.08	0.14	0.00	0.94	0.10*	0.15*	0.16*	0.17*	1.00											
6. R&D outsourcing diversity	0.10	0.12	0.00	0.83	0.05*	0.11*	0.15*	0.15*	0.45*	1.00										
7. Parent company	0.09	0.29	0.00	1.00	0.04*	0.04*	0.08*	0.06*	0.11*	0.10*	1.00									
8. Subsidiary	0.32	0.46	0.00	1.00	0.02*	0.02	0.13*	0.00	0.16*	0.15*	-0.22*	1.00								
9. Firm size	4.29	1.33	0.00	9.23	0.09*	0.06*	0.17*	0.08*	0.28*	0.25*	0.19*	0.42*	1.00							
10. R&D decentralization	1.41	0.66	1.00	14.00	0.03*	0.07*	0.10*	0.04*	0.06*	0.09*	0.02	0.11*	0.15*	1.00						
11. Public support for R&D	0.95	1.53	0.00	4.62	-0.02*	0.06*	0.08*	0.07*	0.25*	0.27*	0.06*	-0.01	0.02*	-0.13*	1.00					
12. Export propensity	0.73	0.44	0.00	1.00	0.08*	0.06*	0.11*	0.05*	0.11*	0.11*	0.09*	0.08*	0.24*	0.12*	0.01	1.00				
13. Science-based	0.25	0.44	0.00	1.00	0.04*	0.01	0.25*	0.05*	0.03*	0.09*	0.00	0.03*	-0.10*	0.13*	-0.02*	0.04*	1.00			
14. Specialized suppliers	0.21	0.41	0.00	1.00	0.03*	0.05*	-0.05*	0.01	0.00	-0.04*	-0.03*	-0.05*	-0.07*	-0.04*	0.02	0.04*	-0.30*	1.00		
15. Scale intensive	0.21	0.41	0.00	1.00	-0.03*	-0.03*	-0.07*	-0.02*	0.01	0.00	-0.02	0.15*	0.19*	-0.04*	0.00	0.00	-0.30*	-0.27*	1.00	
16. Supplied industry	0.33	0.47	0.00	1.00	-0.03*	-0.02*	-0.13*	-0.04*	-0.04*	-0.05*	0.05*	-0.11*	-0.01	-0.05*	0.00	-0.08*	-0.41*	-0.36*	-0.36*	1.00

Note: *correlations are significant at *p<0.01*.

Table 3. Regression results for firms' knowledge combination capabilities

Independent variable	ACAP$_t$	Ambidexterity in R&D$_t$
	Model (1)	Model (2)
Constant	-0.478***	0.018***
	(0.040)	(0.007)
Prior combination capabilities $_{t-1}$	0.542***	0.637***
	(0.008)	(0.007)
Parent company $_{t-1}$	0.099***	0.005
	(0.030)	(0.005)
Subsidiary $_{t-1}$	0.039*	-0.008**
	(0.021)	(0.004)
Firm size $_{t-1}$	0.058***	0.005***
	(0.008)	(0.001)
R&D decentralization $_{t-1}$	0.032**	0.002
	(0.013)	(0.002)
Public support for R&D $_{t-1}$	0.014***	0.001
	(0.005)	(0.001)
Export propensity $_{t-1}$	0.027	0.006*
	(0.019)	(0.003)
Science-based $_{t-1}$	0.296***	0.013***
	(0.024)	(0.004)
Specialized suppliers $_{t-1}$	0.054**	0.006
	(0.024)	(0.004)
Scale intensive $_{t-1}$	-0.009	0.001
	(0.025)	(0.004)
Diversity in R&D cooperation $_{t-1}$	0.178***	0.056***
	(0.062)	(0.011)
Diversity in R&D outsourcing $_{t-1}$	0.206***	0.029**
	(0.077)	(0.013)
Chi-squared (χ2)	7009.22***	9712.46***

Notes: (i) 3,517 observations, 12,576 firms-year observations, (ii) Models were estimated by a dynamic random effects model, (iii) Time dummies are included in all models, (iv) Standard errors in parentheses: **** p<0.01, ** p<0.05, * p<0.1*.

Table 4. Regression results for firm innovative performance

Dependent variables	Novelty to the market $_{t+1}$				Novelty to the firm $_{t+1}$			
Independent variable	**Coeff. Model (3a)**	**M.E. Model (3a)**	**Coeff. Model (3b)**	**M.E. Model (3b)**	**Coeff. Model (4a)**	**M.E. Model (4a)**	**Coeff. Model (4b)**	**M.E. Model (4b)**
Constant	-1.175*** (0.127)	–	-1.087*** (0.129)	–	-0.812*** (0.119)	–	-0.806*** (0.122)	–
Prior innovative performance $_{t-1}$	0.843*** (0.055)	0.270***	0.841*** (0.055)	0.266***	0.960*** (0.051)	0.272***	0.958*** (0.051)	0.271***
Innovative performance at *t=0*	0.723*** (0.069)	0.231***	0.693*** (0.068)	0.219***	0.552*** (0.059)	0.157***	0.549*** (0.059)	0.155***
Parent company $_{t-1}$	0.014 (0.095)	0.005	-0.005 (0.094)	-0.002	-0.072 (0.091)	-0.020	-0.078 (0.090)	-0.022
Subsidiary $_{t-1}$	-0.088 (0.067)	-0.028	-0.093 (0.067)	-0.029	-0.034 (0.063)	-0.010	-0.032 (0.063)	-0.009
Firm size $_{t-1}$	0.067** (0.027)	0.021**	0.052* (0.026)	0.016**	0.067*** (0.025)	0.019***	0.063** (0.025)	0.018**
R&D decentralization $_{t-1}$	0.074** (0.037)	0.024**	0.057 (0.037)	0.018	0.080** (0.034)	0.023**	0.075** (0.034)	0.021**
Public support for R&D $_{t-1}$	0.020 (0.016)	0.006	0.016 (0.016)	0.005	-0.011 (0.015)	-0.003	-0.012 (0.015)	-0.003
Export propensity $_{t-1}$	0.016 (0.059)	0.005	-0.002 (0.059)	-0.001	0.047 (0.056)	0.013	0.041 (0.056)	0.012
Science-based $_{t-1}$	-0.014 (0.079)	-0.004	-0.096 (0.079)	-0.030	0.049 (0.073)	0.014	0.028 (0.075)	0.008
Specialized suppliers $_{t-1}$	0.178** (0.083)	0.057**	0.161** (0.082)	0.051**	0.150* (0.077)	0.043*	0.144* (0.077)	0.041*
Scale intensive $_{t-1}$	-0.073 (0.083)	-0.023	-0.073 (0.082)	-0.023	-0.086 (0.076)	-0.025	-0.086 (0.076)	-0.024
Diversity in R&D collaboration $_{t-1}$	0.578*** (0.196)	0.185***	0.461** (0.195)	0.146**	0.264 (0.191)	0.075	0.213 (0.192)	0.060
Diversity in R&D outsourcing $_{t-1}$	0.438* (0.243)	0.140*	0.352 (0.242)	0.111	0.443* (0.236)	0.126*	0.409* (0.236)	0.116*
Firm's ACAP $_{t}$	–	–	0.107*** (0.023)	0.034***	–	–	0.023 (0.022)	0.007
Ambidexterity in R&D $_{t}$	–	–	0.499*** (0.120)	0.158***	–	–	0.254** (0.115)	0.072**
Chi-squared (χ2)	716.9***		767.8***		763.8***		772.1***	

Notes: (i) M.E = marginal effects, (ii) 2,933 observations, 9,174 firms-year observations, (iii) Models were estimated by dynamic random effects probit models, (iv) Time dummies are included in all models, (v) Standard errors in parentheses: **** p<0.01, ** p<0.05, * p<0.1*.

Table 5a. Results bootstrap test (New to the market)

Independent variable	Effects		Bootstrap standard error	Confidence interval (95%)	
	Type	Amount		Lower limit	Upper limit
Diversity R&D cooperation	ACAP	0.0059	0.0017	0.0035	0.0085
	Ambidexterity	0.0068	0.0013	0.0037	0.0107
	Direct effect	0.0177	0.0169	-0.0160	0.0490
Diversity R&D outsourcing	ACAP	0.0023	0.0009	0.0008	0.0044
	Ambidexterity	0.0034	0.0011	0.0016	0.0061
	Direct effect	0.0069	0.0171	-0.0220	0.0436

Table 5b. Results bootstrap test (New to the firm)

Independent variable	Effects		Bootstrap standard error	Confidence interval (95%)	
	Type	Amount		Lower limit	Upper limit
Diversity R&D cooperation	ACAP	0.0013	0.0013	-0.0012	0.0038
	Ambidexterity	0.0040	0.0018	0.0005	0.0075
	Direct effect	0.0224	0.0175	-0.0126	0.0559
Diversity R&D outsourcing	ACAP	0.0005	0.0006	-0.0004	0.0019
	Ambidexterity	0.0021	0.0010	0.0004	0.0046
	Direct effect	0.0266	0.0179	-0.0071	0.0605

Notes: Number of bootstraps samples for bias corrected bootstrap confidence intervals is equal to 1,000.

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