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Casting a Wide Net for Innovation: Mediating Effect of R&D Human and Social Capital to Unlock the Value from Alliance Portfolio Diversity

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This paper examines the performance effects associated with different alliance portfolio configurations in terms of geographical location and partner type. Based on these distinctions, the authors hypothesize that more diverse alliance portfolios enable firms to gain and exploit innovation opportunities. Additionally, the mediating effects of R&D human and social capital on the R&D alliance portfolio diversity–innovation performance relationship are explored. The authors reason that the absorptive capacity of R&D intellectual capital determines a firm's potential gains from highly diverse alliance portfolios. From panel data of manufacturing firms in Spain for the period 2008–2013, the results confirm the inverted U-shaped relationship between alliance portfolio diversity and firm innovation performance, implying that both insufficient and excessive alliance portfolio diversity may be detrimental to firm innovativeness. Additionally, R&D human and social capital partially mediates the R&D alliance diversity–innovation performance relationship, emphasizing the importance of internal capabilities to leverage the benefits of highly diverse alliance portfolios. These findings add a dynamic dimension to the conceptualization of alliance portfolios and how firms create value by balancing explorative and exploitative alliances.

Introduction

Inter-organizational alliances are increasingly recognized in the innovation management literature as 'access relationships' that enable partners to acquire non-redundant knowledge and capabilities residing outside their organizational and technological boundaries (Chesbrough, 2012; Cui and O'Connor, 2012; De Man and Duysters, 2005; Vasudeva and Anand, 2011). Resource-based scholars argue that strategic alliances facilitate access to diverse markets and technological knowledge and boost innovation by enhancing combinatory search (for recent meta-analysis see Lee, Kirkpatrick-Husk and Madhavan, 2017). These advantages are hypothesized to be particularly relevant for breakthrough innovation and novel technologies (Datta and Jessup, 2013;

Garcia Martinez, 2013) or following technological shocks that create demand for new resources (Asgari, Singh and Mitchell, 2017).

However, too much diversity of external sources could adversely impact firm innovation performance, owing to added complexity and coordination and integration costs (Duysters and Lokshin, 2011; Faems *et al.*, 2010; Oerlemans, Knoben and Pretorius, 2013). Recent research shows that searching widely and deeply has a curvilinear (inverted U-shape) relationship with performance outcomes (Laursen and Salter, 2014; Vlaisavljevic, Cabello-Medina and Pérez-Luño, 2016; Wuyts and Dutta, 2014), suggesting that R&D alliance portfolio diversity (APD), defined as 'the degree of variance in partners' characteristics' (Jiang, Tao and Santoro, 2010), could act as a 'double-edged sword' for knowledge acquisition (Wang and Chen, 2016). The net benefits first increase and then decrease with the degree of APD, as organizational tension, complexity and coordination costs begin to hamper a firm's ability to leverage the benefits of external collaboration for innovation (Nasiriyar, Nesta and Dibiaggio, 2014; Nooteboom *et al.*, 2007). Consequently, innovation search across highly diverse alliance portfolios will face diminishing returns (Garcia Martinez, Zouaghi and Sanchez Garcia, 2017; Oerlemans, Knoben and Pretorius, 2013).

Within extant alliance portfolio research, limited research has considered the contingent role of internal mechanisms and capabilities that determine a firm's ability to extract value from highly diverse alliance portfolios. Lakemond *et al.* (2016) suggest that knowledge integration through open innovation can be considered as a knowledge management problem, which requires firms to form internal alliance capabilities to leverage the newly accessed knowledge (Heimeriks, Klijn and Reuer, 2009; Wuyts and Dutta, 2014). A firm's ability to identify, acquire, transfer and apply new external knowledge depends on its level of absorptive capacity (Cohen and Levinthal, 1990, Todorova and Durisin, 2007), suggesting that there is a path dependence in organizational learning (Lane, Koka and Pathak, 2006; Zahra and George, 2002). Indeed, Weigelt (2009) argues that the more firms rely on external sources for innovation, the larger are the required internal investments in knowledge-generation activities in order to exploit external knowledge.

This paper contributes to the debate on the performance implications of APD and helps to clarify the configurational and capability perspectives of alliance portfolio research. The study draws on the premise that absorptive capacity as a dynamic capability provides firms with sources of competitive advantage (Zahra and George, 2002) by enabling them to combine and redeploy effectively externally generated knowledge from highly diverse alliance portfolios in a unique way. In this context, we examine the mediating effect of R&D intellectual capital to extract value from diverse alliance portfolios and argue that increasing diversity of external knowledge sources might be beneficial to the firm if the latter possesses adequate levels of absorptive capacity, which we operationalize in terms of R&D human and social capital, for an effective internalization and combination of external knowledge assets. This argument builds on recent research on the micro-foundations of absorptive capacity (e.g. Lewin, Massini and Peeters, 2011; Volberda, Foss and Lyles, 2010), suggesting that individuals are often the key to inter-organizational innovation (Caloghirou, Kastelli and Tsakanikas, 2004; Spithoven and Teirlinck, 2010, 2015).

This study makes two contributions to the alliance portfolio literature. First, we improve theoretical understanding of alliance portfolio configuration and how compositional characteristics of the alliance portfolio affect innovation performance. We take a strategic approach and focus on firms' portfolio of R&D collaboration types, where we distinguish between geographical, horizontal and vertical diversity, and provide evidence to the premise that different alliance portfolio compositions influence the type of external knowledge that firms can access and lead to different performance effects (Kotabe and Swan, 1995; Lee, Kirkpatrick-Husk and Madhavan, 2017). The resultant multi-dimensionality, in contrast to an aggregate measure of all alliances, acknowledges the potential for recombination that may spur the creation of innovation (Belderbos *et al.*, 2018; Duysters and Lokshin, 2011; Faems, Van Looy and Debackere, 2005). We argue that salient differences can be expected, depending on the partner type, and offer new insights into how R&D alliance portfolios can be configured to create value, depending on innovation objectives.

Second, this research contributes to the capability perspective by proposing and testing the

mediating role of R&D human and social capital to identify, assimilate and exploit externally generated knowledge for greater innovation performance. This interrelationship has been often conceptualized in the extant literature through a moderating effect (e.g. Cassiman and Veugelers, 2006; Hagedoorn and Wang, 2012; Laursen and Salter, 2006; Lin *et al.*, 2012) which fails to capture the path-dependency nature of absorptive capacity to explain a firm's ability to learn effectively from external sources (Lane, Koka and Pathak, 2006; Zahra and George, 2002). Maintaining strong internal R&D capabilities enables firms to retain the knowledge necessary to discern and unfold the tacit knowledge embedded in external knowledge resources (Weigelt, 2009). We posit that R&D human and social capital becomes the 'means' through which APD benefits innovation outcomes.

The paper proceeds as follows. Next, we provide an overview of the relevant literature on APD and human and social capital and present the research hypotheses. We then outline our sample, measures and analytical techniques. The research results are reported, followed by a discussion of the theoretical and managerial implications of our findings. We conclude with a discussion of the study's limitations and suggested directions for future research.

Theoretical background and hypothesis development

Geographical diversity of alliance portfolios

R&D alliances with partners located in geographically diverse settings can facilitate market access (Glaister and Buckley, 1996), provide complementary knowledge and capabilities (Lane, Salk and Lyles, 2001) and integrate different knowledge bases (Lubatkin, Florin and Lane, 2001). Geographical diversity is found to be important for the adaptation of products to different local requirements and preferences (Lavie and Miller, 2008; Van Beers and Zand, 2014). The literature further suggests that international alliances are better placed to foster the generation of new knowledge moulded by location-based variations compared with domestic alliances that nurture the use of more redundant knowledge (Lavie and Miller, 2008; Rosenkopf and Almeida, 2003). Further, geographically diverse alliances enable firms to survive turbulent times by providing high levels of multimarket contact (Pangarkar, 2007).

However, forming R&D alliances with geographically diverse partners creates high potential for conflict (Goerzen and Beamish, 2005; Tung, 1993) from greater complexity and misunderstanding during cross-border knowledge transfer (Ho and Wang, 2015). International alliances require greater investments to identify the knowledge elements widely dispersed across different geographic partners, since technological knowledge is context-dependent (Lavie and Miller, 2008; Tsai and Wang, 2009) and present increasing managerial complexity, owing to the emergence of cultural barriers (Cassiman and Valentini, 2016; Lee and Park, 2006; Tzabbar and Vestal, 2015). Dooley, Kenny and Cronin (2016) report that the increased operational scope in geographically diverse alliances requires ample financial resources and greater managerial effort to develop and coordinate these distant ties. The challenges for organizations to adjust and manage partners with different values, routines and decision-making styles can overwhelm management capabilities (Goerzen and Beamish, 2005). This argument suggests that, at the portfolio level, greater alliance geographical diversity will enhance innovativeness only up to a certain limit. Beyond that point, geographical diversity may yield few marginal benefits as a situation of information and attention overload emergers that restricts a firm's ability to leaverage the benefits of external collaboration (Chen, Chen and Vanhaverbeke, 2011; De Leeuw, Lokshin and Duysters, 2014; Duysters and Lokshin, 2011). Given the existance of such cognitive, transation and organizational constraints, we therefore propose:

> *H1:* There is an inverted U-shaped relationship between the geographical diversity of a firm's alliance portfolio and innovation performance.

Vertical diversity of alliance portfolios

Allying with firms along the value chain provides market and knowledge access advantages outside the existing boundaries (Jiang, Tao and Santoro, 2010). Vertical alliances enable firms to learn different skills, pool complementary resources, update and modify learning routines and access market information to target innovation efforts better (Miotti and Sachwald, 2003; Walsh, Lee and Nagaoka, 2016), which are likely to make them stronger competitors (Silverman and Baum, 2002). Cooperation with suppliers is found to enhance

efficiency and complement the technological base of the firm (Belderbos, Carree and Lokshin, 2004; Un and Asakawa, 2015). Collaboration with universities and research institutes, in contrast, can provide access to tailor-made, cutting-edge technologies (Tether and Tajar, 2008; Tsai, 2009); however, the more generic nature of knowledge developed in collaboration with universities creates incentives for firms to collaborate subsequently with different industrial partners to exploit such opportunities with other actors in order to implement the technology (Berg-Jensen *et al.*, 2007). Also, alliances with innovation intermediaries are often motivated by the need to achieve novelty goals and reduce development time (Chiaroni *et al.*, 2008).

However, vertical alliances are susceptible to resources misalignment and lack of synergies (Jiang, Tao and Santoro, 2010), resulting in increasing coordination and management efforts (Haeussler, Patzelt and Zahra, 2012). Veer, Lorenz and Blind (2016) show the potential risk of imitation and waste of commercially valuable know-how when firms increased engagement with vertical partners. Research further points to the important challenges firms face when collaborating with universities as a result of the so-called 'conflicting institutional logics' (Sauermann and Stephan, 2013). Researchers at universities, for instance, operate in environments in which autonomy and freedom of exchanging ideas and knowledge are the prevalent features (Du, Leten and Vanhaverbeke, 2014). Thus, greater alliance vertical diversity may be detrimental to innovation outcomes by making integration of external knowledge assets more difficult after a specific point (Walsh *et al.*, 2016). Therefore, we propose:

> *H2:* There is an inverted U-shaped relationship between the vertical diversity of a firm's alliance portfolio and innovation performance.

Horizontal diversity of alliance portfolios

Horizontal alliances link firms to competing organizations in the same industry (Silverman and Baum, 2002). Horizontal alliances are more likely to be strategically motivated, aimed at creating new, state-of the-art technology (Tidd, Bessant and Pavitt, 2005), whereas vertical alliances tend to focus on enhancing existing competences and optimizing an established value chain (Brown and Eisenhardt, 1995). As competitors tend to share

common goals, the search for common innovation ventures will cause co-specialization in the company and a convergence process (Grant and Baden-Fuller, 2004). Firms pursue collaboration agreements with competitors to access technological capabilities that could be difficult, time-consuming, and costly to develop alone within their boundaries (Chen, Chen and Vanhaverbeke, 2011). Given the overlap in backgrounds, experiences, knowledge and technological bases, horizontal alliances offer greater absorptive capacity (Cohen and Levinthal, 1990).

However, collaboration with direct competitors poses unique challenges, owing to the coexistence of competition and cooperation (Xu, Wu and Cavusgil, 2013). Alliance with competitors could lead to conflict of interest and learning races (Doz and Hamel, 1998) and create a temptation for free-ridership (Gilsing and Nooteboom, 2006; Park and Russo, 1996). Hitt, Hoskinsson and Kim (1997) argued that homogeneous firms are not able to exploit all the alliance opportunities. Wu (2014) further points to the rigidity and inefficiency of the innovation process from highly diverse horizontal alliances. We therefore propose:

> *H3:* There is an inverted U-shaped relationship between the horizontal diversity of a firm's alliance portfolio and innovation performance.

Mediating effect of R&D human capital

Human capital theory affirms that individual skills, knowledge and capabilities are valuable resources and an important source of economic productivity, and that those skills can be built through education and experience (Becker, 1964). Effectively managing and integrating external knowledge flows requires the development of complementary internal capabilities (Chiaroni, Chiesa and Frattini, 2010; Teece, Pisano and Shuen, 1997). A firm's ability to learn new knowledge through its interaction with external partners requires sufficient technical understanding to capitalize on that knowledge (Huang *et al.* 2015). By accumulating a relevant base of knowledge, firms are likely to have better understanding of the new knowledge and harness external knowledge assets to support their innovative activities (Arora and Gambardella, 1994, Laursen and Salter, 2004). Such open sourcing strategies require high levels of human capital (Fukugawa, 2013; Teixeira and Tavares-Lehmann, 2014). Moreover, firms with a

broad knowledge base can learn faster (Hamel, 1991), since their strong absorptive capacity increases their ability to build links between new and existing knowledge bases – 'connecting the dots' (Baron, 2006). Further, prior knowledge diversity also influences the locus of search (Shane, 2000; Zahra and George, 2002). Individuals with high prior knowledge diversity are inclined to search more broadly and are therefore more likely to identify new knowledge opportunities.

Reflecting the cumulative nature of knowledge, this hypothesizing assumes that a highly skilled workforce possess a higher ability to integrate and apply new knowledge (Garcia Martinez, Zouaghi and Sanchez Garcia, 2017; Huang *et al.*, 2015; Teirlinck and Spithoven, 2013). They have a broader domain-specific repertoire and can relate better to people from other domains (Madhavan and Grover, 1998). Hence, we argue that R&D human capital matters for the determination of a firm's absorptive capacity; it becomes the means through which APD benefits innovation outcomes. Firms with high R&D human capital would be better positioned to harness new knowledge assets emanating from highly diverse alliances portfolios.

> *H4a:* Human capital mediates the inverted U-shaped relationship between the geographical diversity of a firm's alliance portfolio and innovation performance.

> *H4b:* Human capital mediates the inverted U-shaped relationship between the vertical diversity of a firm's alliance portfolio and innovation performance.

> *H4c:* Human capital mediates the inverted U-shaped relationship between the horizontal diversity of a firm's alliance portfolio and innovation performance.

Mediating effect of R&D social capital

Cross-fertilization of knowledge and capabilities and integration of external knowledge assets depends not only on firms' internal knowledge bases, but also the dynamics of interaction between partners (Subramanian and Soh, 2017). Empirical studies have confirmed that effective knowledge transfer occurs when there are close relationships or strong social ties between partners (e.g. Inkpen and Tsang, 2005; Tsai, 2001). A key premise in absorptive capacity literature is that the place

where the knowledge is recognized and acquired is distant from the place where it is transformed and exploited (Cohen and Levinthal, 1990). Thus, social integration mechanisms are central to understanding absorptive capacity. Social capital as a dynamic capability can help reduce collaborative tensions in R&D alliances, as it facilitates personal contact, interaction and trust among collaborative partners (Harryson, Kliknaite and Dudkowski, 2007). When firms maintain fluid and collaborative relationships with external partners, a cumulative effect emerges (Escribano, Fosfuri and Tribó, 2009; Zahra and George, 2002) that leads them to develop a higher capacity to identify, understand and assimilate external knowledge assets.

The effects of structural capital, particularly the case of managerial flexibility and organizational learning capacity (Huchzermeier and Loch, 2001; Levardy and Browning, 2009), and relational capital, particularly networks for innovation (Reagans and Zuckerman, 2001), have been found to be important dimensions of social capital in R&D alliances (Adler and Kwon, 2002; Tsai, 2000). Developing an 'organizational memory' (Walsh and Ungson, 1991) helps companies to identify and combine external knowledge. Structural capital supports firm innovation performance by providing a collective infrastructure for knowledge development activities within the organization (Kianto, Sáenz and Aramburu, 2017). Relational capital refers to the strength and quality of relationships and shared experiences (Nahapiet and Ghoshal, 1998). Having a higher relational capital facilitates the successful transfer of knowledge and reduces searching costs (Zaheer, Gulati and Nohria, 2000). Extant literature clearly indicates the importance of nurturing social networks and relationships as a means to gain access to valuable external knowledge assets critical to innovation (Moran, 2005; Tsai and Ghoshal, 1998). Ho and Wang (2015) suggest that knowledge flows best through trusting communities and believe that relational capital facilities knowledge transfer and learning processes in international strategic alliances. Relational capital, characterized by strong, trusted and fluid ties with partner firms, can help firms to avoid some drawbacks and task conflicts as well as foster innovation and creativity (Cuevas Rodríguez, Cabello Medina and Carmona Lavado, 2014; Vlaisavljevic, Cabello-Medina and Pérez-Luño, 2016). Thus, we hypothesize that social capital among partner firms can help leveraging the
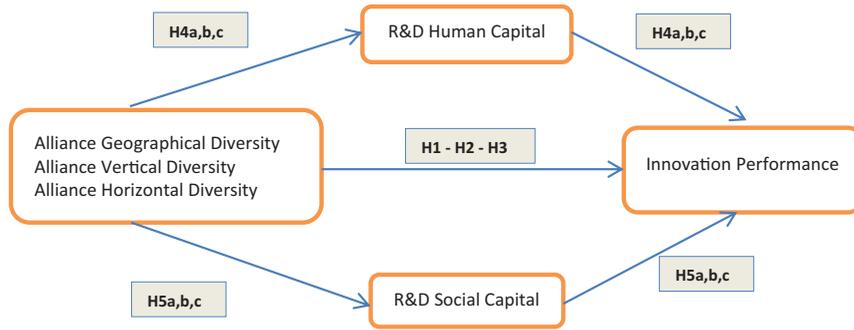
Figure 1. Research framework [Colour figure can be viewed at wileyonlinelibrary.com]

positive effects of diverse alliance portfolios on innovation performance:

H5a: Social capital mediates the inverted U-shaped relationship between the geographical diversity of a firm's alliance portfolio and innovation performance.

H5b: Social capital mediates the inverted U-shaped relationship between the vertical diversity of a firm's alliance portfolio and innovation performance.

H5c: Social capital mediates the inverted U-shaped relationship between the horizontal diversity of a firm's alliance portfolio and innovation performance.

Our hypothesized model is depicted in Figure 1.

Methodology

Data and sample

The data for the quantitative analysis have been drawn from the Spanish Technological Innovation Panel (PITEC), which is a statistical instrument for studying the innovation activities of Spanish companies over time.[1] The database is compiled by the Spanish National Statistics Institute (INE) in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The PITEC data set contains panel data for more than 13,000 firms since 2003. The data set has been used in innovation studies, including R&D collaboration research (e.g. Barge-Gil,

2010; Lucena, 2016) and internal capabilities of R&D teams (e.g. D'Este, Rentocchini and Vega-Jurado, 2014; Díaz-García, González-Moreno and Sáez-Martínez, 2013). In this study, the focus is on manufacturing firms across 24 industries, based on the Spanish National Classification of Economic Activity (CNAE-2009), that have introduced radical or/and incremental innovations over the period 2008–2013. Our final sample contained 13,653 observations.

Measures

Dependent variable. Innovation performance is the dependent variable of the model measured as the percentage of the firm's total sales from innovations (Hitt *et al.*, 1996). Consistent with CIS-based studies (e.g. Laursen and Salter, 2006; Sofka and Grimpe, 2010), we distinguish between incremental and radical innovation, depending on their newness to the company or the market place, respectively. Radical innovation is measured as the percentage of the firm's total sales in year t from innovations new to the market during the period between $t-2$ and t. Incremental innovation is defined as the percentage of the firm's total sales in year t from innovations new to the firm during the period between $t-2$ and t.

Independent variables. The diversity variables were constructed using the Blau's (1977) index of heterogeneity:

$$D = 1 - \sum_{i=1}^{k} p_i^2$$

where k represents the total number of different partner categories, and p_i is the proportion of partners that fall in the ith category. The result of this

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[1]A more detailed description of the data and sampling can be found on the FECYT website: https://icono.fecyt.es/pitec/por-que.

calculation is a diversity score with values between 0 (a perfectly homogeneous group) and 1 (a perfectly heterogeneous group – balanced distribution of partners among all categories).

To operationalize the diversity variables, for each year, we used PITEC questions where firms indicate whether they have formed R&D alliances with different partner types during the period between t and $t-2$. For geographical diversity, we distinguished the type of alliances companies established into three categories: '1' for an alliance formed with a domestic partner; '2' with a (rest of) EU partner; and '3' with partners from other countries. For vertical diversity, we consider alliances with the following partner types: (1) customers; (2) suppliers (of equipment, materials, components and software); (3) universities (and other higher education institutions); (4) private R&D institutes (and consultants and commercial R&D labs); and (5) public research institutes. Finally, for horizontal diversity, we include competitors (or other firms in the same sector of the firm) distinguishing in terms of their geographical location: (1) domestic competitors; (2) (rest of) EU competitors; and (3) other countries' competitors. To test that all three diversity criteria show an adequate level of heterogeneity and are comparable in their level of diversity, we normalized the diversity indices on a 0 to 1 metric scale by dividing them by their respective operational maximum (Spickermann, Zimmermann and von der Gracht, 2014).

Mediating variables. R&D human capital was measured by the log of higher education intensity of R&D staff (Spithoven and Teirlinck, 2015). Highly educated staff increase a firm's capacity to absorb and apply new knowledge to their innovation processes and facilitate knowledge-sharing within the organization (Escribano, Fosfuri and Tribó, 2009). R&D social capital was operationalized using two dimensions: structural capital and relational capital. In the case of structural capital, we use managerial flexibility, measured by the introduction of innovations in management and procedures (Sánchez, López and Salazar-Elena, 2014). Regarding relational capital, we measure the introduction of innovations in external relationships. Interactions based on mutual trust and commitment would drive firms to engage in knowledge transfer (Ho and Wang, 2015).

Control variables. Firm size is measured by the natural logarithm of the number of employees,

which influences a firm's ability and incentive to form alliances (Ahuja, 2000). In addition, we account for non-linear effects of firm size by computing firm size squared (Acs and Audretsch, 1990, 1991). Larger firms are more likely to have richer endowments of resources to engage in R&D alliances (Almeida, Dokko and Rosenkopf, 2003; Bayona, Garcia-Marco and Huerta, 2001). We include a dummy variable to capture a firm's alliance experience, since prior experience enables firms to build up routines, establish procedures and develop tacit knowledge for accessing diverse knowledge within an alliance portfolio (Hargadon and Sutton, 1997, Sampson, 2007). We include R&D intensity, measured as the ratio of R&D expenditure to total sales (Huang *et al.*, 2015; Laursen and Salter, 2004), as a key input into the innovation process and a source of absorptive capacity necessary to absorb and deploy external knowledge efficiently (Arora and Gambardella, 1990; Griffith, Redding and van Reenen, 2003). Export intensity is measured by the logarithm of the ratio of export sales to total sales (Antolín *et al.*, 2013). Firms competing in international markets are under intense innovation pressure to remain competitive and might be involved in R&D collaborations with foreign firms to have broader access to locally embedded knowledge (Cassiman and Veugelers, 2006; Salomon and Shaver, 2005). Firms' innovation behaviour is closely linked to their industry affiliation (Audretsch, 1997; Malerba, Orsenigo and Peretto, 1997); hence we control for industry effects with dummy variables that indicate whether the firms can be classified into high-tech or low-tech industries, according to the classification proposed by Van Beers and Zand (2014). Finally, we included time-dummies to control for period effects that might influence R&D collaboration and firm innovation performance (Lin, 2014). Table A1 in Appendix A describes the variables used in this study.

Estimation models

We use a Generalized Structural Equation Model (Stata 13 gsem command) to analyse the data. This allows random-effects Tobit specification for our censored dependent variables (share of turnover generated by radical and incremental innovation), provides a means for testing simultaneous equations, and generates output for testing mediating effects with Sobel (1982) tests and bootstrapping.

Further, we included clustered robust standard errors to counter the effects of heteroscedasticiy[2] (Pepper, 2002). Since the data for both measures of innovation outcomes are highly skewed to the left, the assumption of a normal distribution of the residuals made in a Tobit analysis is violated (significance of Shapiro–Wilk test of 0.000 for both dependent variables). Thus, we have log-transformed the dependent variable (Filippucci, Drudi and Papalia, 1996; Papalia and Di Iorio, 2001). In addition, we established a lag structure in our data by measuring the explanatory and control variables (except for industry dummies, which do not vary across panel waves) in year $t-1$, consistent with the survey implementation rhythm, to avoid simultaneity and reverse causality problems (Mairesse and Mohnen, 2010). This reduced our sample to an unbalanced panel of six years and 11,132 observations.

Our analysis followed the methodology proposed by Baron and Kenny (1986) for mediation (Hypotheses 4 and 5), using simultaneous path models (Skrondal and Rabe-Hesketh, 2004). Step 1 of the test for mediation is to show that a significant relationship exists between the independent variable and the dependent variable ($X \rightarrow Y$); Step 2 is to show that a significant relationship exists between the independent variable and the mediator ($X \rightarrow M$); Step 3 is to show that the mediator variable is related to the dependent variable ($M \rightarrow Y$); and Step 4 is to show that the effect of the independent variable on the dependent variable is less when the mediator variable is included in the model ($X \rightarrow M \rightarrow Y$). If these four conditions described by Baron and Kenny (1986) are met, we are able to conclude that a mediation effect occurs. Additionally, we use Sobel (1982) tests and bootstrapping confidence intervals (CIs) to test the indirect effects of R&D human and social capital on firm innovation performance. The Sobel test of significance assumes that the indirect effect of the independent variable is normally distributed, an assumption that may make this a conservative test (MacKinnon, Warsi and Dwyer, 1995). The indirect effect is considered to be significant when the Sobel test Z value is significant (>1.96) (Rodríguez and Nieto, 2016). Bootstrapping (Bollen and Stine,

1990, Shrout and Bolger, 2002) is a non-parametric method that takes into account the skew of the distribution. When the resultant bootstrapped CIs do not contain value 0, the indirect effect is different from 0. Since these tests make different assumptions, it is advisable to use them both.

Results

Table 1 reports descriptive statistics, pairwise correlations and collinearity diagnostic for the variables used in the empirical study (with the exception of year and sectoral dummies). The raw values for all variables are presented in Table 1, although standardized values were used in the analysis for the hypotheses tests. Correlation values among all variables are generally low to moderate, suggesting there is a low risk of facing collinearity issues or redundancies with this set of variables. This is confirmed by the analysis of the variance inflation factor (Vif) values. The maximum Vif value is 1.37, well below the rule of thumb cut-off of 10, suggesting the absence of multicollinearity problems in the models (Neter *et al.*, 1996).

Since the indicators used in the analysis are self-reported, we tested for common method bias (CMB) following the guidelines set by Podsakoff *et al.* (2003). First, we employed the Harman's one-factor method. A principle component analysis including the dependent and explanatory variables was conducted. Because the analysis retained four factors with eigenvalues greater than 1 and the first factor did not account for the majority of the variance (this factor accounted for 25.5% of the total variance), one could claim the absence of a CMB problem. Second, we estimated a hypothesized model introducing a new latent variable to control for any influence a method factor could have on the estimated relationships (Podsakoff *et al.*, 2003). The analysis did not find any evidence that CMB had influenced our results.

Tables 2 and 3 present the results of the generalized structural equation models. Models 1 and 7 are the baseline models consisting of control variables and Models 2–6 (radical innovation) and Models 8–11 (incremental innovation) include the explanatory variables used to test our hypotheses. Models 1 and 7 show that several control variables are statistically significant in the expected directions, with most relationships holding across all the models. Alliance experience has a significant

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[2]Dropping the clustered robust option from the analysis did not qualitatively alter the findings. We also ran the robust standard errors option, and the results were qualitatively identical.

Table 1. Descriptive statistics and correlation matrix

Variable	Mean	S.D.					Correlation coefficients						
			1	2	3	4	5	6	7	8	9	10	11
1. Radical innovation	11.68	23.41	1										
2. Incremental innovation	48.96	44.61	−0.17*	1									
3. Geographical diversity$_{t-1}$	0.13	0.24	0.03*	0.04*	1								
4. Vertical diversity$_{t-1}$	0.17	0.29	0.05*	0.10*	0.57*	1							
5. Horizontal diversity$_{t-1}$	0.01	0.07	0.03*	0.02	0.29*	0.20*	1						
6. R&D human capital$_{t-1}$	2.70	1.77	0.13*	0.21*	0.24*	0.27*	0.09*	1					
7. R&D social capital$_{t-1}$	0.68	0.77	0.09*	0.10*	0.22*	0.23*	0.12*	0.23*	1				
8. R&D intensity$_{t-1}$	0.06	0.44	0.07*	−0.01	0.02*	0.05*	0.02*	0.09*	0.01	1			
9. Export intensity$_{t-1}$	0.12	0.19	0.04*	−0.02*	0.11*	0.09*	0.08*	0.12*	0.04*	0.02*	1		
10. Alliance experience$_{t-1}$	5.83	8.70	0.03*	−0.12*	0.62*	0.58*	0.34*	0.23*	0.21*	0.03*	0.14*	1	
11. Firm size (Ln)$_{t-1}$	4.40	1.39	0.01	0.10*	0.26*	0.22*	0.11*	0.22*	0.22*	−0.09*	0.03*	0.25*	1
Vif			1.36	1.33	1.24	1.25	1.35	1.34	1.35	1.37	1.28	1.20	1.35

$N = 11,132$
*$p < 0.01$; S.D = standard deviation; Vif = Variance Inflation Factor

and positive effect on the likelihood of introducing both radical and incremental innovations. Prior interactions between partner firms reduce the causal ambiguity involved in knowledge transfers and facilitate more effective knowledge exchanges (Zahra and George, 2002). The R&D intensity has a significant and positive effect on radical innovation performance, since breakthrough innovation and novel technologies embody new knowledge, so greater innovation support is required. Firm size has a significant and positive effect on incremental innovation, but the quadratic term is negative, suggesting that, although larger firms tend to introduce more incremental innovations, the oversize can generate monitoring costs and management problems that decrease the probability of introducing incremental innovations.

Hypotheses testing

Hypothesis 1 suggests a curvilinear relationship between geographical diversity and firm innovation performance. Models 2a and 8a show that the linear coefficient of geographical diversity is positive and statistically significant ($p<0.001$), while the negative direction and statistical significance of its quadratic term proves that, consistent with previous theorizations, geographical diversity displays diminishing returns to firm innovation performance. Therefore, we support Hypothesis 1.

Hypothesis 2 posits an inverted U-shaped relationship between vertical diversity and firm innovation performance. Models 2a and 8b show that the linear term for vertical diversity is positive and statistical significant ($p<0.001$), while its squared term is negative and statistically significant. These results imply that the relationship between vertical diversity and firm innovation performance is mainly positive, but the positive effect decreases with vertical diversity. Therefore, Hypothesis 2 is supported.

Hypothesis 3 suggests a curvilinear relationship between horizontal diversity and firm innovation performance. The results of the regression analyses depicted in Models 2c and 8c provide support only to our hypothesizing that horizontal diversity displays diminishing returns for radical innovation performance. The relationship between horizontal diversity and incremental innovation performance is linear. Therefore, we find partial support for Hypothesis 3. Horizontal diversity helps firms in their exploitative activities, as long as firms learn

Table 2. *Generalized structural equation models for radical innovation performance*

	Baseline	Radical innovation			Human capital			Social capital			Radical innovation		
	Model 1	Model 2a	Model 2b	Model 2c	Model 3a	Model 3b	Model 4b	Model 5a	Model 5b	Model 5c	Model 6a	Model 6b	Model 6c
Direct effects													
Geographical diversity$_{t-1}$		1.70***			1.71***			0.63***			1.49***		
		(0.28)			(0.17)			(0.07)			(0.32)		
H1: Geographical diversity$^2_{t-1}$		−0.86**			−1.02***			−0.29***			−0.74**		
		(0.31)			(0.18)			(0.08)			(0.34)		
Vertical diversity$_{t-1}$			2.06***			1.58***			0.47***			1.33***	
			(0.34)			(0.19)			(0.08)			(0.35)	
H2: Vertical diversity$^2_{t-1}$			−1.28***			−0.82***			−0.06			−0.64	
			(0.40)			(0.21)			(0.10)			(0.40)	
Horizontal diversity$_{t-1}$				4.97***			1.52***			0.67***			4.91***
				(0.53)			(0.28)			(0.18)			(0.39)
H3: Horizontal diversity$^2_{t-1}$				−4.03***			−2.02***			−1.08***			−3.98***
				(0.84)			(0.47)			(0.32)			(0.50)
Mediating effects													
H4: R&D human capital$_{t-1}$											0.26***	0.27***	0.28***
											(0.03)	(0.03)	(0.3)
H5: R&D social capital$_{t-1}$											0.30***	0.30***	0.30***
											(0.05)	(0.05)	(0.05)
Controls													
Firm size (Ln)$_{t-1}$	0.28	0.24	0.26	0.28	0.75***	0.76***	0.79***	0.03	0.04	0.05	−0.01	0.01	0.02
	(0.18)	(0.17)	(0.18)	(0.019)	(0.09)	(0.09)	(0.09)	(0.03)	(0.03)	(0.03)	(0.18)	(0.18)	(0.18)
Firm size$^2_{t-1}$	−0.1	−0.01	−0.01	−0.01	−0.06***	−0.06***	−0.06***	0.01	0.01	0.01	0.01	0.01	0.00
	(0.1)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Alliance experience$_{t-1}$	0.04***	0.03***	0.03***	0.03***	0.02***	0.02***	0.04***	0.03***	0.03***	0.03***	0.02***	0.02***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
R&D intensity$_{t-1}$	0.45***	0.42***	0.43***	0.44***	0.28**	0.28**	0.30**	0.01	0.01	0.01	0.31*	0.31	0.32*
	(0.11)	(0.11)	(0.11)	(0.11)	(0.14)	(0.14)	(0.15)	(0.02)	(0.02)	(0.02)	(0.18)	(0.19)	(0.18)
Export intensity$_{t-1}$	0.04	0.02	0.01	0.02	0.48***	0.47***	0.53***	0.07	0.08	0.09*	−0.07	−0.07	−0.07
	(0.22)	(0.22)	(0.22)	(0.22)	(0.13)	(0.13)	(0.13)	(0.05)	(0.05)	(0.05)	(0.24)	(0.24)	(0.23)
Log likelihood	−14530.31	−14484.05	−14492.49	−14445.26	−20886.52	−20883.02	−21033.87	−10815.15	−10810.70	−10957.70	−14401.64	−14409.44	−14351.68

Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%. Year and sector dummy variables were included in the analysis, but results are omitted here.

Table 3. Generalized structural equation models for incremental innovation performance

	Baseline	Incremental innovation			Human capital			Social capital			Incremental innovation		
	Model 7	Model 8a	Model 8b	Model 8c	Model 9a	Model 9b	Model 9c	Model 10a	Model 10b	Model 10c	Model 11a	Model 11b	Model 11c
Direct effects													
Geographical diversity$_{t-1}$		3.02***			1.71***			0.63***			2.73***		
		(0.31)			(0.17)			(0.07)			(0.37)		
H1: Geographical diversity$^2_{t-1}$		−2.19***			−1.02***			−0.29***			−2.04***		
		(0.36)			(0.18)			(0.08)			(0.38)		
Vertical diversity$_{t-1}$			3.09***			1.58***			0.47***			2.33***	
			(0.37)			(0.19)			(0.08)			(0.42)	
H2: Vertical diversity$^2_{t-1}$			−2.15***			−0.82***			−0.06			−1.83***	
			(0.43)			(0.21)			(0.10)			(0.47)	
Horizontal diversity$_{t-1}$				1.37**			1.52***			0.67***			1.18**
				(0.64)			(0.28)			(0.18)			(0.46)
H3: Horizontal diversity$^2_{t-1}$				−0.27			−2.02***			−1.08***			−0.09
				(1.02)			(0.47)			(0.32)			(0.62)
Mediating effects													
H4: R&D human capital$_{t-1}$											0.37***	0.37***	0.39***
											(0.03)	(0.03)	(0.03)
H5: R&D social capital$_{t-1}$											0.23***	0.24***	0.25***
											(0.06)	(0.06)	(0.06)
Controls													
Firm size (Ln)$_{t-1}$	1.39***	1.33***	1.32***	1.40***	0.75***	0.76***	0.79***	0.03	0.04	0.05	1.02***	1.03***	1.06***
	(0.19)	(0.02)	(0.13)	(0.19)	(0.09)	(0.09)	(0.09)	(0.03)	(0.03)	(0.03)	(0.21)	(0.21)	(0.21)
Firm size$^2_{t-1}$	−0.11***	−0.11***	−0.11***	−0.11***	−0.06***	−0.06***	−0.06***	0.01	0.01	0.01	−0.09***	−0.09***	−0.09***
	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Alliance experience$_{t-1}$	0.03***	0.02***	0.02***	0.03***	0.02***	0.02***	0.04***	0.03***	0.03***	0.03***	0.01**	0.01**	0.02***
	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)
R&D intensity y$_{t-1}$	−0.12	−0.15	−0.18	−0.12	0.28*	0.28**	0.30**	0.01	0.01	0.01	−0.30**	−0.29**	−0.27**
	(0.11)	(0.11)	(0.11)	(0.11)	(0.14)	(0.14)	(0.15)	(0.02)	(0.02)	(0.02)	(0.014)	(0.13)	(0.26)
Export intensity y$_{t-1}$	0.07	0.04	0.03	0.05	0.48***	0.47***	0.53***	0.07	0.08	0.09*	−0.10	−0.11	−0.10
	(0.02)	(0.24)	(0.25)	(0.25)	(0.13)	(0.13)	(0.13)	(0.05)	(0.05)	(0.05)	(0.25)	(0.25)	(0.26)
Log likelihood	−17177.32	−17107.38	−17130.96	−17166.84	−20886.52	−20883.02	−21033.87	−10815.15	−10810.70	−10957.70	−16997.47	−17018.95	−17042.99

Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%. Year and sector dummy variables were included.

to mitigate the challenges of managing the diversity of strategic partners (Parkhe, 1991). Increasing horizontal diversity in an alliance portfolio increases the willingness of competing firms in the same industry to share knowledge for incremental innovation outputs, as partners are less concerned about knowledge leakage. Conversely, our findings suggest that increasing horizontal diversity of alliance portfolios poses challenges to the firm in terms of identifying, assimilating and exploiting diverse knowledge to support explorative innovation activities.

A closer interpretation of the significant coefficients shows that both geographical and vertical diversity exhibit similar effects on incremental innovation performance, but also diminishing returns. In contrast, horizontal diversity exerts the strongest effect on radical innovation performance, but also diminishing returns. These results suggest that explorative efforts benefit when resources similar those that the firm already owns are accumulated to; thereby the need to balance exploration and exploitation across alliance compositional characteristics (Lavie, Kang and Rosenkopf, 2011). Managers should adopt a portfolio perspective and use different alliance portfolio configurations to enhance creativity and innovation performance.

Following De Leeuw, Lokshin and Duysters' (2014) approach, we obtain the optimal diversity levels for the different alliance configurations (Figures 2 and 3). Findings show that more diverse R&D alliances are required to enhance exploration performance. According to the nonlinear specification of geographical diversity, these numbers correspond to maintaining 2.98 (radical) and 2.49 (incremental) different types of partners. For vertical diversity, these numbers correspond to 4.5 (radical) and 4.24 (incremental) different types of partners.

Mediating effect of R&D human capital

Hypothesis 4 concerns whether R&D human capital mediates the relationship between alliance diversity variables and firm innovation performance. For the specification of the mediation link, we follow Baron and Kenny's (1986) procedure and find that all four steps are fulfilled. These results are displayed in Tables 2 and 3. A mediation effect exists if the coefficient of the direct path between the independent variable (alliance diversity) and the dependent variable (firm innovation performance) is reduced when the indirect path via the mediator (R&D human capital) is introduced in the model.

Tables 2 and 3 show that the four conditions hold for geographic and vertical diversity of alliance portfolio, but only partially for horizontal diversity. Models 6a and 11a show that, after entering R&D, human capital in the model reduces the magnitude and significance of the effect of geographic diversity[2] on firm innovation performance. Thus, our data support a partial mediation role of R&D human capital on the geographic diversity[2]-firm innovation performance relationship. A similar partial mediation effect is found for the impact of vertical diversity[2] on incremental innovation; however, R&D human capital exhibits a full mediation effect for radical innovation. In the case of horizontal diversity, R&D human capital partially mediates the curvilinear relationship between horizontal diversity[2] and radical innovation. The results of the formal tests of the indirect effects are shown in Table 4. The results of the Sobel tests provide significant evidence of the existence of an indirect effect (as the Sobel Z values are significant: $Z > 1.96$) for the above models. The bootstrap results confirm the Sobel test, with a bootstrapped 95% of CIs not containing zero.

As indicated, Hypothesis 3 was partially supported as we did not find a direct relationship between horizontal diversity[2] and incremental innovation (Model 8c). In this situation, Baron and Kenny's methodology is not applicable. However, the absence of a direct association does not imply that horizontal diversity[2] cannot exert an indirect effect on innovation performance via R&D human capital (Hayes, 2009). Hence, we focused on the indirect path and tested it with the previously described formal significant tests (Sobel and bootstrap CIs). Model 9c shows the positive and significant impact of horizontal diversity[2] on incremental innovation. Further, Model 11c provides evidence of the positive and significant impact of R&D human capital on incremental innovation. The results of the Sobel test and the bootstrapped CIs and bias-corrected CI show significant evidence of the existence of an indirect effect (Table 4).

Mediating effect of R&D social capital

Lastly, we test whether R&D social capital mediates the relationship between alliance diversity variables and firm innovation performance
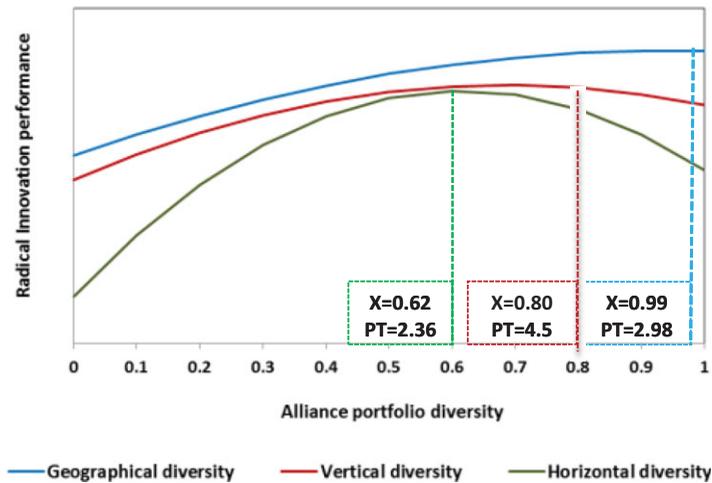
Figure 2. Relationship between APD and radical innovation performance [Colour figure can be viewed at wileyonlinelibrary.com]
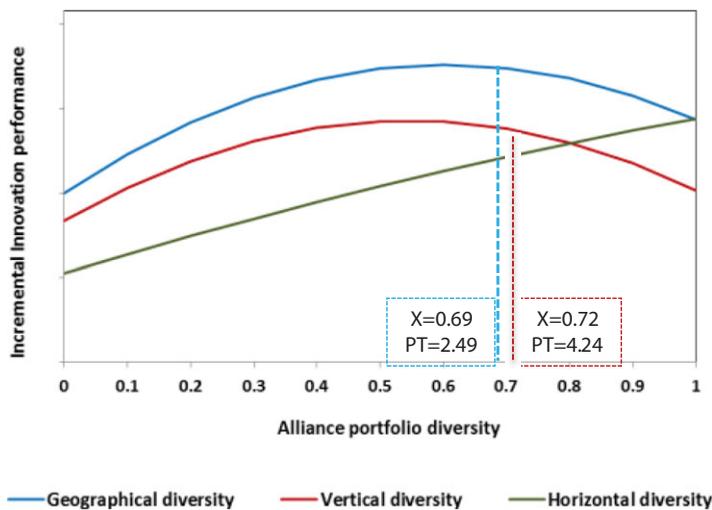
Figure 3. Relationship between APD and incremental innovation performance [Colour figure can be viewed at wileyonlinelibrary.com]

(Hypothesis 5). Similarly to R&D human capital, Models 6a and 11a show that, after entering R&D, social capital in the model reduces the magnitude and significance of the effect of geographic diversity[2] on firm innovation performance. Thus, our data support a partial mediation role of R&D social capital on the geographic diversity[2]–firm innovation performance relationship. However, we do not find a significant relationship between vertical diversity[2] and R&D social capital. In the case of horizontal diversity[2], R&D social capital partially mediates the curvilinear relationship between horizontal diversity[2] and radical innovation. The results of the formal tests of the indirect effects are shown in Table 4. The results of the Sobel tests

provide significant evidence of the existence of an indirect effect (as the Sobel Z values are significant: $Z>1.96$) for the above models. The bootstrap results confirm the Sobel test, with a bootstrapped 95% of CIs not containing zero. Similarly to R&D human capital, formal significant tests (Sobel and bootstrap CIs) show significant evidence of the existence of an indirect effect of R&D social capital on the horizontal diversity[2] and incremental innovation performance (Table 4).

Robustness tests and alternative models

To further validate the results and test their consistency, several robustness checks have been

Table 4. Test of mediation

Mediator: R&D human capital

	Geographical diversity			Vertical diversity			Horizontal diversity		
	Sobel test	CI(P)[a]	CI(BC)[b]	Sobel test	CI(P)[a]	CI(BC)[b]	Sobel test	CI(P)[a]	CI(BC)[b]
Radical innovation	4.89***	(0.035; 0.061)	(0.036; 0.062)	3.63***	(0.020; 0.051)	(0.021; 0.052)	4.01***	(0.024; 0.054)	(0.025; 0.056)
Incremental innovation	5.07***	(0.035; 0.064)	(0.036; 0.065)	3.70***	(0.019; 0.053)	(0.020; 0.055)	4.08***	(0.024; 0.056)	(0.026; 0.057)

Mediator: R&D social capital

	Geographical diversity			Vertical diversity			Horizontal diversity		
	Sobel test	CI(P)[a]	CI(BC)[b]	Sobel test	CI(P)[a]	CI(BC)[b]	Sobel test	CI(P)[a]	CI(BC)[b]
Radical innovation	2.96***	(0.016; 0.039)	(0.017; 0.042)	0.59	(−0.013; 0.024)	(−0.013; 0.025)	2.63***	(0.012; 0.039)	(0.012; 0.041)
Incremental innovation	2.63***	(0.012; 0.032)	(0.016; 0.036)	0.68	(−0.011; 0.025)	(−0.012; 0.026)	2.51***	(0.011; 0.037)	(0.012; 0.038)

[a] Percentile CI
[b] Bias-corrected CI
Significance at 5%;*significance at 10%.

performed and alternative specifications are explored.[3] In addition to the convex specification of APD, we also applied a concave specification and regressed it on innovation outcomes. Results were similar to those obtained with the convex specification of APD. Next, we estimated our model using OLS and Poisson regression, and the results were consistent. Additionally, we applied an Ordered Probit model similar to that of Henkel (2006), where the dependent variable can take values between 1 and 5 ('1' indicates that the share lies in the first quartile (0–20%), '2' indicates 21–40%, etc.). This model specification allows for a non-linear dependence of the share of sales from radical and incremental innovation on the explanatory variables inside the interval (0–100%). The results were highly robust to these changes in specification.

Additionally, we address endogeneity issues in our analysis by applying an instrumental-variable approach. Specifically, we analyse whether our mediator variables are exogenous. The Hausman endogeneity test is one of the most used methods to ensure the robustness of estimates potentially threatened by endogeneity (Antonakis *et al.*, 2010). According to this approach, if the co-variance of the disturbances is significant, the mediator variable is endogenous with respect to the dependent variable. Our results show that both mediators – human and social capital – are not endogenous, as the covariance of the disturbances is not significant.

Discussion and conclusion

The main objective of this paper was to examine the performance effects associated with different alliance portfolio configurations. Understanding how firms can extract value from highly diverse alliance portfolios is a central question in open innovation research. Laursen and Salter (2014) refer to the 'paradox of openness', suggesting that knowledge search and integration in R&D alliances is full of tensions and frictions, despite the evident benefits in knowledge-sharing. By distinguishing between geographic, vertical and horizontal diversity, we contribute to the configurational perspectives of alliance portfolio research (Wassmer, 2010).

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[3]These estimations are available on request.

Consistent with past studies (e.g. De Leeuw, Lokshin and Duysters, 2014; Lin, 2014; Jiang, Tao and Santoro, 2010), our results show a curvilinear relationship between a firm's R&D APD and innovation performance, underlining the challenges to extract value from highly diverse alliance portfolios (Vlaisavljevic, Cabello-Medina and Pérez-Luño, 2016). A tipping point is likely to be reached when it becomes increasingly challenging to identify, assimilate and exploit diverse external knowledge (Cohen and Levinthal, 1990, Vasudeva and Anand, 2011). Beyond this threshold, raising cognitive, transaction and organizational costs may diminish a firm's ability to absorb knowledge from these collaborations (Rothaermel and Deeds, 2006). Thus, an optimal level of partner diversity exists for companies to maximize innovation performance, depending on the portfolio architecture and product novelty.

Our study verifies empirically that different alliance portfolio compositions influence the type of external knowledge that firms can access, and lead to different performance effects (Haeussler, Patzelt and Zahra, 2012; Rothaermel and Deeds, 2004). Hence, a balance between explorative and exploitative alliances is critical to achieve optimal performance in the long term (Lavie and Rosenkopf, 2006). Collaborating with competing firms facilitates discovery and development of next-generation technology (Tidd and Bessant, 2013). In contrast, forming alliances with partners in geographically diverse settings supports firms' exploitation efforts.

In this paper, we complement emerging research efforts on the contingent role of internal firm characteristics shaping the capability of firms to extract value from highly diverse alliance portfolios (Garriga, Von Krogh and Spaeth, 2013; Monteiro, Mol and Birkinshaw, 2017; Wassmer, Li and Madhok, 2017). The alliance portfolio literature has widely acknowledged the complementary relationship between internal knowledge bases and external linkages and its influence on firm innovation performance (Cassiman and Veugelers, 2006; Escribano, Fosfuri and Tribó, 2009). Specifically, we show that high levels of intellectual capital yield strong absorptive capacity, and enable firms to successfully internalize and apply external knowledge assets for commercial ends (Ferreras-Méndez *et al.*, 2015; Spithoven, Clarysse and Knockaert, 2011). Firms with high levels of internal R&D capabilities avoid the loss of relevant process knowledge to help them exploit external knowledge assets (Kotabe, 1990). Our findings suggest that highly qualified R&D staff, by enabling assimilation capacity, act as a facilitating mechanism to integrate partners' distinct knowledge into their existing knowledge base. Absorptive capacity can also help reduce the coordination costs associated with diverse alliance portfolios through social integration mechanisms (Fernhaber and Patel, 2012). Social integration increases knowledge-sharing (Huang, 2009) and problem-solving (Rico *et al.*, 2007) while reducing cognitive load (Kang, Yang and Rowley, 2006). Knowledge transfer is facilitated by intensive social interactions among partner firms in geographical and horizontal diverse alliances. Relational social capital in the alliance creates a normative context that would reduce the fear of opportunistic behaviour among partners (Vlaisavljevic, Cabello-Medina and Pérez-Luño, 2016).

Managerial implications

Several managerial implications follow from this discussion and should be of interest to managers. First, the APD optimal level is dependent on the alliance portfolio configuration and product novelty; thus, alliance managers entrusted with steering and coordinating alliance activities should pay particular attention to the specific portfolio design that allows them to minimize the cognitive, transaction and organizational costs associated with diversity. A change in the compositional characteristics of alliance portfolios can influence the proportion of high-impact innovations produced over time. Our results indicate that, to maximize radical innovation performance, firms should source knowledge and capabilities from related knowledge bases residing in competing firms. Given the overlap in backgrounds, experiences, knowledge and technological bases, horizontal alliances offer greater absorptive capacity (Cohen and Levinthal, 1990). Organizational learning theory (Parkhe, 1991) suggests that it is the similarities between partners, rather than their differences, that facilitate the absorption of external knowledge. In contrast, managers can opt for geographical and vertical alliances to maximize the likelihood of exploitative efforts. The alliance portfolio literature increasingly recognizes the important role of alliance managers (Heidenreich, Landsperger and Spieth,

2016; Landsperger, Spieth and Heidenreich, 2012) to develop an alliance portfolio architecture that supports explorative and exploitative innovation efforts. Reaping the benefits of complementarity between alliances with different partner types requires managing the governance risks in diverse alliance portfolios (Belderbos *et al.*, 2018).

Second, our findings advocate the need to develop alliance integration and learning capabilities to manage effectively diverse knowledge from alliance partners. As a capability, alliance learning capability enables firms to articulate, codify, share and internalize knowledge (Kale and Singh, 2007). Upskilling and training R&D staff allow firms to tap into more diverse knowledge sources and develop absorptive capacity (Lin, 2014; Muscio, 2007). By investing in the acquisition of new skills, R&D employees could more effectively absorb and deploy local or distant knowledge relevant to future innovation (Huang *et al.*, 2015). Further, job-rotation, working in cross-functional teams (Jansen, Van den Bosch and Volberda, 2005) and exchanging staff between firms (Lowik *et al.*, 2012) enhance potential absorptive capacity. A broad knowledge base allows firms to build 'architectural competence' by integrating disperse knowledge into a coherent whole (Henderson and Clark, 1990). In addition, social integration, such as open interaction, trust and shared understanding, helps firms to manage intensive communication and tacit knowledge exchanges (Nielsen and Nielsen, 2009) and mitigate the fear of opportunistic behaviour (Vlaisavljevic, Cabello-Medina and Pérez-Luño, 2016). Alliance integration capability emphasizes the processes deployed to develop a relational platform for learning (Kohtamäki, Rabetino and Möller,

2018). To enhance network diversity, managers could encourage employees attending network meetings, conferences and trade fairs (Büchel and Raub, 2002). Our results, interestingly, did not find support for the mediating effect of R&D social capital in vertical diversity. A broad internal knowledge base offers more opportunity for firms to capture value from highly diverse alliance portfolios compared with social relational capital.

Limitations and future research

We acknowledge several limitations in our paper. First, the focus of this study is specifically on firms' internal capabilities to absorb and apply external knowledge for innovation. Future research could be extended by examining the key role of strategic HRM practices, such as knowledge management, training programmes and developmental plans, usually linked to higher adaptability, flexibility and competitive advantage (Cabrera and Cabrera, 2005). Second, future studies could incorporate multiple levels of analysis and examine other organizational-level as well as country-level variables. Third, an alternative approach to the diversity score would have been to consider the number of inter-organizational ties with each partner (Wassmer, 2010). Unfortunately, PITEC data do not capture this level of information or distinguish between the knowledge resources within each partner type. Finally, we use data from Spain, so evidence from other countries on the differential impact of absorptive capacity dimensions on innovation performance might help to develop more general empirical evidence in future research direction.

Appendix A1: Description of variables

Variables	Type	Definitions
Dependent variables		
Radical innovation	Continuous	Percentage of the firm's total sales in year *t* from innovations new to the market during the period between *t*−2 and *t* (Ln)
Incremental innovation	Continuous	Percentage of the firm's total sales in year *t* from innovations new to the firm during the period between *t*−2 and *t* (Ln)
Independent variables		
Geographic diversity	Continuous	Alliance portfolio diversity index based on partners' geographical locations (0,1)
Vertical diversity	Continuous	Alliance portfolio diversity index in terms of upstream and downstream partners types (0,1)

Variables	Type	Definitions
Horizontal diversity	Continuous	Alliance portfolio diversity index in terms of horizontal partner types (0,1)
Mediating variables		
R&D human capital	Continuous	Log of higher education intensity of R&D staff
R&D social capital	Continuous	Number of changes in organisational capabilities relating to management and procedures and external relationships.
Control variables		
Firm size	Continuous	Number of employees (Ln)
Firm size^2	Continuous	Number of employees (Ln) squared
Alliance experience	Continuous	Cumulative number of alliances formed by each firm from 2008 to 2013, measured at the end of each year
R&D intensity	Continuous	R&D expenditure as a proportion of total sales
Export intensity	Continuous	Ratio of export sales to total sales
Industry	Dichotomous	Dummy variables indicating the sector where the firm operates
Year	Dichotomous	Dummy variables indicating the year to which observations belong to (2008–2013)

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