Capturing Value from Alliance Portfolio Diversity: The Mediating Role of R&D Human Capital in High and Low Tech Industries

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Abstract

Research has demonstrated the value of external linkages to augment in-house R&D efforts; however, very little is known about how managers can operationally leverage the potential benefits of open innovation to create an innovative edge. This paper examines the value of alliance portfolio diversity and whether R&D human capital is the pathway through which alliance portfolio diversity influences innovation novelty. We reason that the absorptive capacity of R&D human capital determines a firm's potential gains from highly diverse alliance portfolios. Using data from the Spanish Technological Innovation Panel (PITEC) for the period 2005–2012, results support the curvilinear (inverted U-shaped) association between alliance portfolio diversity and firm innovation performance reported in studies, suggesting that not only too little, but also too much alliance portfolio diversity may be detrimental to firm innovation performance. Findings emphasise the value of alliance portfolio diversity in high-technology industries to achieve explorative performance objectives, given the technological complexity, market uncertainty and the divergent skill sets required for breakthrough innovations in these sectors. Further, we find evidence that R&D human capital plays an important role in innovation novelty by partially mediating the relationship between alliance partner diversity and firm innovation performance, emphasising the importance of internal capabilities to harness external knowledge assets. This study provides valuable insights to managers aiming to increase the effectiveness of their alliance portfolios.

Keywords: alliance portfolio diversity, innovation performance, R&D human capital, education, skills, absorptive capacity, generalized structural equation model, Spain.

1. Introduction

Today's fast paced business environment and shortening product life cycles require firms to consider externally generated scientific knowledge and technology to augment in-house R&D efforts (Dahlander and Gann, 2010). Open innovation research has underscored the value of external sources of knowledge and external collaboration relationships to boost firms' innovative performance and meet new business challenges (Chesbrough, 2012, Enkel et al., 2009, Laursen and Salter, 2006, de Man and Duysters, 2005). Heterogeneity of external partners enables firms to access diverse markets and technological knowledge (Lin, 2014, Zhou and Li, 2012) and facilitates the process of innovation by allowing firms to make new linkages and associations (Cohen and Levinthal, 1990).

However, too much diversity of external sources could adversely impact firm innovation performance due to increased organisational and managerial complexity (Duysters and Lokshin, 2011, Bader and Enkel, 2014, Foss et al., 2011). Studies report a curvilinear (inverted U-shaped) relationship between R&D alliance portfolio diversity (APD), defined as the distribution of differences in partners' characteristics (Oerlemans et al., 2013), and firm innovation performance, suggesting that an increase in APD will enhance innovativeness only up to a certain limit. Beyond that point, APD may yield few marginal benefits as resources become spread too thin and greater coordination and integration costs are incurred (Chen et al., 2011, Duysters and Lokshin, 2011, de Leeuw et al., 2014). Limited research, however, has focused on a systematic investigation of the underlying mechanisms that explain how APD matters. Particularly, the role exerted by internal capabilities to extract value from APD remains largely under-researched (Foss et al., 2011, Spithoven and Teirlinck, 2015). Absorptive capacity, defined as 'the ability of a firm to recognize the value of new external information, assimilate it and apply it to commercials ends' (Cohen and Levinthal, 1990, p. 128), determines the effectiveness of external knowledge sourcing. A firm's absorptive capacity depends on its existing stock of knowledge, much of which is embedded in its products, processes and people (Escribano et al., 2009). Specifically, we contend that R&D human capital, defined as the knowledge, skills and abilities residing and used by individuals (Subramaniam and Youndt, 2005), determines a firm's potential gains from highly diverse alliance portfolios.

Responding to call for more research on how to manage business ecosystem (Biemans and Langerak, 2015), this study draws on the resourced-view (RBV) premise that dynamic capabilities are sources of competitive advantages (Barney, 1991, Barney et al., 2011, Teece et al., 1997) and the theory of human capital (Becker, 1964) to examine the role of R&D human capital to channel the impact of APD on innovation novelty – incremental and radical innovation. Human capital enables firms to expand their technological boundaries and successfully absorb and deploy new and substantially different knowledge domains (Subramaniam and Youndt, 2005, Faems and Subramanian, 2013). Our hypothesising suggests that R&D human capital enables firms to extract value from highly diverse alliance portfolios.

This paper contributes to the literature in two important ways. First, we contribute to innovation management theory by proposing and testing the mediating role of R&D human capital in the effect of APD in firm innovation performance. Open innovation research has largely focused on the environmental context of the firm (e.g., type of industry) (Chesbrough and Crowther, 2006) and organisational factors (e.g., structures, systems and procedures) (Petroni et al., 2011, Ritala et al., 2009); however there is yet little understanding of the intermediate factors that delineate APD's implications for firm's innovativeness. Recent literature suggests the need to consider firm's human capital and training investments that capture the path-dependency nature of absorptive capacity to explain a firm's ability to effectively learn from external sources (Zahra and George, 2002, Lane et al., 2006). Maintaining strong internal R&D capabilities enable 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 capital becomes the 'means' through which APD benefits innovation outcomes.

Second, we contend that the heterogeneity of technological intensity in manufacturing sectors creates distinct contexts for knowledge creation and sharing, and thereby benefit from different levels of APD (Denicolai et al., 2014). Our study demonstrates the need for firms to assess and develop R&D human capital strategies based on the type of innovation activity pursued (incremental and radical) as its dimensions of 'general' and 'specific' human capital impact firms' ability to benefit from APD differently.

The paper is structured as follows. Following this introduction, in section two we provide an overview of the relevant literature on APD and R&D human capital and present the research hypotheses. Section three details the research design and methods, and section four presents the results. We discuss our findings in section five together with the theoretical and managerial implications of our findings, and a direction for future research and practice in external collaboration.

2. Theoretical background and hypotheses development

2.1. Alliance portfolio diversity and innovation performance

Increasing global competition, rapid technological advances and shortening product life cycles put firms under unprecedented pressure to introduce new products and services to survive and remain competitive (Teirlinck and Spithoven, 2013, van Beers and Zand, 2014). Breakthrough innovation requires a wider-knowledge base and organisations increasingly rely on external knowledge assets for the successful realisation of their innovative endeavours (Garcia Martinez, 2013, Chiaroni et al., 2010). Sustainable superior innovation performance can be attained by combining diverse market and technological knowledge sources in the alliance portfolio (Lin, 2014) and exploiting possible complementarities and synergies (de Leeuw et al., 2014). R&D alliances are an ideal platform for learning as external partners bring diverse knowledge and resources that firms can integrate into new products and services (Doz, 1996, Hamel, 1991, Cohen and Levinthal, 1990, Chen, 2004). As firms develop a more balanced alliance portfolio that incorporates core as well as non-core activities, they gain access to supplementary and complementary knowledge assets and expand their knowledge bases (Jiang et al., 2010). In general, the larger and more diverse the alliance portfolio, the higher the innovation performance of a firm (Caloghirou et al., 2004, Laursen and Salter, 2006).

Acknowledging the increasing importance of strategic alliance to firms' overall performance, scholars have looked at alliance characteristics and impact on innovation outcomes. At the portfolio level, allying with partners along the value chain provides market and knowledge access advantages (Jiang et al., 2010). Vertical alliances enable firms to pool complementary resources and access market information to better target innovation efforts (Miotti and

Sachwald, 2003). Cooperation with suppliers is found to enhance efficiency and complement the technological-base of the firm (Belderbos et al., 2004, Un and Asakawa, 2015). Collaboration with universities and research institutes, on the other hand, can provide access to tailor made, cutting edge technologies (Tether and Tajar, 2008, Tsai, 2009); however, it may require firms to collaborate with other actors in order to implement the technology (Berg-Jensen et al., 2007). Horizontal alliances with partners at the same level of the value chain provide access to knowledge in design, prototyping, testing, development and new product introductions (George et al., 2001). Horizontal alliances are more likely to be strategically motivated to improve long-term product technology development whereas vertical alliances tend to be more concerned with cost reduction (Kotabe, 1990). Collaboration with competitors enables firms speedy market penetration (van Beers and Zand, 2014) and access to technological abilities that can be difficult, time-consuming, and costly to develop alone within their boundaries (Chen et al., 2011).

Increasingly strategies alliances involve partners from diverse geographical locations. Cross-border collaboration can facilitate market access (Glaister and Buckley, 1996), provide complementary capabilities (Lane et al., 2001), and integrate different knowledge bases (Lubatkin et al., 2001). Geographical diversity is found to be important for the adaptation of existing products to different local requirements and preferences (van Beers and Zand, 2014, Lavie and Miller, 2008). Terjesen et al. (2011) argue that alliances with local, national, and international suppliers enable firms to benefit from location-based variations in resources, market and technologies to deliver consistently high performing products.

Recent research suggests differing effects of APD on innovation novelty (Oerlemans et al., 2013) and reduced utility from alliance variety as firms become more innovative (Egbetokun, 2015). Radical innovation represents a dramatic departure from existing products in terms of technology and generate greater information processing and exposure to a variety of knowledge domains (Wuyts et al., 2004, Leifer et al., 2000). Scholars argue that internally generated knowledge provides low potential for creating radical innovation outputs (Rosenkopf and Nerkar, 2001), limiting firms' ability to remain competitive in dynamic business environments (e.g., Laursen and Salter, 2006, Lichtenthaler, 2009). Not surprisingly, organisations increasingly collaborate with a wide range of external partners to tap into new

and non-redundant knowledge bases and competencies enhancing firm innovativeness and reducing time to market (Chiang and Hung, 2010, Subramaniam and Youndt, 2005). Variety is essential for effective experimentation and choice under circumstances of great uncertainty (Pavitt, 1999). Incremental innovation derives from local search and new combinations of well-used components (Nelson and Winter, 1982). Internal knowledge creation capabilities enable firms to improve incremental innovation performance (Hernandez-Espallardo et al., 2012, Soosay et al., 2008); hence R&D alliances are confined to partners in related technological fields (Zhang et al., 2007).

However, managing coordinated innovation by alliance partners requires management attention (Foss et al., 2011). Highly diverse alliance portfolios can lead to high coordination and integration costs (Combs and Ketchen, 1999), resulting in an unsuccessful transfer of tacit knowledge by firms to their internal innovation processes (Grimpe & Kaiser 2010). These complexities can cause diminishing and negative rates of innovation performance (Katila and Ahuja, 2002, Laursen and Salter, 2006) as firms are required to coordinate R&D activities with a broader set of external sources within the internal constraints of time and resources (Lin, 2014). Internal tensions might evolve as firms have to decide how to allocate scarce resources within the alliance portfolio and distribute attention among alliance partners (Hoang and Rothaermel, 2005, Hoffmann, 2005). In the event of extreme diversity, the cognitive limits of a firm to deal which such level of complexity are quickly reached and as a consequence the disadvantages of diversity ultimately outweigh the benefits (Duysters and Lokshin, 2011).

Thus, we hypothesise a positive but non-linear relationship between APD and firms' innovation performance, suggesting that both insufficient and excessive diversity would be detrimental to firms' innovativeness. The net benefits first increase and then decrease with the degree of APD as organizational tension, complexity and coordination begin to hamper a firm's ability to leverage the benefits of external collaboration for innovation. Consequently, innovation search across highly diverse alliance portfolios will face diminishing returns.

Hypothesis 1. The relationship between alliance portfolio diversity and a) incremental and b) radical innovation performance is curvilinear: it is positive as alliance portfolio diversity increases initially but becomes negative as partner variety further increases.

2.2. Intersectoral differences in optimal levels of APD

The present study hypothesises that high-tech and low-tech manufacturing sectors create distinct contexts for knowledge creation and sharing, and thereby benefit from different levels of APD. High-tech industries are characterised by high levels of technological sophistication and extensive R&D activities (Covin et al., 1990). These industries require a broad range of external partners to remain competitive in their rapidly changing business environments (Ili et al., 2010, Martín de Castro, 2015, Alcalde Heras, 2014). High-tech firms enter multiple alliance agreements to overcome uncertainty and optimise risks of organisational failure, and to access multiple knowledge and skills bases across the various phases of their value chain (George et al., 2001). A heterogeneous pool of knowledge and capabilities is expected to support high-tech firms' orientation towards the development of advanced technological and scientific know-how (Satta et al., 2016).

In contrast, firms in low-tech sectors exhibit lower levels of external search breadth (Laursen & Salter 2006). Innovation in low-tech sectors is driven by customer-related and practical knowledge (Hirsch-Kreinsen, 2008, Von Tunzelmann and Acha, 2005, Heidenreich, 2009) and is usually not an outcome of the latest scientific or technological knowledge (Som, 2012). Empirical studies demonstrate that low-tech industries acquire externally developed mature and well-established technologies, modify these or apply them in a new context (Bender, 2008), thereby showing a strong dependence on the external provision equipment and knowledge (Heidenreich, 2009). Thus, we hypothesise that high-tech industries engage in more open sourcing strategies to cope with highly turbulent environmental and time discontinuities (van Beers and Zand, 2014) whereas low-tech industries by focusing on incremental innovation activities collaborate with less diverse alliance portfolios (Hansen and Winther, 2014).

Hypothesis 2. Different levels of APD are beneficial for different levels of technological intensity. For high-tech sectors, the optimum will be at a higher level of APD compared to low-tech industries.

2.3. The mediating role 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). Open innovation research demonstrates that a firm's ability to learn new knowledge through its interaction with external partners requires investments in internal R&D capabilities (Huang et al. 2015). This internal capability, referred to as absorptive capacity (Cohen and Levinthal, 1990, Cohen and Levinthal, 1989), determines a firm's ability to assimilate and utilise external knowledge flows successfully (Kim and Inkpen, 2005, Lane and Lubatkin, 1998). 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 (Teixeira and Tavares-Lehmann, 2014, Fukugawa, 2013). Reflecting the cumulative nature of knowledge, this hypothesising assumes that better educated people and trained employees possess higher ability to integrate and apply new knowledge, and that a firm's absorptive capacity level depends on the level of education, experience and training of its employees (Spithoven and Teirlinck, 2015, Spithoven and Teirlinck, 2010, Caloghirou et al., 2004).

Becker's (1964) theory of human capital distinguishes between 'firm-specific' and 'general' human capital; general human capital relates to knowledge and skills that are easily transferable across jobs, firms and industries, whereas specific human capital refers to knowledge and skills that can be used within the context of a specific job or a specific firm (Ucbasaran et al., 2008). Formal education, which is the main source of general human capital (Schwerdt and Turunen, 2007), enables a person to acquire the skills necessary to identify business opportunities (Arvanitis and Stucki, 2012) and increases firms' absorptive capacity through the knowledge accumulation phase (Vinding, 2006). Mangematin and Nesta (1999) argue that highly educated employees, in particular, through their daily tasks, will increase the stock of knowledge of an organisation. They will further encourage relationships with peers outside the firm, thus facilitating access to external networks of knowledge, particularly in the case of employing scientific knowledge (Rothwell and Dodgson, 1991). Carter (1989) posits that top educated employees are the main contributors

to know-how trading due to the high level of knowledge embodied in these individuals and thereby will be in a better position to recognise and value new external knowledge.

Thus, we argue that general knowledge, in terms of formal education, matters for the determination of a firm's absorptive capacity; thus becoming the means through which APD benefits innovation outcomes. Firms with high general human capital would be better positioned to harness new knowledge assets emanating from highly diverse alliances portfolios.

Hypothesis 3. R&D education intensity mediates the inverted U-shaped relationship between APD and a) incremental and b) radical innovation performance.

Beside formalised knowledge, tacit knowledge is an important component of innovation (Rosenberg, 1982, Dosi, 1982, Senker, 1995). Firm's absorptive capacity might be developed through the accumulation of experience and this kind of firm-specific knowledge, in other words, knowledge established through 'learning by doing', may be measured by work experience of the employees (Kriechel and Pfann, 2005). Recent research highlights the importance of a highly skilled workforce to assimilate and integrate external knowledge assets (Teirlinck and Spithoven, 2013, Huang et al., 2015), suggesting that the value of human capital increases as it becomes more firm-specific (Dutta et al., 2005). Particularly, high task specific human capital is required to assimilate external knowledge with high degree of tacitness associated with highly sophisticated, complex technological processes (Gibbons and Waldman, 2004). Hence, we expect firm specific knowledge, in terms of work experience/skills intensity, to mediate the relationship between APD and firm innovation performance.

Hypothesis 4. R&D Skills intensity mediates the inverted U-shaped relationship between APD and a) incremental and b) radical innovation performance.

Our hypothesised model is depicted in Figure 1.

Figure 1. Research framework
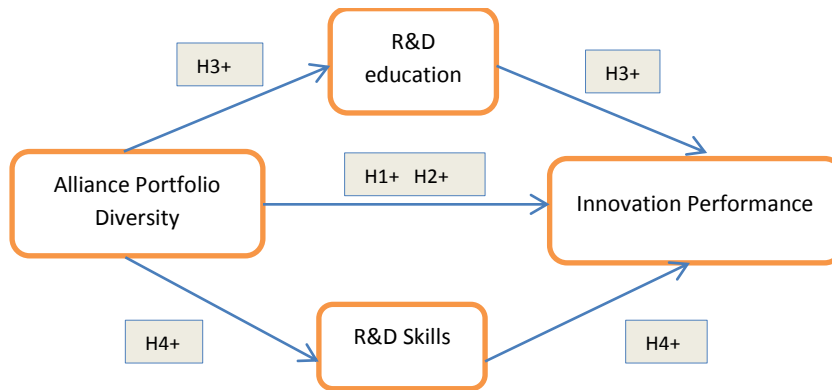
3. Methodology

3.1. Data and sample

The data for the quantitative analysis has been drawn from the Technological Innovation Panel (PITEC), which is a statistical instrument for studying innovation activities of Spanish companies over time. 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 dataset contains panel data for more than 12,000 firms since 2003. The study was conducted using information on firms' innovation performance and R&D employment characteristics for the period 2005-2012. For the purposes of this research, the dataset was confined to manufacturing firms that have introduced radical or/and incremental innovations over the studied period. Our final sample contained 32836 observations, 14740 for high-tech sectors and 18096 for low-tech sectors.

3.2. Measures

3.2.1. Dependent variable

Firm 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. *Radical innovation* is measured as the percentage of the firm's total sales

from innovations new to the market in the last 2 years. *Incremental innovation* is defined as the percentage of the firm's total sales from innovations new to the firm in the last 2 years.

3.2.2. Independent variable

Alliance Portfolio Diversity: consistent with prior research, we consider survey information on cooperation agreements for innovation in the previous two years. Collaborative alliances are distinguished by means of eight partner types: 1) customers, 2) suppliers, 3) competitors, 4) firms belonging to the same enterprise group, 5) universities, 6) public research organizations, 7) technological centres, and 8) commercial laboratories/R&D enterprises. For each type of partners, information is further categorized by their geographical location: Spain, EU and Other Countries. Thus, 24 binary variables are generated, representing all possible combinations between partner type and geographical location. Following de Leeuw et al.'s (2014) approach, APD is calculated by dividing the number of different partner types of a firm by the maximum possible number of partner types (24 in our case) and then squaring the result. The result of this calculation is a diversity score with values between 0 (no diversity – all partners belong to the same category) and 1 (balanced distribution of partners across a larger number of different categories).

3.2.3. Mediator variables

R&D human capital: our study uses the traditional measures of human capital: education and skills, employed in empirical research to capture the 'general' and 'specific' dimensions of human capital, respectively (Kriechel and Pfann, 2005). *R&D education intensity* is a continuous variable capturing the percentage of R&D staff with third level education or higher (Xia, 2013, Teixeira and Tavares-Lehmann, 2014). Top educated staff increase a firm's capacity to absorb and apply new knowledge into their innovation processes (Rothwell and Dodgson, 1991) and facilitate knowledge sharing within the organisation (Schmidt, 2010). *R&D skills intensity* is also a continuous variable accounting for the percentage of top skilled R&D workers (researchers and technicians) (Teixeira and Tavares-Lehmann, 2014). Skilled workers offer greater ability to find, integrate and use new tacit knowledge and later developmental opportunities (Yang et al., 2009).

3.2.4. Control variables

Firm size has been related to innovation capabilities and the novelty of innovations (Ettlie and Rubenstein, 1993, Chandy and Tellis, 2000, 1998). To account for the non-normality of the size measure, a logarithm transformation was used (Damanpour, 1992). In addition, we account for non-linear effects of firm size by computing firm size squared (Acs and Audretsch, 1991, 1990). We expect firm size to have a positive effect since larger firms have the necessary internal capabilities to engage in R&D alliances (Veugelers and Cassiman, 2005).

Alliance experience: we include a dummy variable to capture a firm's prior experience in external collaboration since alliance-experienced firms are more likely to effectively manage highly diverse alliance portfolios (Kim and Inkpen, 2005, Duysters et al., 2012).

R&D intensity, defined as firm R&D expenditure as a proportion of firm total sales (Laursen and Salter, 2004, Huang et al., 2015), contributes to the internal knowledge base of the firms, so-called absorptive capacity (Cohen and Levinthal, 1990, Zahra and George, 2002), necessary to efficiently absorb and deploy external knowledge (Griffith et al., 2003, Arora and Gambardella, 1990). R&D intensity is expected to complement (rather than substitute) external knowledge search and have a positive impact on innovation outputs (Veugelers, 1997).

Export intensity is measured by (the natural 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 (Kirner et al., 2009). Hence, export intensity might act as an incentive to improve innovation performance through collaborative innovation (Alarcón and Sánchez, 2016).

Industry effects: firms' innovation behaviour is closely linked to their industry affiliation (Malerba et al., 1997, Audretsch, 1997); hence we control for industry effects based on the classification proposed by van Beers and Zand (2014). We created two industry dummy variables identifying high-tech and low-tech industries.

Year effects. We use firm-level innovation performance data from 2005 to 2012; hence eight year dummy variables were included to control unobservable factors that change over time but remain relatively constant across industries (Lin 2014). Table A.1 in Appendix A describes the variables used in this study.

3.2.5. Model and estimation

We use a Generalised Structural Equation Model (Stata 13 gsem command) to estimate the relationship between APD and firm innovation performance (H1 an H2). This model allows a random-effect Tobit specification for our dependent variable and provides a means for testing simultaneous equations. The dependent variables (radical and incremental innovation performance) are percentage measures and thereby conditioned on values between 0% and 100%. Since the data for both measures of innovation outcomes is 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 et al., 1996, Papalia and Di Iorio, 2001).

In order to observe inter-sectoral differences, estimations are reported for two industry groups: high-tech and low-tech industries. Standard one-tailed z-test is used to compare regression coefficients between the two groups (Paternoster et al., 1998, van Beers and Zand, 2014):

$$Z = \frac{|b_1 - b_2|}{\sqrt{\sigma_{b_1}^2 + \sigma_{b_2}^2}}$$

where b_1 and b_2 are the estimated coefficients associated with the two subsamples, and σ_{b1} and σ_{b2} are the standard errors.

To test the mediation hypotheses (H3 and H4), which postulate a mediation effect of R&D human capital on the impact of APD on firm innovation performance, we follow the methodology proposed by Baron and Kenny (1986). Step 1 of the test for mediation is to show that a significant relationship exists between the independent variable and the dependent variable; step 2 is to show that a significant relationship exists between the independent variable and the mediator; step 3 is to show that the mediator variable is

related to the dependent variable; 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. If these four conditions describe by Baron and Kenny (1986) are met, we are able to conclude that a mediation effect occurs.

Additionally, we use Sobel tests (Baron and Kenny, 1986, Sobel, 1982) and bootstrapping confidence intervals (CIs) to test the indirect effects of R&D human 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 et al., 1995). The indirect effect is considered to be significant when the Sobel test Z value is significant (>1.96) (Rodríguez and Nieto, 2015). 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 confidence intervals (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.

Table 1 presents the summary statistics and correlations among the study variables. 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. The highest correlation is 0.58, far less than the problematic level. The general rule of thumb is that correlation values should not exceed 0.75 (Tsui et al., 1995). This is confirmed by the analysis of Variance of Inflation (Vif). The maximum Vif value is 1.49, well below the rule of thumb cut-off of 10, which again indicates that there are no serious multicollinearity problems in the models (Neter et al., 1996).

Table 1. Descriptive statistics and correlation coefficients

Variables	Mean	S.D.	Correlation Coefficients								
			1	2	3	4	5	6	7	8	9
1.Radical Innovation	10.14	22.68	1								
2.Incr Innovation	50.47	45.77	-0.13*	1							
3.APD	0.04	0.09	0.08*	0.15*	1						
4.R&D education	29.74	33.77	0.14*	0.24*	0.24*	1					
5.R&D skills	50.12	43.09	0.16*	0.29*	0.24*	0.58*	1				
6.R&D intensity	0.04	0.21	0.10*	0.02*	0.09*	0.15*	0.14*	1			
7.Export intensity	0.12	0.20	0.05*	0.07*	0.13*	0.16*	0.15*	0.01	1		
8.Alliance experience	0.27	0.44	0.07*	0.13*	0.50*	0.18*	0.21*	0.08*	0.04*	1	
9. Firm size (Ln)	4.02	1.39	-0.01*	0.14*	0.28*	0.20*	0.16*	-0.13*	0.14*	0.16*	1
Vif			1.48	1.46	1.40	1.19	1.18	1.48	1.49	1.42	1.46

N = 32836

*p < 0.01; S.D = standard deviation; Vif= Variance Inflation Factor

4. Results

Table 2 and 3 present the models for the hypotheses. Hypothesis 1 suggests a curvilinear relationship between APD and firm innovation performance. Model 1.1 (Table 2) and Model 2.1 (Table 3) show that the linear APD term has a significant positive coefficient (p<0.01), while APD^2 has a significant negative coefficient (p<0.01), suggesting an inverted U-shaped relationship between APD and radical and incremental innovation performance. An increase in APD can improve firm innovation performance, but too much diversity after the optimal point can negatively affect innovation outcomes. Therefore, Hypothesis 1 is supported.

Hypothesis 2 posits that the optimal level of APD differs in terms of industry's technological intensity. Following de Leeuw et al. (2014) approach, we find that APD optimal level is lower for radical innovation outcomes in low-tech industries (0.40) than for high-tech industries (0.50). According to the non-linear specification of APD, these numbers correspond to maintaining 15.4 (low-tech) and 17.0 (high-tech) different types of partners (Model 1.1 in Table 2). The difference between the two subsamples is statistically significant (z=1.63, p<0.05). For incremental innovation performance, APD optimal level is also lower for low-tech industries (0.43) compared to high tech industries (0.48). These numbers correspond to 15.7 (low-tech) and 16.6 (high-tech) different types of partners (Model 2.1 in Table 3).

However, the difference between both sectors is not significant (z= 0.88, ns). Therefore, Hypothesis 2 is partially supported. These results suggest that the impact of APD on firm innovation performance is contingent upon the industry's technological intensity and the novelty of innovations (Figure 2). Greater product complexity, market uncertainty and the divergent skills sets needed to achieve explorative performance objectives in high-tech industries require highly diverse alliance portfolios (van Beers and Zand, 2014). Radical innovation draws on new knowledge and is inherently more risky than incremental innovation (March, 1991; Levinthal and March, 1993). It is associated with higher variability in performance outcomes and higher probability of failure (Story et al., 2014). Figure 2 shows lower levels of radical innovation performance compared to incremental innovation for both high-tech (z test=1.34, p<0.1) and low-tech sectors (z test=2.11, p<0.05). In contrast, both sectors require similar partner diversity to maximise incremental innovation performance.

Figure 2. Relationship between APD and firm innovation performance – Industry Differences
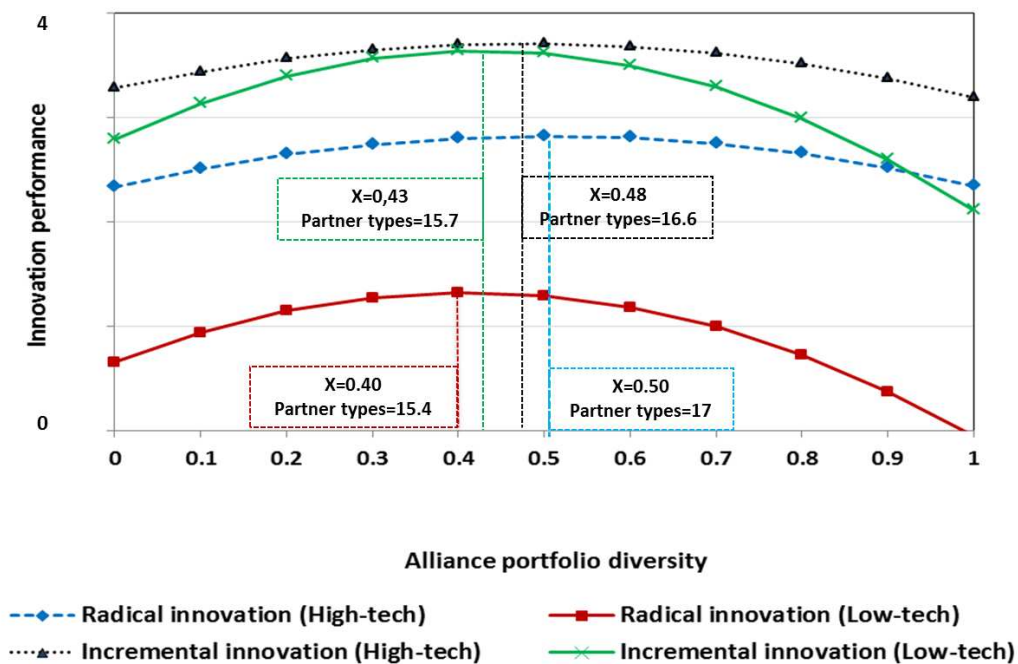
4.2. Mediating effects of R&D human capital

Hypotheses 3 and 4 concern whether R&D general (education) and firm-specific (skills) human capital mediates the relationship between APD 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. A mediation effect exists if the coefficient of the direct path between the independent variable (APD) 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. Step one requires a relationship between the independent variable and the dependent variable. Models 1.1 and 2.1 show that APD^2 is significantly related to radical and incremental innovation performance ($p<0.01$) (Hypothesis 1). The second step involves establishing a direct relationship between the independent variable and the mediating variables. Models 1.2 and 2.2 show that there is a significant relationship between APD^2 and R&D education ($p<0.01$) and Models 1.3 and 2.3 show that APD^2 is significantly related to R&D education ($p<0.01$). The third step requires that the mediator influences the dependent variable when the effect of the independent variable is controlled for and this established in Models 1.4 and 2.4. The final step is to establish that the effect of the independent variable on the dependent variable is reduced to non-significance or becomes smaller in the presence of the mediator variable, which provides evidence for full or partial moderation. Models 1.4 and 2.4 show that after entering R&D education and skills in the model reduces the magnitude and significance of the effect of APD^2 on firm innovation performance. Thus, our data supports a partial mediation role of R&D human capital.

In order to confirm the mediating relationship and eventually determine the mediation type, we examined the significance of indirect effects using the Sobel test and a bootstrapping method (with n= 5000 bootstrap resamples) recommended by Preacher and Hayes (2008). The results of the Sobel tests provide significant evidence of the existence of an indirect effect (as the Sobel Z is significant: Z>1.96) for all models, except for the partial mediation effect of R&D education in the relationship between APD and incremental innovation performance in low-tech industries (Table 4). Bias-corrected at 95% CIs were calculated (Efron, 1987) and point estimates of indirect effects were considered significant if zero was not contained in the confidence interval. The bootstraping method reveals that the

mediating effect is significantly different from zero at p<0.5, confirming a partial mediation effect of R&D education and skills between APD and firm innovation performance except for the effect of R&D education in the relationship between APD and incremental innovation performance in low-tech industries (Table 4).

4.3. Robustness tests and alternative models

To further validate the results and test their consistency, several robustness checks have been performed and alternative specifications are explored. 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 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' between 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.

Table 2. Random-effects Tobit models for radical innovation performance

	High-tech Industries				Low-tech Industries				z-test
	Model 1.1 Radical innovation	Model 1.2 R&D education	Model 1.3 R&D skills	Model 1.4 Radical innovation	Model 1.1 Radical innovation	Model 1.2 R&D education	Model 1.3 R&D skills	Model 1.4 Radical innovation	
Direct effects									
APD	5.803*** (0.774)	3.883*** (0.432)	4.529*** (0.476)	4.985*** (0.763)	9.833*** (1.037)	9.837*** (0.817)	11.616*** (0.929)	7.918*** (0.984)	4.030*** (1.294)
H1. APD^2	-5.763*** (1.581)	-4.946*** (0.829)	-5.823*** (0.901)	-4.811** (1.526)	-11.948*** (2.484)	-14.465*** (2.163)	-17.223*** (2.519)	-9.225*** (2.289)	6.185** (2.944)
H2. N. Partner Types at Tipping Point	17.028*** (0.503)			-	15.395*** (0.49)				1.633** (0.702)
Mediating effects									
H3. R&D education				0.003* (0.001)				0.005** (0.002)	0.002 (0.002)
H4. R&D Skills				0.013*** (0.001)				0.015*** (0.001)	0.002** (0.001)
Controls									
R&D intensity	0.662** (0.270)	1.222*** (0.237)	1.237*** (0.252)	0.391 (0.233)	0.634* (0.224)	1.882*** (0.416)	2.158*** (0.494)	0.275 (0.218)	0.028 (0.351)
Export intensity	0.515** (0.173)	0.425*** (0.105)	0.363*** (0.113)	0.420* (0.170)	0.398 (0.224)	0.377** (0.154)	0.554*** (0.173)	0.286 (0.219)	0.117 (0.283)
Alliance experience	0.411*** (0.077)	0.197*** (0.043)	0.219*** (0.048)	0.376*** (0.076)	0.493*** (0.087)	0.376*** (0.055)	0.435*** (0.063)	0.426*** (0.086)	0.082 (0.116)
Firm size (Ln)	0.354* (0.167)	1.496*** (0.131)	1.527*** (0.138)	0.136 (0.162)	0.905*** (0.192)	2.271*** (0.190)	2.598*** (0.202)	0.543** (0.182)	0.551** (0.254)
Firm size Sq	-0.022 (0.019)	-0.119*** (0.015)	-0.129*** (0.016)	-0.005 (0.018)	-0.072*** (0.022)	-0.183*** (0.021)	-0.233*** (0.023)	-0.043* (0.021)	0.050* (0.029)
Log Likelihood	-19011.48	-24126.86	-25713.13	-18883.57	-18533.55	-24958.41	-27495.72	-18357.55	

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. Random-effects Tobit models for incremental innovation performance

	High-tech Industries				Low-tech Industries				z-test
	Model 2.1 Incremental innovation	Model 2.2 R&D education	Model 2.3 R&D skills	Model 2.4 Incremental innovation	Model 2.1 Incremental innovation	Model 2.2 R&D education	Model 2.3 R&D skills	Model 2.4 Incremental innovation	
Main effects									
APD	5.346*** (0.884)	3.883*** (0.432)	4.529*** (0.476)	4.127*** (0.881)	11.971*** (1.425)	9.837*** (0.817)	11.616*** (0.929)	9.076*** (1.347)	6.625*** (1.677)
H1. APD^2	-5.599*** (1.612)	-4.946*** (0.829)	-5.823*** (0.901)	-4.209* (1.833)	-13.992*** (3.223)	-14.465*** (2.163)	-17.223*** (2.519)	-9.928** (2.896)	8.393** (3.604)
H2. N. of Partner at Tipping Point	16.58*** (1.70)				15.697*** (1.110)				0.883 (2.030)
Mediating effects									
H3.a. R&D education				0.003* (0.001)				0.001 (0.003)	0.002 (0.003)
H3.b. R&D Skills				0.018*** (0.001)				0.024*** (0.002)	0.006*** (0.002)
Controls									
R&D intensity	-0.142 (0.220)	1.222*** (0.237)	1.237*** (0.252)	-0.578** (0.181)	1.001*** (0.252)	1.882*** (0.416)	2.158*** (0.494)	0.469* (0.211)	1.143*** (0.335)
Export intensity	0.145 (0.208)	0.425*** (0.105)	0.363*** (0.113)	0.005 (0.186)	-0.015 (0.338)	0.377** (0.154)	0.554*** (0.173)	-0.188 (0.327)	0.160 (0.397)
Alliance experience	0.446*** (0.089)	0.197*** (0.043)	0.219*** (0.048)	0.387*** (0.090)	0.773*** (0.124)	0.376*** (0.055)	0.435*** (0.063)	0.681*** (0.122)	0.327** (0.153)
Firm size (Ln)	1.363*** (0.197)	1.496*** (0.131)	1.527*** (0.138)	1.051*** (0.165)	2.418*** (0.287)	2.271*** (0.190)	2.598*** (0.202)	1.947*** (0.273)	1.055*** (0.348)
Firm size Sq	-0.119*** (0.022)	-0.119*** (0.015)	-0.129*** (0.016)	-0.094*** (0.019)	-0.221*** (0.034)	-0.183*** (0.021)	-0.233*** (0.023)	-0.182*** (0.032)	0.102*** (0.040)
Log Likelihood	-22776.65	-24126.86	-25713.13	-22599.79	-24248.45	-24958.41	-27495.72	-24080.25	

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 4. Test of Mediation

| | **Mediator**: R&D education | | | | | |
| | **High-Tech Industry** | | | **Low-Tech Industry** | | |
	Sobel test	LL95%CI	UL95%CI	Sobel test	LL95%CI	UL95%CI
Radical innovation	2.88**	0.010	0.047	3.46***	0.016	0.053
Incremental innovation	2.96**	0.010	0.048	0.83	-0.011	0.028
	Mediator: R&D skills					
	High-Tech Industry			**Low-Tech Industry**		
	Sobel test	LL95%CI	UL95%CI	Sobel test	LL95%CI	UL95%CI
Radical innovation	4.38***	0.026	0.062	9.75***	0.085	0.110
Incremental innovation	8.07***	0.075	0.087	7.58***	0.070	0.082

LL=lower level; UL: upper level. Number of re-samples for bias corrected bootstrap intervals=5,000

significance at 5%;*significance at 10%.

5. Discussion and Conclusions

Our aim in this research has been to add to our understanding of the relationship between APD and firm innovation performance. Specifically, it aims to contribute to the literature by focusing on the differential effects of APD on innovation outcomes depending on the novelty of innovation and industry, and the intermediary role of human capital as a source of influence on firm innovation performance. APD has attracted significant interest among organisations and policy makers as collaboration becomes a key vector of innovation-related knowledge flows (OECD, 2010). In line with previous work (de Leeuw et al., 2014, Lin, 2014), our results show a positive, curvilinear association between APD and firm innovation performance, which implies that exists an optimal level of partner diversity and that the marginal returns to APD increase at a diminishing rate and then become negative beyond the optimal level. Openness towards external knowledge sources enables firms to access diverse markets and technological knowledge (Lin, 2014); however too much partner diversity beyond the optimal point could lead to high management and integration costs, negatively affecting as a result the transfer of external knowledge by firms into their innovation processes (Katila and Ahuja, 2002, Laursen and Salter, 2006). Thereby, being too specialised or too diversified does not result in better innovation performance.

However, significant differences are found in the optimal level of APD depending on the industry's technological intensity (high vs low) and the novelty of innovations (radical vs incremental). Our findings indicate that high-tech industries, characterised

by rapid technological changes, require a broader set of external partners to maximise radical innovation performance than low-tech industries. Interestingly, we did not find significant industry differences for incremental innovation performance.

Two important conclusions can be drawn for these findings. First, our results corroborate the view that high-tech industries need a broad business ecosystem to remain competitive in their rapidly changing business environment (Ili et al., 2010, George et al., 2001). Second, both sectors require similar partner diversity to maximise incremental innovation performance, thus emphasising the effect of partner diversity in high-tech industries to achieve explorative performance objectives (van Beers and Zand, 2014).

Indirect effects indicate a partial mediation of R&D specific human capital on the relationship between APD and radical and incremental innovation performance (Hypothesis 4). These findings support previous work concerning the importance of R&D skills to assimilate and integrate external knowledge into internal innovation activities (Teirlinck and Spithoven, 2013, Huang et al., 2015). Further, specific human capital may give firms an advantage as these skills are not easy transferable (Grant, 1996). Similarly, we find a partial mediation of R&D general human capital, except for incremental innovation performance in low-tech industries, suggesting that top educated employees are less important in exploitation activities. Taken together, these results suggest that top educated and highly skilled R&D staff, by enabling internal capabilities, act as a facilitating mechanism to explore and deploy external knowledge flows successfully. 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).

Regarding industry differences, the mediating effect of human capital is particularly significant in low-tech industries where the impact of APD on innovation performance is reduced in magnitude (absolute terms) and significance, except for R&D education in low-tech incremental innovation performance were partial mediation was not confirmed. These findings support the view regarding the complementarity between internal R&D and external knowledge flows (Grimpe and Kaiser, 2010, Mol, 2005,

Veugelers, 1997) and the need to invest in in-house R&D to benefit from external ideas and technology. Low-tech industries generally possess limited internal capacity and recourses to take advantage from highly diverse alliance portfolios (Spithoven et al., 2011). Hence, reflecting on the cumulative nature of knowledge, investing in R&D specific and general human capital would enable low-tech sectors to capture value from more open sourcing strategies.

5.1. Contributions and managerial implications

Several managerial implications follow from this discussion and should be of interest to managers. First, this study contributes to a better understanding of alliance portfolios and their potential effect on value creation. Results indicate that managers should configure their alliance portfolios in terms of the type of innovation they seek to develop. High-tech industries require a more diverse business ecosystem to maximize radical innovation performance compared to incremental innovation. In contrast, low-tech industries, due to a more limited absorptive capacity, exhibit similar partner diversity for both innovation outcomes. However, being too specialised or too diversified might be detrimental to innovation performance. Therefore, managers should carefully design alliance portfolios to counterbalance the two governing forces in order to extract value from diverse business ecosystems, particularly if resources are limited (Lin, 2014).

The second implication of our study centres on the role of R&D human capital as a pathway to capture value from partner diversity. Our findings highlight the need to invest in internal research capabilities by upskilling and training R&D staff to harness external knowledge assets (Lin, 2014, Muscio, 2007). Absorptive capacity results from a prolonged process of investment and knowledge accumulation (Chen, 2004). By investing in the development and acquisition of new skills, R&D employees would more effectively absorb and deploy local or distant knowledge relevant to future innovation (Huang et al., 2015).

Our focus on manufacturing firms offers an important contribution to the open innovation literature, as we demonstrate how 'general' and 'specific' human capital

can maximize partner diversity to ensure sustainable competitive advantage through increased innovative performance. Managing partner diversity is especially important for high-tech firms, which require a wider knowledge base to remain competitive in their complex and dynamic business environments. These industries strongly require specific knowledge and skills to ensure cross-fertilization and combination of new streams of knowledge (Covin et al., 1990).

Finally, our findings suggest why firms differ in their internal ability to capture value from diverse alliance portfolios. R&D education and skills act as an internal mechanism to capture value from more open sourcing strategies. Therefore, managers should develop high internal capabilities to integrate external knowledge beyond established industry boundaries and enhance potential absorptive capacity for future knowledge transfer and knowledge sharing (Enkel and Heil, 2014). Organisations should consider their external relationships structure as a capability enhancing process (Xia, 2013) that will allow their employees to develop broader skills in the future. This is particularly relevant for low-tech firms, which are constrained in their ability to collaborate with highly diverse alliance portfolios due to their limited absorptive capabilities. Hence, we argue that this needs to be reflected in a firm's investments in absorptive capacity. External collaboration does not substitute lacking or insufficient internal innovation capabilities; rather it increases complexity for firms (Lin et al., 2012). Thus, dealing with increasing complexity requires building stronger internal capabilities.

Human resources practices (HRM), including staffing, performance management and rewards, can play a key role in supporting organisations' outsourcing strategy (López Cabrales et al., 2011). Staffing practices must be directed to the creation of human capital with the orientation changing depending on the necessity of general and/or specific training (Matusik and Hill, 1998). Hence, careful selection of staff, high investment in training and broad developmental plans can be specified towards the development of R&D general and specific human capital to harness external knowledge assets.

Alliances should be view as a portfolio (George et al., 2001) requiring the development of different internal capabilities depending on the portfolio characteristics (Rothaermel

and Deeds, 2006). Further, appraisals and rewards also serve as a mechanism to maintain and develop human capital attributes that are valuable and unique (Prendergast, 1993), particularly more firm-specific human capital. Companies could develop a path of upwards mobility across jobs so R&D staff can start accumulating firm-specific human capital even when they are in jobs that require more general human capital (Slaughter et al., 2007). Teamwork is also viewed as a powerful tool to help integrate new knowledge assets within internal processes that can subsequently be applied to different situations, supporting organisations' continuous strategic renewal (Forés and Camisón, 2016).

5.2. Limitations and future research

We acknowledge several limitations in our paper and suggest related opportunities for future research. First, the focus of this study is specifically on firms' internal capabilities embodied in their educated and skilled human resources 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 programs and developmental plans, usually linked to higher adaptability, flexibility and competitive advantage (Cabrera and Cabrera, 2005). Second, our study includes a single APD measure combining partner type and geographical location. A more reliable way of assessing the impact of partner diversity on explorative and exploitative outcomes would be to operationalise APD as a multidimensional construct, as studies show differential impacts on innovation performance (Wassmer, 2010). Third, an alternative approach to the diversity score would have been to consider the number of inter-organisational ties with each partner. Unfortunately, PITEC data does not capture this level of information nor distinguishes 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, such as education, skills and training on innovation performance might help to develop more general empirical evidence in future research direction.

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Appendix 1 - Table A.1. Variables' Description

Variables	Type	Definitions
Dependent Variables		
Radical Innovation	Continuous	Percentage of the firm´s sales from products new to the market in the last 2 years
Incremental Innovation	Continuous	Percentage of the firm´s sales from products new to the firm in the last 2 years
Independent Variables		
APD	Continuous	Alliance Portfolio Diversity
ADP^2	Continuous	Alliance Portfolio Diversity squared
Moderator variables		
R&D education	Continuous	Percentage of R&D staff with third level education or higher
R&D Skills	Continuous	Percentage of R&D top skilled workers
Control variables		
Firm Size	Continuous	Number of employees (Ln)
Firm SizeSq	Continuous	Number of employees (Ln) squared
Alliance experience	Binary	Firm's prior experience in external collaboration
R&D intensity	Continuous	R&D expenditure as a proportion of total sales
Export intensity	Continuous	Ratio of export sales to total sales
Industry	Binary	Dummy variables indicating the sector where the firm operates
Year	Binary	Dummy variables indicating the year to which observations belong to (2005-2012)