International Journal of Innovation Management
Vol. 21, No. 1 (2017) 1750001 (24 pages)

DOI: 10.1142/S1363919617500013

THE EFFECTS OF ALLIANCE PORTFOLIO DIVERSITY ON INNOVATION PERFORMANCE: A STUDY OF PARTNER AND ALLIANCE CHARACTERISTICS IN THE BIO-PHARMACEUTICAL INDUSTRY

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Published 9 May 2016

This study investigates the effects of alliance portfolio diversity on the innovation performance of firms. Alliance portfolio diversity is defined using partner characteristics (partner industrial background) and alliance characteristics (alliance objective). We also investigate the interaction between these two measures of diversity on innovation performance. The hypotheses are tested on a dataset of R&D alliances in the US biopharmaceutical industry from 1998–2002. We find an inverted U-shape relationship between the diversity of alliance partners' industrial background and innovation performance, and a negative interaction of partner diversity and the diversity of the alliance objectives. This study contributes to the growing field of alliance portfolio diversity research by introducing a new alliance characteristic-based dimension of diversity and testing the interaction of different diversities. Our findings imply that firms with diverse alliance partners in particular need to be careful not to focus on too many objectives at the same time.

Keywords: Alliance portfolio diversity; innovation performance; partner diversity; alliance objective.

Introduction

In today's high-tech industries, changing technological paradigms create an uncertain environment that forces firms to continually innovate. To overcome the limitations of internal R&D and to acquire technologies and knowledge from outside sources are increasingly utilizing strategic alliances (Hagedoorn, 1993; Mowery *et al.*, 1996). Often a single partner cannot provide all the required inputs and firms pursue more than one alliance at the same time, giving rise to the concept of alliance portfolios (Lavie, 2007). The increased importance of alliance portfolios resulted in research focusing on issues such as interactions between the individual alliances and the management of the portfolio (George *et al.*, 2001; Parise and Casher, 2003; Wassmer, 2010). Within the alliance portfolio focused research, in recent years the concept of alliance portfolio diversity has been given increasing attention. Research has begun to investigate the origins and determinants of diverse alliance portfolios (e.g., Collins, 2013; Duysters and Lokshin, 2011; Golonka, 2015) and how they affect the performance of firms (e.g., De Leeuw *et al.*, 2014; Faems *et al.*, 2010; Van de Vrande, 2013). Prior literature on the link between alliance portfolio diversity and firm performance has dealt with different definitions of diversity but for the most part focused on characteristics of the alliance partners when defining alliance portfolio diversity. We follow prior studies in investigating the effect of alliance partner diversity on firm performance. As firms do not only decide who to partner with, but also what the actual objective and focus area of the alliance is, we move beyond the partner-based definitions and introduce a new alliance portfolio diversity measure, based on the objective of the alliances in the portfolio. Previous literature has identified several factors that can moderate the relationship between alliance portfolio diversity and firm performance. Recently Bengtsson *et al.* (2015) demonstrated the influence of the collaborations' explorative or exploitative knowledge content on the relationship between partner diversity and innovation performance. However, literature has not yet given much consideration to the interactions between different dimensions of alliance portfolio diversity itself. This research hypothesizes and tests the effects of alliance portfolios which are diverse in two different dimensions, i.e., consist of alliances with diverse objectives which are conducted with diverse partners.

The hypotheses of this study are tested on a dataset of biopharmaceutical companies. The results of this empirical analysis confirm an inverted U-shape relationship between alliance partner diversity and innovation performance. They also confirm a negative interaction effect of alliance partner diversity and alliance objective diversity on innovation performance. This study contributes to strategic alliance literature by expanding the research on alliance portfolio diversity based on alliance characteristics by investigating the effects of diversity of the alliance objectives on innovation performance. Unlike previous studies (e.g., Jiang *et al.*, 2010), which compare the effects of different dimensions of alliance portfolio diversity on innovation performance, this research studies the interaction between two of those dimensions, partner industrial background and alliance objectives.

The remainder of this paper is organized as follows: First, we discuss the relevant literature and develop hypotheses which link alliance portfolio diversity, defined by either partner or alliance characteristics, with the firm's innovation performance. We also propose an interaction of the diversity of alliance partners and the diversity of the alliance objectives. Second, we test our hypotheses using a dataset of US firms in the biopharmaceutical industry. Finally, we present our empirical results and conclude with a discussion of implications, limitations, and directions for future research.

Literature

Within the diverse field of literature on strategic alliances, in recent years, a number of studies have focused on the diversity of the alliance portfolio and more specifically, on the relationship between alliance portfolio diversity and firm performance. Many of the studies found an inverted U-shape relationship between alliance portfolio diversity and firm performance (e.g., De Leeuw *et al.*, 2014; Duysters *et al.*, 2012; Jiang *et al.*, 2010; Oerlemans *et al.*, 2013). A recurring finding is that at lower levels of alliance portfolio diversity, positive effects are limited due to the similar resources provided. Too high levels of diversity, on the other hand, increase transaction costs and reduce the benefits of the access to the more diverse knowledge (Oerlemans *et al.*, 2013).

Previous studies have defined alliance portfolio diversity in a variety of ways, which fall into two broad categories: those based on the characteristics of the alliance partners, and those based on the characteristics of the alliance deal itself. One example for a measure based on the diversity of partners' characteristics is the diversity of the partners' technological resources. Srivastava and Gnyawali (2011) as well as Vasudeva and Anand (2011) defined alliance portfolio diversity using a Herfindahl-based measure on the distribution of the partner firms' patents in distinct technological categories based on patent classes. De Leeuw *et al.* (2014); Laursen and Salter (2006), Faems *et al.* (2010), and Oerlemans *et al.* (2013) employed a measure based on the diversity of the type of alliance partners. Common partner types found in these studies are suppliers, competitors, universities, and research institutes. Aloini *et al.* (2015) used a multi-dimensional construct which combines the diversity of the alliance partners with the capabilities they provide in the collaboration, and the number of different phases of the innovation process affected by the collaboration. Jiang *et al.* (2010) based their measure on the partners' industrial background. It is based on the number of shared digits of the focal firm's and partner firms' Standard Industrial Classification (SIC) codes. They further introduced a measure based on the number of foreign countries in the national background of partner firms. Bruyaka and Durand (2012) defined the diversity of the alliance portfolio in terms of partners' position along the value chain. The research considers three distinct relationships: upstream, downstream, and horizontal.

On the other hand, diversity measures solely based on alliance characteristics include the diversity of the mode of governance and the functional diversity of the alliance portfolio. Jiang *et al.* (2010) defined the mode of governance using six categories ranging from non-equity to dominant equity share. To calculate the functional diversity, they considered four different types of alliances: marketing, manufacturing, R&D, and others. Van de Vrande (2013) defined the diversity of technology sourcing portfolios by defining five categories of sourcing partnerships including CVC, alliances, and joint ventures.

Previous research has empirically tested the effects of alliance portfolio diversity on various dimensions of firm performance. Owing to the focus on high-tech industries and R&D-driven alliances, most studies have focused on the innovation performance of the firm. Faems *et al.* (2010), De Leeuw *et al.* (2014), and Oerlemans *et al.* (2013), whose studies were based on Community Innovation Survey data, focused on product innovation performance, defined as the percentage of turnover generated by new or technologically improved products. Sampson (2007), Van de Vrande (2013), and Vasudeva and Anand (2011) focused on the patenting performance of the firm. All three studies employed measures that simultaneously capture the number as well as the impact of the patents. Also focusing on patenting performance, Srivastava and Gnyawali (2011) based their innovation performance measure on the firms' rate of breakthrough innovation, i.e., the number of highly cited or impactful patents. Other than innovation performance, studies have also investigated the effects of alliance portfolio diversity on general alliance success, financial performance or firm exit: Duysters *et al.* (2012) employed a survey-based indicator on subjective alliance success; Jiang *et al.* (2010) focused on the three year average of the firms' net profit margin, and Bruyaka and Durand (2012) dependent variable is based on firm exit, i.e., whether a firm sells off or shuts down.

The relationship between various definitions of alliance portfolio diversity and the performance of the firm has been investigated using datasets from a diverse range of knowledge-intensive industries including semiconductors (Srivastava and, Gnyawali, 2011), fuel cell technology (Vasudeva and Anand, 2011), telecommunication equipment (Sampson, 2007), pharmaceuticals (Van de Vrande, 2013), biotechnology (Bruyaka and Durand, 2012), and automobile (Jiang *et al.*, 2010). A number of studies have tested their hypotheses on multi-industry datasets (e.g., (Duysters *et al.*, 2012; Faems *et al.*, 2010).

Theory and Hypotheses

Firms are forming alliances with their partners for various reasons such as to share risks, or quickly move into new markets. Among the motivations for alliances, the access to resources provided by the partners (Eisenhardt and Schoonhoven, 1996) is a key factor. The resources provided are not limited to physical resources but also include knowledge, routines, and the partners' experience. The exact nature of the resources provided depends on the partner, as different firms often possess different resources. This is especially the case when the partner firms belong to different industries which have distinct knowledge bases. When investigating the diversity of an alliance portfolio, following a resource-based perspective, the diversity of the resources provided presents itself as a logical starting point of investigation. While some research has investigated the diversity of the resources offered by the partners in the alliance portfolio by looking into the patents held by these firms (Srivastava and Gnyawali, 2011; Vasudeva and Anand, 2011), another approach is to look at the diversity of the partners' industrial background. As firms in the same industry are likely to possess similar resources, routines, knowledge, and backgrounds, partners' industrial diversity is a useful proxy for the resources these partners can provide to the focal firm. Consequently, this research will also investigate the effects of alliance portfolio diversity, defined as the diversity of the partners' industrial background, on the innovation performance of the firm.

The resources available through the partners are a valuable dimension of alliance portfolio diversity and in fact are one of the most common definitions used in alliance portfolio research. However, alliance portfolio diversity cannot just be defined based on the characteristics of the partners, but, less commonly used in prior literature, also can be based on characteristics of the alliance deals. When firms make the decision to enter into an alliance, they make a number of decisions. One is whom to partner with; the results of this decision are captured by investigating the diversity of the alliance portfolio in terms of partner characteristics such as industrial background. Another decision is the objective of the alliance. In which field should the alliance activities take place? The background of the alliance, which denotes objective and the knowledge background of the alliance deal has been previously studied on a dyadic level in the study of Wen and Chuang (2010). While investigating alliance governance-mode choices in strategic alliances, they considered different combinations of knowledge of the two alliance partners and the alliance itself. Knowledge background was defined as the SIC code of the partner firms and the alliance and possible combinations included co-exploration (when the alliance activity was in a field different from the industrial background of the partners), co-exploitation (when both the alliance partners and the alliance itself were assigned the same SIC code), and learning/teaching (when only one of the two firms shared the SIC code of the alliance). With the research focusing on the alliance portfolio level, this study also investigates the industrial classification of the alliance as a key variable. However, similar to the partner characteristics on the alliance portfolio level, this characteristic becomes a diversity measure. Analog to the alliance portfolio diversity, which we define as the diversity of the partners' industrial background, we investigate alliance objective diversity, the diversity of the background of the alliance which hints at the objective and knowledge area of the alliances.

In this section, we will hypothesize the direct effects of two important alliance portfolio diversities: First, alliance portfolio diversity defined as the diversity of the industrial background of the alliance partners, and second, a diversity defined as the diversity of the alliances background. We will also look into the interaction between these different dimensions of diversity which is especially interesting as one is a partner-based characteristic, and the other is alliance-based.

Alliance portfolio diversity (partners' industrial background)

The resource-based view of the firm has long argued that resources form the basis for firms' competitive advantage (Peteraf, 1993; Wernerfelt, 1984). Further extensions to the view have acknowledged the fact that these resources are not just internal to the firm, but span organizational boundaries and firms enter into alliances to access the resources of their partners (Das and Teng, 2000; Dyer and Singh, 1998; Lavie, 2006). At low levels of APD, partners are very similar in background, which means they are likely to possess similar resources and knowledge. This increases the risk of redundancies of resources (Bruyaka and Durand, 2012) and limits learning. High levels of overlap have been shown to contribute little to the subsequent innovation of the firm (Ahuja and Katila, 2001). The correlation among the options in the portfolio is also known to reduce the value of the portfolio (Vassolo *et al.*, 2004). With increasing diversity of the partners in the alliance portfolio, the firm gains access to more diverse resources which it can employ in its innovation generating processes. The diverse resources improve the firm's ability to innovate through resource recombination (Carnabuci and Operti, 2013) by increasing the possibility of developing useful combinations of knowledge (Katila and Ahuja, 2002). Diverse resources in the alliance portfolio also strengthen the firm's strategic flexibility and allow it to better deal with uncertainties in its environment (Hoffmann, 2007).

While an increasing diversity of the partners offers possibilities for innovation, it also brings about negative effects. These will require the firm to invest more of its valuable resources and prevent it from taking full advantage of the diverse portfolio. The issues related to high levels of diversity can be broadly classified into two major categories: issues resulting from increased transaction costs and issues resulting from attention allocation. Dealing with a more diverse set of alliance partners increases the potential for conflicts and increases the complexity of coordinating the alliances in the portfolio, leading to an increase in managerial costs (Jiang *et al.*, 2010). Trust issues and lack of understanding of the partners will further increase monitoring costs (Goerzen and Beamish, 2005). In terms of attention allocation, Koput (1997) summarizes some of the problems that occur when the firm tries to process strongly diversified knowledge. The main difficulty is to identify useful knowledge, which can further be made more difficult due to too many ideas to process and ideas arriving at the wrong time and place.

In summary, alliance partner diversity positively contributes to the firm's innovation performance by enabling access to the resources of a diverse range of partners. As the partner's diversity increases, so does the diversity of the resources and knowledge held by them. Innovation requires constant new inputs to create novel combinations of different knowledge elements. On the other hand, dealing with more diverse partners places a burden on the firm and increases transaction costs due to more complex monitoring. At the same time, the firm reaches the limits of its ability to acquire, process and use vast amounts of diverse knowledge, preventing it from taking full advantage of the diversity. These positive and negative effects of increasing alliance partner diversity lead us to the following hypothesis:

Hypothesis 1: *Alliance Portfolio Diversity* (*diversity of alliance partners' industrial backgrounds*) *has an inverted U-shape relationship with innovation performance.*

Alliance portfolio diversity (alliance objectives)

Besides the diversity of the partners' industrial background, the effects of alliance objective diversity, i.e., the dimension of alliance portfolio diversity defined as the diversity of the alliance objectives and knowledge background, also is expected to affect the firm's innovation performance. The pursuit of a wider range of objectives provides more learning opportunities to the firm. This is due to the fact that innovation can be realized by bridging fields. Galunic and Rodan (1997: p. 13) refer to these "recombinations that take place between competence areas, through the interaction or exchange of the underlying (input and knowledge-based) resources". Kogut and Zander (1992) refer to innovation being the product of the firm's "combinative abilities", and see these capabilities resulting from both internal and external learning. Fleming (2001) has argued that increasing familiarity with the combinations of an invention increases the invention's usefulness. Being involved in more diverse alliances, i.e., forming alliances spanning more diverse fields, helps the firm to become more familiar with a wider range of technologies and combinations, further increasing their innovation performance.

On the other hand, firms have only limited capabilities and capacities to handle increasingly diverse bodies of knowledge (Cohendet and Llerena, 2009) and face problems being engaged in diverse alliances at the same time. Firms who try to cover too many objectives at once, i.e., have alliance portfolios with a high level of alliance portfolio diversity (objectives), will suffer from an information overflow and find it hard to allocate their attention (Koput, 1997).

In summary, we expect the diversity of the alliance objective to positively contribute to the firm's innovation performance as diverse alliance objectives allow for a greater recombinative potential. As the diversity increases, however, the firm suffers from increasing problems with attention allocation. The combination of these two effects leads us to the following hypothesis:

Hypothesis 2: *Alliance Portfolio Diversity* (*diversity of alliance objectives*) *has an inverted U-shape relationship with innovation performance.*

The interaction between partner and objective diversity

The alliance portfolio perspective advocates the understanding that the different alliances a firm is undertaking at the same time should not be viewed separate from each other. Rather than being stand-alone activities of the firm, there is an interaction between them. While firms may enter the individual alliances to pursue different objectives with different partners, knowledge and resources can be shared between the individual alliances in the portfolio (Khanna *et al.* 1998). Literature has stated that the ease of transferring knowledge and resources is closely related to the concept of absorptive capacity (Cohen and Levinthal, 1990). Absorptive capacity is increased when the knowledge and experiences overlap with each other. Consequently, firms will find it easier to transfer and share knowledge between alliances from similar fields, i.e., in an alliance portfolio with a low level of objective diversity. On the other hand, a high diversity of the alliance objectives, showing that the individual alliances in the firm's alliance portfolio focus on many different objectives, will decrease the absorptive capacity and impede knowledge sharing across alliances.

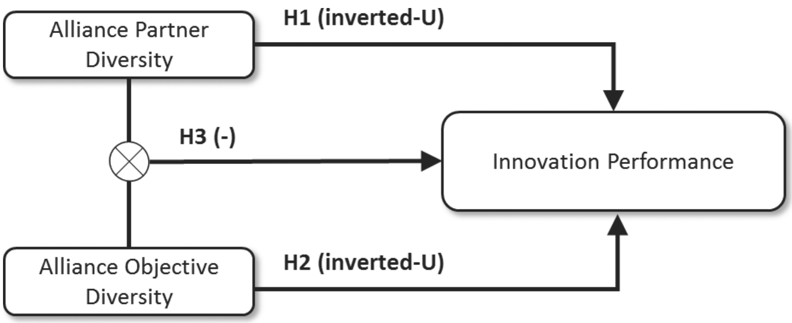

Fig. 1. Conceptual model.

The absorptive capacity argument also holds for resource diversity. An increasing level of resource diversity also lowers the absorptive capacity (Cohen and Levinthal, 1990; Cui and O'Connor, 2012; Sampson, 2007). Firms with a highly diverse alliance portfolio in terms of partners' industrial background already find it hard to transfer and benefit from the diverse resources offered by their partners due to increasing costs and complexities. If they simultaneously face a highly diversified alliance portfolio in terms of alliance objectives, the reduced levels of absorptive capacity will further impede their ability to transfer knowledge from partners and across alliances and will weaken their capabilities to innovate.

Another possible explanation is that a focus on a small number of areas, i.e., a small alliance portfolio diversity in terms of alliance objectives, could act as a filter for resources and information. Firms overwhelmed by the knowledge of their diverse partners can better select knowledge which corresponds to and fits with a smaller number of objectives. This filtering can reduce the problems associated with high levels of alliance portfolio diversity such as those resulting from knowledge overflow. The interaction of alliance portfolio diversity (partners) and alliance portfolio diversity (objectives) leads us to the following hypothesis:

Hypothesis 3: *The diversity of the alliance objectives negatively moderates the relationship between Alliance Portfolio Diversity* (*partner industrial background*) *and innovation performance.*

Methodology

Data and sample

For our empirical analysis we have compiled a dataset of US biopharmaceutical firms. The biopharmaceutical industry is knowledge-intensive and recognized for its high rate of alliance activity (Diestre and Rajagopalan, 2012; Hagedoorn, 1993;

Scillitoe *et al.*, 2015). Due to these characteristics, it has served as the setting for a number of previous studies on alliances (e.g., Rothaermel, 2001; Shakeri and Radfar, 2016; Xia and Roper, 2008; Zhang *et al.*, 2007) and alliance portfolios (e.g., Baum *et al.*, 2000; Caner *et al.*, 2015; Shan *et al.*, 1994; Vassolo *et al.*, 2004).

This study focuses on the time period from 1998 to 2002. This time period was chosen for two main reasons: First, owing to technological progress and the emergence of new dedicated biotech companies, the rate of R&D focused collaboration peaked during the late 1990s and early 2000s (Riccaboni and Moliterni, 2009). The selection of this period ensures a sufficient number of alliances in the sample to calculate the diversity of firms' alliance portfolios. Second, the chosen time period ends before the stagnation of growth experienced by the biopharmaceutical industry during the mid-2000s, until which the industry had averaged yearly sales growth rates of over 10% (Gassmann *et al.,* 2008).

In collecting the dataset used in this study, we adhered to the following procedure: First, we compiled the alliance portfolios of US biopharmaceutical firms using the alliance data available from the Thomson Reuters SDC Platinum database. In this study, biopharmaceutical firms are those with an assigned SIC code of 283. Following the established time frame of this study, we collected information on alliances formed between 1998 and 2002. Focusing on R&D alliances, we excluded all alliances whose Activity Code and Activity Description section, i.e., the section which describes the general purpose of the alliance, did not contain any mention of research and development. This limited the final selection to pure R&D alliances as well as multi-purpose alliances with an R&D element, e.g., manufacturing and R&D alliances. Further information about the focal firms, such as firm size or R&D expenditures were collected from the Compustat North America database. To assess the innovation performance of the firms, for which we employ a patent-based indicator, as well as for the construction of some of the control variables, we collected information on the patents granted to the focal firms from the database of the US Patent and Trademark Office (USPTO). The use of US patent data also explains this study's focus on US biopharmaceutical companies, as non-US firms might patent their innovations in other countries first or at higher rates. A number of companies and related alliance deals had to be excluded from the final dataset for a number of reasons: First, during the observation period financial and patent data for some, mostly small, target firms was unavailable. This concerned a number of small, mostly privately owned firms as well as some firms which were the target of some of the frequent mergers & acquisitions (M&As) in the biopharmaceutical industry. Second, alliance and patenting activities were in some cases carried out by subsidiaries of a firm. We follow the approach taken in previous studies (e.g., Kim and Inkpen, 2005; Van de Vrande, 2013) and consolidated the available patent and alliance data at the level of the parent corporation. The final dataset contains the information on 70 firms which conducted R&D-focused alliance deals during the observation period. While these numbers are low compared to sample sizes in alliance-related studies performed in other industrial settings, they fall well in line with previous research using datasets from the biopharmaceutical industry (e.g., Hoang and Rothaermel, 2005; Van de Vrande, 2013).

Measures

Dependent variable. The dependent variable of this study is the innovation performance of the firms. Previous literature has used patent count as a measure of innovation performance (e.g., Ahuja and Katila, 2001; Henderson and Cockburn, 1996; Penner-Hahn and Shaver, 2005). This method, however, has limitations as it treats all patents the same, while in reality the importance of individual patents can vary (Lanjouw *et al.*, 1998). Consequently, literature has found ways to compensate for these variations by including other measures such as the number of citations a patent received. The use of patent citations is a suitable approach as they have been shown to be correlated with technical importance (Albert *et al.*, 1991), value of the patent (Harhoff *et al.*, 1999) and firms' market value (Hall *et al.*, 2005). This study uses an approach based on a combination of the number of granted patents as well as the number of citations these patents received. Specifically, we use a measure based on the linear weighted patent count suggested by Trajtenberg (1990). The formula used to calculate the weighted patent count for each firm is shown below with n_j being the total number of granted patents applied for by firm j during the observation period and C_i the number of forward citations received by patent i.

$$\mathrm{WPC}_j = \sum_{i=1}^{n_j} (1 + C_i)$$

Following other literature which used a weighted patent count-based approach (Sampson, 2007), this study adopts a four-year difference between alliance and patent observation periods to account for the time it takes for the knowledge gained through alliances to become patented knowledge. This time lag is the result of the time it takes to transfer the knowledge, adapt and process it, and apply it to new innovation as well as the time it takes to prepare a patent for application. Patents applied for before the year 2002, thus, are unlikely to be the result of the firm's alliance activity during the observation period. Patents were collected for the 2002–2006 timeframe and citations were considered until the year 2010. This leads to a truncation of the citations received for especially the patents applied for late in the observation period. As patent citations are known to peak within the first three years (Mehta *et al.*, 2010), however, this effect can be neglected and longer observation periods for forward citations are not considered to be necessary (Lanjouw and Schankerman, 1999).

Independent variables. The independent variable, *Alliance portfolio diversity (partner),* is the diversity of the alliance partners' industrial backgrounds. The partners' industrial background is a good proxy for the resources, technology, routines, capabilities of the partners as firms in the same industry are likely to be able to offer similar resources to the focal firm (Wang and Zajac, 2007). Similar approaches of defining partner diversity using the SIC code have been used in a number of previous studies (e.g., Cui and O'Connor, 2012; Jiang *et al.*, 2010). To calculate the diversity of the alliance portfolio, we employ a measure based on the Herfindahl Index. Specifically:

$$\text{Alliance Portfolio Diversity} = 1 - \sum_i p_i^2$$

where p_i is the proportion of the alliance partners with a primary SIC code of i. The variable ranges from 0 to 1, with 0 showing that all alliance partners have the same industrial background, i.e., the same SIC code, and 1 showing that the partners are fully diverse with each partner firm belonging to a different industry.

The operationalization for the independent variable *Alliance portfolio diversity (objective)* followed a similar Herfindahl Index-based approach. It is based on diversity of the objectives of the alliances in a firm's alliance portfolio. The objective is indicated by the alliance main SIC code assigned by the experts at Thomson Reuters to each alliance in the SDC Platinum database.

Control variables. The empirical analysis includes five control variables: firm size, R&D intensity, patent stock, alliance experience, and number of alliances during the patent observation period. The size of a firm might be an indicator as to the amount of resources it can use to arrange alliances, manage them, and gain advantages which translate into an increased firm performance. We define *firm size* as the average amount of sales from 1998 to 2002 and, due to large inter-firm differences, have log-transformed the variable.

The firm's capabilities to perform in-house R&D can be expected to affect our results in two ways: First, increased R&D can directly lead to an improved innovation performance. Second, a firm's R&D capabilities are often seen as a proxy for the firm's absorptive capacity (Cohen and Levinthal, 1990) which influences the firm's ability to identify, transform and assimilate external knowledge from its alliance portfolio. We define *R&D intensity* as the average of the firm's R&D expenses in the 1998–2002 period divided by the average of sales during the same period. We also control for the firm's recent patenting activity, a proxy for experience and capabilities, that can be expected to affect the quality and quantity of subsequent patents. In this study, *Knowledge stock,* is defined as the number of patents applied for by the firm from 1998–2001.

As firms enter into more alliances, they increase their alliance related experience, which can help them to obtain better outcomes through improved alliance management. While some studies have defined alliance experience as being accumulated prior to the observation period (De Leeuw *et al.*, 2014; Sampson, 2007), this study joins others (Duysters *et al.*, 2012; Heimeriks, 2010) in focusing on the contemporary experience, i.e., experience obtained during the measurement period of the alliance portfolio diversity. Consequently, *Alliance experience* is defined as the number of alliances of each firm in the 1998–2002 timeframe. Finally, Sampson (2007) argues that the number of ongoing alliances is likely to affect the patenting activities of a firm. To control for this effect, we define *Alliance during observation period* as the number of alliances the focal firm is conducting during the patent observation period (2003–2006).

Method

The dependent variable of our study, *innovation performance*, is based on the concept of the weighted patent count and is a non-negative count variable. A closer look at its characteristics reveals that it suffers from over-dispersion, i.e., its variance is larger than its mean value. This leads us to adopting a negative binomial regression model (Barron, 1992).

Results

Table 1 shows a summary of the descriptive statistics and the correlations among the variables used in our study. Of interest is the correlation between the diversity of the alliance partners and the diversity of the alliance objectives (0.34), which shows that the decision about partnering with firms of a certain industrial background and the decision of the alliance objective are made quite independent of each other. It can also be seen that the highest levels of correlation are found between firm size and innovation performance as well as between knowledge stock and innovation performance. Larger firms who also have a larger knowledge stock, produce more and/or higher cited patents. To check for possible problems due to multicollinearity, we performed a variance inflation factor (VIF) test. The results of this test are shown in Table 2 and the low values (average of 1.74) indicate that this study does not have any problem with multicollinearity.

Table 3 contains the results of our regression analysis using the negative binomial regression model. Model 1 contains all the control variables used in our

Table 1. Descriptive statistics and correlation matrix.

Variables	Mean	SD	1	2	3	4	5	6	7	8
Firm size	5.53	3.01	1							
R&D intensity	1.32	2.14	−0.61	1						
Knowledge stock	157.27	228.79	0.63	−0.24	1					
Alliance experience	2.96	1.76	0.17	−0.06	0.40	1				
Alliance during obs period	4.8	7.73	0.50	−0.21	0.51	0.24	1			
Alliance portfolio diversity (partner)	0.48	0.25	0.37	−0.28	0.34	0.29	0.36	1		
Alliance portfolio diversity (objectives)	0.45	0.23	0.26	−0.22	0.23	0.26	0.17	0.34	1	
Innovation performance	819.03	1238.08	0.64	−0.28	0.70	0.36	0.54	0.34	0.17	1

study. Two of the control variables, *firm size* and *knowledge stock*, show consistently significant results, not just in Model 3, but in all the models. It shows that large firms in the biopharmaceutical industry produce more and/or more influential patents. The significance of knowledge stock, which is defined as the number of patent applied for by the firm between 1998 and 2001, shows that firms that had a high innovation output in that time period, also performed well in the patent observation period of 2002–2006. All other control variables did not show any significant results in any of the models.

Models 2 and 3 test Hypothesis 1, which predicts an inverted U-shape relationship between the diversity of the alliance partners' industrial background and the innovation performance of the firm. While the linear term is not significant in Model 2, in Model 3, which tests the predicted curvilinear relationship, both *alliance portfolio diversity (partner)* as well *as alliance portfolio diversity (partner) squared* are significant. The positive sign of *alliance portfolio diversity (partner)*

Table 2. VIF test results.

Variables	VIF
Firm size	2.90
R&D intensity	1.74
Knowledge stock	2.15
Alliance experience	1.30
Alliance during obs period	1.52
Alliance portfolio diversity (partner)	1.36
Alliance portfolio diversity (objective)	1.20
Average	1.74

Table 3. Negative binomial regression results six.

Depend variable:	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
Innovation performance	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
Control variables														
Firm size	0.3070***	0.0746	0.3040***	0.0744	0.2880***	0.0761	0.3220***	0.0719	0.3240***	0.0708	0.301***	0.0697	0.2870***	0.0697
R&D intensity	0.0652	0.0931	0.0684**	0.0924	0.0391	0.0913	0.0256	0.0914	0.0314	0.0915	−0.0140	0.0858	−0.0204	0.0863
Knowledge stock	0.0023**	0.0009	0.0022**	0.0009	0.0025**	0.0010	0.0023**	0.001	0.0024***	0.0009	0.0024***	0.0009	0.0025***	0.0009
Alliance experience	0.0572	0.0740	0.0510	0.0739	0.0569	0.0738	0.0924	0.0748	0.0979	0.0746	0.1100	0.0726	0.1050	0.0717
Alliances during obs. period	−0.0042	0.0235	−0.0067	0.0235	0.0097	0.0251	−0.0050	0.0225	−0.0065	0.0222	0.0092	0.0233	0.0092	0.0231
Independent variables														
Alliance portfolio diversity (partner)			0.4570	0.635	3.6240**	1.5890					4.6250***	1.5560	5.1320***	1.5670
Alliance portfolio diversity (partner) squared					−4.7500**	2.2290					−4.3110**	2.0880	−3.8490*	2.2340
Alliance portfolio diversity (objective)							−1.120*	0.5820	0.2420	1.6790			1.6780	1.5900
Alliance portfolio diversity (objective) squared									−2.0770	2.4030			−0.6470	2.6150
APD (partner) × APD (objective)											−3.2000***	1.1230	−5.3310**	2.4790
N	70		70		70		70		70		70		70	
Log likelihood	−490.334		−490.084		−487.923		−488.432		−488.069		−483.686		−482.840	
Pseudo R^2 [a]	0.0650		0.0654		0.0696		0.0686		0.0693		0.0776		0.0793	
LR Chi^2	68.14		68.64		72.97		71.95		72.67		81.44		83.13	

[a]McFadden's pseudo R-squared.

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

and the negative sign of *alliance portfolio diversity (partner) squared* show the inverted U-shape relationship, thereby confirming our Hypothesis 1.

Models 4 and 5 test Hypothesis 2, which predicts an inverted U-shape relationship between the diversity of the alliance objectives and the innovation performance of the firm. While the linear term *alliance portfolio diversity (objective)* shows a low level of significance in Model 4, both that and the quadratic term *alliance portfolio diversity (objective) squared* are insignificant in Model 5 as well as in the full Model 7. Summarizing the results for *alliance portfolio diversity (objective)* and *alliance portfolio diversity (objective) squared,* we find that that our Hypothesis 2 about a direct effect of alliance portfolio diversity defined in terms of alliance objective on the firms' innovation performance is not supported.

Model 6 tests our Hypothesis 3, which predicts a negative interaction of the alliance portfolio diversities based on partner and objectives on the innovation performance. As can be seen in Table 3, the coefficient for *APD (partner)* × *APD (objective)* is negative and significant in Model 6 as well as in Model 7. This

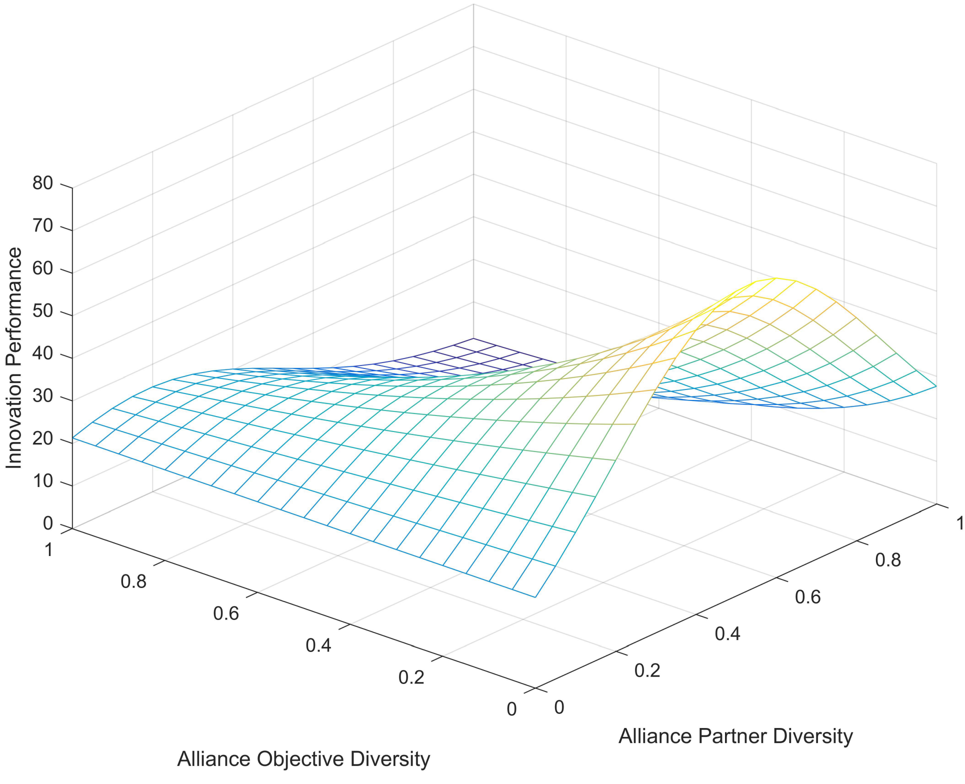

Fig. 2. The interaction of alliance portfolio diversity (partner) and alliance portfolio diversity (objective) on the innovation performance.

supports our Hypothesis 3. The interaction of alliance portfolio diversity and alliance objective diversity and their effect on innovation performance is plotted in the 3D-graph in Fig. 2. In this graph, one can clearly see the inverted U-shape relationship between alliance portfolio diversity and innovation performance as well as the negative effect of increasing alliance objective diversity.

Model 7 is the full Model which contains all the control variables and independent variables used in the empirical analysis. *Alliance portfolio diversity (partner)*, *alliance portfolio diversity (partner) squared*as well as the interaction term *APD (partner)* $\times$ *APD (objective)* show significance and the predicted direction of the effect, further lending support for our Hypotheses 1 and 3.

Discussion

This study investigates the effects of alliance portfolio diversity on firms' innovation performance. Specifically, focusing on various definitions of alliance portfolio diversity, we examined the effects of diversity in terms of alliance partners' industrial background and in terms of alliance objectives as well as the interaction between these two dimensions. Our hypotheses were tested on a sample of R&D focused alliances formed by US biopharmaceutical companies.

Our empirical results confirm that the alliance portfolio diversity, defined as the diversity of the partners' industrial background, has an inverted U-shape relationship with innovation performance. While increasing diversity first improves the innovation performance of the focal firm by providing access to a broader range of resources whose recombinations with each other and with the resources held by the focal firm can increase innovation output, firms are not able to profit as well from too high levels of diversity. At higher levels of diversity, the firms face increasing costs and complexities in managing the portfolio. Managers of alliance portfolios need to be aware of the relationship between alliance portfolio diversity and innovation performance. They should strive to find the optimal level of diversity that allows access to sufficiently diverse resources, but at the same time be careful not to increase diversity to the point where the firm is unable to handle the diverse partners. Unfortunately, due to firm heterogeneity, it is difficult to generalize how to achieve the optimal level of alliance portfolio diversity for individual firms. Wuyts (2014) suggests that 'managerial resources committed to portfolio management' and 'the presence of internal routines to deal with extramural knowledge' account for why some firms are able to gain more benefits from diverse alliance portfolios than other firms. Bahlmann *et al.* (2012), tackle this optimization issue by suggesting a 'core-crust' design which adjusts 'crust' alliances responding to changing market conditions and achieves the optimum level of portfolio diversity on top of suboptimal 'core' portfolio. To practically implement such a portfolio design, firms need to set up dedicated alliance functions and multi-alliance management roles which constantly monitor their whole alliance portfolios (Hoffmann, 2005). These specialized organizations and roles enable firms to secure relevant resources and routines for managing their alliance portfolios and timely control their portfolio diversity optimized for increasing performance.

Our research failed to confirm direct effects of the diversity of the alliance objectives, but confirmed the important interaction between alliance portfolio diversity and alliance objective diversity. Previous studies have focused on one dimension of diversity at a time, but have generally not considered interaction effects. Our study finds a significant negative interaction effect of alliance portfolio diversity in terms of partner background and in terms of alliance objectives. Together, high diversities significantly affect the innovation performance of the firm. The major implication of this finding is that managers need to be aware that not just partners can be diverse, but also diverse objectives of the alliances in the portfolio need to be considered. The negative interaction shows that especially firms who are already dealing with a highly diverse range of partners in their portfolio need to be careful not to pursue too diverse range of objectives at the same time. Both diverse partners and diverse alliance objectives lead to drastically reduced innovation performance. Firms with diverse partners should thus focus on a smaller number of objectives, i.e., ensure that the alliances pursue objectives in similar business fields.

This study contributes to the research on strategic alliances, especially the research focused on the effects of alliance portfolio diversity. Previous research has begun to investigate the effects of alliance portfolio diversity on firm performance in a variety of settings and has focused to a large part of describing the effects of partner characteristic-based diversities. Following this research, we have confirmed an inverted U-shape relationship between the partners' industrial background and the focal firm's innovation performance. Our research compliments the results of Jiang *et al.* (2010) who found a similar relationship between the industrial background of alliance partners and firms' financial performance in the automotive industry. Alliance decisions are, however, not limited to selecting partners, and the focus on the diversity of partner characteristics does not allow for a complete understanding of the effects of diversified alliance portfolios. We address this issue and contribute to the ongoing research by introducing a diversity measure based on the objective of the alliances in the portfolio, which we measure by employing the SIC code associated with each alliance. To our knowledge, our research is the first to investigate this alliance-based characteristic, which so far has been studied in the dyadic perspective of alliances, on the alliance portfolio level. We further extend previous research on the effects of alliance portfolio diversity by investigating the interaction between two different dimensions of alliance portfolio diversity, the diversity of the partners' industrial background and the diversity of the alliance objectives. Our findings demonstrate that focusing on a smaller number of objectives in an alliance portfolio can improve the innovation performance and that especially firms with a high diversity of alliance partners need to be careful of not engaging in a too diverse range of objectives at the same time as firms' capabilities to innovate are severely impeded when the diversity of both partners and objectives is high.

Limitations and Future Research

While providing important insights into effects of partner characteristic and alliance characteristic-based alliance portfolio diversity as well as their interaction, our study has some limitations, which we hope will be overcome by future research in this field. First, this study has defined alliance portfolio diversity using partner industrial background and the alliance's business field. Future research can further increase our understanding about the interaction between different diversities in terms of partner and alliance characteristics on firm performance by considering other definitions of alliance portfolio diversity, some of which have been studied, although in different contexts, in prior studies. Second, this study tests its hypotheses on a sample of R&D alliances formed by US firms from the biopharmaceutical industry. While this industry is known for its propensity to form alliances, studies using datasets from this industry usually have smaller datasets than studies in other industrial settings. Prior literature on the effects of alliance portfolio diversity on firm performance have been conducted using a wide range of industry datasets and we hope that future research will test the effects of alliance objective diversity as well as the effects of the interactions of different dimensions of diversity in alliance portfolios using also datasets from other industries to further increase the validity and impact of our findings. This study has focused on the effects of engaging in diverse activities with diverse partners, but did not consider to which extent the firms in the sample had prior knowledge and experience with the technologies and business fields covered by the alliance activities. However, research has indicated that familiarity with technologies and markets environments can influence the firm's performance and strategic decisions. (Roberts and Berry, 1984). Future research can take a more in-depth look at the detailed content of the alliance deals and contrast it with the knowledge and prior experiences of the focal firm. Last, this study has investigated the interaction of partner diversity and alliance objective diversity and found significant effects. We hope that future research will study this interaction using a wider range of theoretical lenses and empirical approaches.

Acknowledgements

We wish to thank the Managing Editor, Joe Tidd, and the anonymous reviewers for their helpful suggestions. The Institute of Engineering Research at Seoul National University provided research facilities for the duration of this research.

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