Innovation outcomes and partner-type selection in R&D alliances: The role of simultaneous diversification and sequential adaptation

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Abstract: This study focuses on how firms form and sequentially adapt their inter-organizational knowledge sourcing structures within research and development (R&D) alliances and how this process impacts their innovation performance. In contrast to the previous literature that mainly ignores the dynamic aspects of how firms adapt their search strategies, our approach accounts for sequential adaptation. Our proposed framework explores the role of simultaneous diversification and sequential adaptation of collaboration partners within R&D alliances according to specific innovation outcomes. The results emphasize that firms should not remain within the same search activities indefinitely, as non-adapting inter-organizational knowledge transfer structures lead to inferior performance. Notably, this study highlights important partner-type selectivity and identifies appropriate simultaneous diversification and sequential adaptation strategies in relation to specific innovation outcomes and firm sizes.

Keywords: Strategic alliances; organizational learning; sequential adaptation; simultaneous diversification; R&D collaboration; innovation strategy; innovation performance; radical innovation; incremental innovation.

1 Introduction

Today's highly competitive and rapidly changing market and technological environment challenge firms to effectively manage their innovation search activities. One of the strategies that firms undertake to respond to these challenges is to form strategic research and development (R&D) alliances with external partners to gain access to new technologies, complementary know-how and other additional resources (Gulati, Nohria, & Zaheer, 2000; Mowery, Oxley, & Silverman, 1996). The ways in which firms are able to manage these inter-organizational structures of knowledge exchange and technology transfer with external sources are crucial for the firms' innovativeness and long-term competiveness, and this type of management represents a key aspect of managerial decision making and organizational learning (Argote & Ingram, 2000; Teece, Pisano, & Shuen, 1997).

However, important issues remain: we must determine which structural patterns of R&D alliance partners are most appropriate to achieving specific innovation outcomes. Moreover, firms must decide how to organize the dynamic adaptation of collaboration partner types in R&D alliances. For instance, firms could maintain the same collaboration patterns to benefit from experience with the same partners, or they could adapt partners more frequently to be more dynamic, and therefore, able to react more quickly to changing market demands. These issues culminate in the focus of our study on how should firms simultaneous and sequentially select their collaboration partners in R&D alliances to meet specific objectives.

Despite the importance of these partner-type selection issues for firms' competitive advantage, surprisingly few studies have focused on their dynamic aspects (Bakker & Knoben, 2014; Belderbos, Carree, Lokshin, & Sastre, 2015; Katila & Ahuja, 2002). Even more surprisingly, little is known about the performance implications of the dynamic adaptation of R&D alliances. The objective of this paper is to fill this void by deriving a conceptual framework and empirically testing the role of simultaneous diversification and sequential adaptations of types of collaboration partners in R&D alliances to generate specific firm innovation outcomes, such as radical or incremental innovations. First, we focus on simultaneous patterns of inter-organizational collaboration, and our goal is to identify appropriate simultaneous diversification patterns of R&D partners to achieve specific firm innovation outcomes. Second, we focus on the sequential adaptation of R&D alliances and explore the effective sequential adaptation strategies of collaboration partner types to generate different innovation outcomes. A more profound understanding about which adaptation strategies are aligned to specific innovation outcomes is crucial for managers. This knowledge would increase managers' ability to effectively orient organizational resources along firms' innovation objectives of fostering either radical or incremental innovations. Finally, as the previous literature indicates that organizational learning is affected by the firm size, our conceptual framework accounts for different firm size classes (Arora, Belenzon, & Rios, 2014; Brunswicker & Vanhaverbeke, 2015; Patel & Pavitt, 1997; Zeng, Xie, & Tam, 2010).

By enlarging the understanding of how simultaneous and sequential selections of collaboration partner types are associated to innovation outcomes, our study contributes to the literature on organizational learning, innovation strategies, and open innovation (Arora et al., 2014; Chesbrough, 2003a; Levitt & March, 1988). Hence, this study operates at the crossroads of the organizational learning and strategic alliance literature by linking the impact of various structural alliance compositions to innovation performance implications. In particular, we contribute to the literature on R&D alliances and organizational learning by providing new insights about the performance implications of the dynamic adaptation of R&D partners in strategic alliances. These structures and mechanisms of dynamic inter-organizational knowledge exchanges and technology transfers within R&D alliances are still unclear and deserve further research (Bakker & Knoben, 2014; Dahlander & Gann, 2010; Easterby-Smith, Lyles, & Tsang, 2008; Kale & Singh, 2009; Laursen & Salter, 2014).

To extend the conceptual understanding of inter-organizational knowledge exchanges and technology transfers within R&D alliances, we introduce the concepts of simultaneous partner diversification and sequential partner adaptation. Our approach links these concepts to different innovation outcomes and examines whether certain simultaneous diversification and specific sequential adaptation strategies are associated with superior innovation outcomes. The previous literature has largely acknowledged the use of interfirm R&D alliances to integrate technology-based capabilities and other forms of knowledge from external collaboration partners such as suppliers, customers, competitors or science centers (Kogut, 1988; Mowery et al., 1996). However, there is a lack of understanding of how different compositions of alliance partners influence the opportunities to enhance the technological capabilities and innovation performance of firms. In particular, there is a void in the empirical research with respect to how technological opportunities of firms are affected by inter-organizational structures of knowledge exchanges. Part of this void can be attributed to the difficulties in measuring changes in the technological potential of a firm (Mowery et al., 1996). To advance the knowledge in this field, this study introduces a new measure that accounts for a change in the firm's opportunities for technological capabilities and relates this measure to more traditional indicators of innovation outcomes such as radical and incremental innovation performance (Beck, Lopes-Bento, & Schenker-Wicki, 2014; Meuer, Rupietta, & Backes-Gellner, 2015).

In our study, based on a sample of 2,087 Swiss firms for the period 1999-2013 and stemming from Community Innovation Survey (CIS) data, we find evidence of partner-type selectivity in R&D alliances in relation to specific innovation outcomes. In addition, our results highlight the importance of firms effectively adapting their inter-organizational knowledge structures according to both specific innovation outcomes and their own sizes. Based on our findings, we can draw important managerial implications, and by systemically acknowledging the dynamics within R&D alliances, our study enlarges the development of an innovation theory that accounts for the organizational dynamics in firms' innovation activities.

2 Theoretical background and conceptual framework

2.1 Inter-organizational learning in R&D alliances

Organizations face the challenge of finding solutions for technological problems in changing market and technological environments. In addition to the possibility of solving a problem with the current routines and practices, organizations can initiate learning and search processes by including external sources of knowledge (March & Simon, 1958; Nelson & Winter, 1982). Overall, firms have the ability to make (internal R&D), buy (external R&D) or organize (R&D collaboration) the necessary knowledge and technology (Arora et al., 2014). Finding an optimal interplay between internal and external searches represents a fundamental facet of innovation theory and constitutes a crucial managerial task (Koka & Prescott, 2008; Laursen & Salter, 2014; Levinthal & March, 1993; Li & Rowley, 2002; Parmigiani & Mitchell, 2009; Rivkin, 2000; Teece et al., 1997).

Given the increasing importance of openness in the innovation process, re-combinations of existing solutions to solve new technological problems form a crucial part of innovation and are often found outside the boundaries of the firm. Open innovation practices cannot only be found in small and medium-sized enterprises (SME) (Brunswicker & Vanhaverbeke, 2015; Cerchione, Esposito, & Spadaro, 2015; Hottenrott & Lopes-Bento, 2014; van de Vrande, de Jong, Vanhaverbeke, & de Rochemont, 2009; Zeng et al., 2010), though SMEs may be more exposed to the lack of internal complementarities of resources, capabilities and know-how; instead, those practices are also present in large firms. An example of the effectiveness of this integrated approach of external knowledge sourcing in large firms is the case of Roche Diagnostics (Birkinshaw & Crainer, 2009). To gather experience on whether Roche is able to effectively harvest ideas and solutions from external sources of knowledge, Roche conducted an experimental learning challenge in which it compared the results of an R&D research team composed by exclusively internal R&D workers to the pay-offs of an integrated external community of R&D workers. The findings showed that by drawing on a mix of knowledge derived from internal and external networks, Roche was able to overcome their traditional search routines and could create some brilliant and unexpected solutions to apparently intractable problems.

The previous literature highlights that joint R&D activities with external partners in R&D alliances constitute an important mechanism in the process of organizational learning to create, retain and transfer knowledge (Argote, 2011; Gulati et al., 2000). These inter-organizational structures of knowledge transfers with different types of partners increase the complementarities of existing knowledge within the firm and can constitute an essential source of competitive advantage and dynamic capabilities (Teece et al., 1997). Empirical studies confirm the positive effects of these complementarities between different types of partners on the innovation performance (Belderbos, Carree, & Lokshin, 2006). However, very little is known about the complementarities and congruencies between different external partners and how to match them according to different innovation objectives, such as radical or incremental innovation outcomes. According to Teece et al. (1997), this recognition is critical to understanding organizational learning.

As argued above, different complementarities between collaboration partners can lead to different innovation outcomes. Our approach explicitly relates specific compositions of R&D alliances to different types of innovation outcomes.[1] According to Raisch and Birkinshaw

[1] The previous literature emphasizes the existence of major heterogeneities in the motives and objectives for collaboration (Belderbos, Carree, Diederen, Lokshin, & Veugelers, 2004a; de Faria, Lima, & Santos, 2010; Kaiser, 2002; Tether, 2002). For instance, Belderbos, Carree, and Lokshin

(2008), a central aspect in the organizational literature regarding technological innovation is the distinction between incremental and radical innovation (Abernathy & Clark, 1985; Atuahene-Gima, 2005; Dewar & Dutton, 1986; Garcia & Calantone, 2002; Tushman & Anderson, 1986). Incremental innovations represent significant but relatively minor improvements or adaptations of existing products or business concepts. In contrast, radical innovations, as stated by Raisch and Birkinshaw (2008), "refer to fundamental changes leading to a switch from existing products or concepts to completely new ones."[2] Further studies have noted that organizations often pursue both types of innovations. Scholars assume that effectively balancing both types of innovations can enhance dynamic capabilities and provide additional competitive advantage (Ancona, Goodman, Lawrence, & Tushman, 2001; Colbert, 2004). However, there are various organizational tensions (such as the "capability-rigidity paradox") to finding an appropriate balance between different innovation objectives (Atuahene-Gima, 2005; Brown & Eisenhardt, 1997) and the interrelationships between internal and external knowledge sourcing processes (Cohen & Levinthal, 1990; Kogut & Zander, 1992; Lin, Yang, & Demirkan, 2007; Raisch et al., 2009). The present approach builds and extends the previous theory regarding the performance implications of inter-organizational structures of knowledge exchanges in relation to specific types of innovation outcomes.

2.2 Conceptual framework

Extending the current literature, our approach introduces the concepts of simultaneous partner diversification and sequential partner adaptation, and it connects these concepts of inter-

(2004b) show that collaboration with competitors or suppliers aims at enhancing labor productivity growth, whereas collaboration with universities or competitors can increase market novelties.

[2] In this line, other literature in the field of organizational ambidexterity (Raisch, Birkinshaw, Probst, & Tushman, 2009; Tushman & Smith, 2002) relates incremental innovations to exploitive relationships and radical innovations to explorative relationships.

organizational mechanisms of knowledge exchange with different firm innovation outcomes. Contrary to the previous studies in this field, our approach provides a conceptual framework to explicitly explore the role of dynamic adaptations of R&D collaboration patterns that are related to different innovation outcomes.

Simultaneous partner diversification

Our first key concept is simultaneous partner diversification. This concept refers to simultaneous partnership diversification within R&D alliances, and it explicitly accounts for the complementarity effects between collaborating partner types at the same time.

In our setting, a firm can use various collaboration partner types such as suppliers and customers (vertical partners), competitors (horizontal partners), or universities (scientific partners) in its search activities. Following the idea of communities of practices by Cook and Brown (1999), each of these channels is aligned to different collaboration partner types and represents a separate search space with different institutional norms, habits, and rules; however, each channel also requires appropriate organizational practices to manage these partnerships effectively (Beck & Schenker–Wicki, 2014; Laursen & Salter, 2006). For instance, collaborating with end-users requires different skills, mind-sets, experience and knowledge than collaborating with an international research laboratory, including different intellectual property practices, norms of disclosure, and social and cultural attitudes. According to evolutionary economists (Metcalfe, 1994; Nelson & Winter, 1982), this variety and complementarity can help firms to find and create new combinations of technologies and knowledge. However, firms must be careful not to over-search, as over-searching can be related to the costs exceeding the benefits based on a certain threshold (Beck & Schenker–Wicki, 2014; Laursen & Salter, 2006). For instance, lacking managerial expertise and ineffective managerial attention may lead firms to not select the right partners and to coordinate inefficiently (Katila, Rosenberger, & Eisenhardt, 2008).

While some previous studies, such as Belderbos et al. (2006), take the complementary composition of R&D collaboration into account, they do not relate these patterns to different degrees of innovation novelty. Although other studies account for different degrees of innovation novelty created by knowledge sourcing strategies (Laursen & Salter, 2006), they ignore the structural composition of complementary partnerships within R&D alliances. Thus, our approach combines these two perspectives and interrelates simultaneous partner diversification with different types of innovation outcomes.

In summation, after acknowledging the existence of complementarity effects between collaboration partner types, it remains unclear which combinations of partner types are associated with which innovation outcomes. In our framework, we argue that specific simultaneous diversification patterns are more appropriate to achieving different types of innovation outcomes. In this vein, we expect that firms that manage to organize their external knowledge exchanges with the best potential complementarity mix between the focal firms' resources, capabilities, and innovation objectives and their partners' resources and know-how show superior innovation performance. This expectation leads to the following hypothesis:

Hypothesis 1: Simultaneous partner diversification within R&D alliances is associated with specific innovation outcomes, and this relationship shows important partner-type selectivity effects.

Sequential partner adaptation

Our second key concept refers to sequential partner adaptation. Some scholars note that if we ignore sequential adaptation, the extent of the complementarity effects between collaboration partner types will not be fully taken into account (Battisti, Colombo, & Rabbiosi, 2014; Jovanovic & Stolyarov, 2000; Smith, 2005). Our approach accounts at least partly for the dynamics within R&D alliances and contributes to the reasoning on how routines and path-dependent behavior in firms' knowledge sourcing strategies is related to innovation outcomes in changing external environments (Koka & Prescott, 2008; Li & Rowley, 2002).

As some studies argue that long-term firm success requires an organizational balance between continuity and change (Brown & Eisenhardt, 1997; Raisch & Birkinshaw, 2008), we expect superior performance in those firms that sequentially adapt their organizational knowledge sourcing structures. Accordingly, the next hypothesis is as follows:

Hypothesis 2: Firms that sequentially adapt their collaboration patterns in R&D alliances exhibit superior innovation performance compared to firms that persist in having the same collaboration patterns.

We extend this reasoning and argue that firms should not only change their collaboration patterns over time, but should also pay attention to where to search for new knowledge and technology. To that end, the (dynamic) selection among different collaboration partner types is relevant. The previous literature on collaboration indicates a major heterogeneity between partners and emphasizes that where to search is relevant for innovation (Belderbos et al., 2004a; Cassiman & Veugelers, 2006; Kaiser, 2002). Following this logic, we argue that heterogeneity is not only important in the simultaneous selection of partners but also in the dynamic adaptation of collaboration partners. Consequently, we expect that in addition to changing their collaboration patterns, it is important for firms to adapt their collaboration partners effectively and to select appropriate partners to achieve specific innovation outcomes. This notion leads to the following hypothesis:

Hypothesis 3: R&D alliances exhibit important partner-type selectivity effects with respect to the impact and direction of sequential adaptation of collaboration partner types and the associated innovation outcomes.

Firm size

Several scholars have noted that the relationship between inter-organizational structures of knowledge exchange and innovation depends on the firm size (Arora et al., 2014; Beck & Schenker–Wicki, 2014; Belderbos et al., 2006). The literature also notes that the firm's size may be linked to features such as its absorptive capacity or previous alliance experience (Sampson, 2005). Hence, we observe characteristics that are aligned to influence the outcomes of R&D collaborations. In our next step, we take the firm size into account to analyze the sensitivity of our results to these characteristics. While these studies refer to simultaneous structures of knowledge exchange (Beck & Schenker–Wicki, 2014; Belderbos et al., 2006), there are several reasons why we argue that the firm size also affects the role of the sequential adaptation of knowledge structures for specific innovation outcomes.

First, change and transformation processes are related to costs (Teece et al., 1997). Second, these processes require managerial attention (Ocasio, 1997) and coordination (Atuahene-Gima, 2005). These aspects demand financial and managerial resources that are differently allocated between SMEs and large firms. Hence, the ability and capacity to manage reconfigurations of knowledge structures may depend on characteristics that are aligned with firm size. Overall, we expect that the role of simultaneous partner diversification and sequential partner adaptation in achieving specific innovation outcomes will vary based on the firm size. These arguments lead to the following hypothesis:

Hypothesis 4: The relationship between simultaneous diversification, sequential adaptation in R&D alliances and the associated innovation outcomes is moderated by the firm size.

3 Data and methods

3.1 Sample

The empirical analysis uses data that are derived from the Swiss Innovation Survey. This survey has been conducted every three years by the Swiss Economic Institute (KOF) at the

ETH Zurich since 1990. The survey is part of the European Community Innovation Survey (CIS) of the European statistical office (Eurostat) and follows the guidelines described in the Oslo manual developed by the Organisation for Economic Co-operation and Development (OECD) (OECD, 1997). This dataset provides us with a representative sample of Swiss firms with at least five employees from both the manufacturing and service industries. The sample contains firm-level information on innovation activities, R&D expenditures, knowledge sourcing, intellectual property practices, and performance measures among many other firm characteristics. The CIS and the Swiss Innovation Survey constitute a reliable, valid and well-established source of information on firms' innovative activities and commercial success. Indeed, the datasets derived from these surveys have been used in a wide range of recent and prominent studies (Arvanitis, 2012; Beck et al., 2014; Cassiman & Veugelers, 2002; Laursen & Salter, 2006; Leiponen & Helfat, 2010; Meuer et al., 2015). In our analysis, we use information from six consecutive waves covering a time period from 1999 to 2013. The postal survey received response rates of 33.8 % (1999), 39.6 % (2002), 38.7 % (2005), 36.1 % (2008), 35.9 % (2011), and 32.7 % (2013).[3] After eliminating the missing values, we restrict our sample to those firms that are observed at least in two consecutive waves. In total, our dataset comprises 3993 observations from 2087 different firms.

3.2 Empirical strategy

In our analysis, we focus on the role of simultaneous diversification and sequential adaptation strategies in R&D alliances in firms' innovation performance. Our models measure how firms' innovation outcomes are associated with specific simultaneous diversification and

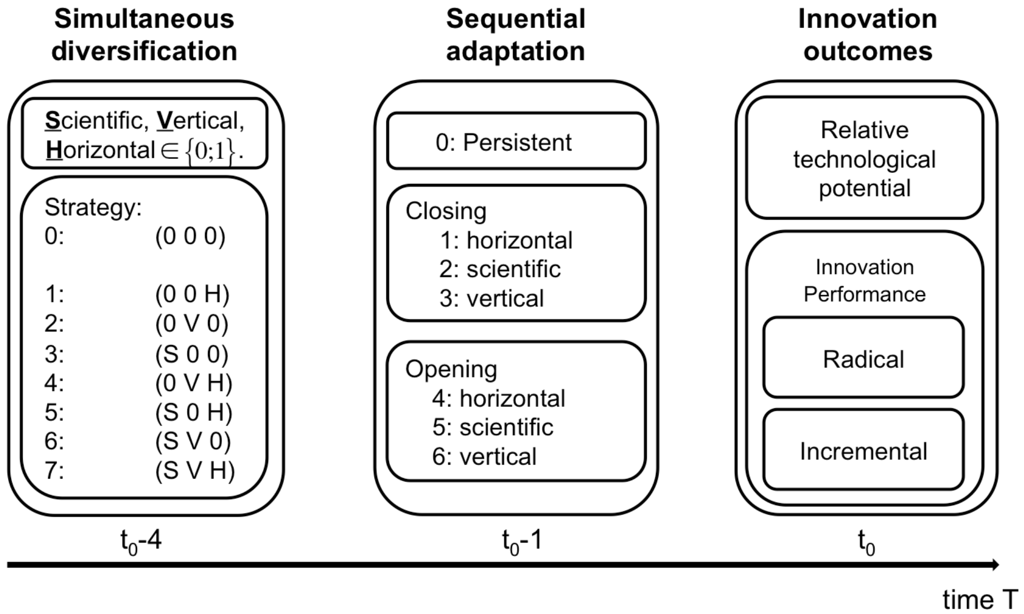
[3] From 1999 until 2011, the survey was conducted every three years, but from the beginning of 2013 the Swiss Economic Institute changed the timing of the survey to every two years. The structure of the responses for different industry affiliations, regions, and sizes are largely consistent with the previous surveys. An overview on the innovation surveys from 1999 to 2013 and the corresponding innovation activities of Swiss firms from 1997 to 2012 can be found in Arvanitis et al. (2014).

sequential adaptation strategies as well as other firm characteristics. Because firms make their managerial choices about their diversification and adaptation strategies based on different innovation objectives, we account for three different innovation outcomes to evaluate the effectiveness of these diversification and adaptation strategies, namely, the firm's relative technological potential, radical innovation and incremental innovation output.

Following the previous literature, we define the radical innovation performance as the share of generated sales attributed to innovative products that are new to the firm, and we define the incremental innovation performance as products that are significantly improved (Beck et al., 2014; Garcia & Calantone, 2002; Meuer et al., 2015). Accounting for the firm's relative technological position, we introduce a new measure that indicates if a firm is able to improve its technological potential towards the technological frontier within an industry. This measure of technological opportunities has so far not received much attention in the empirical literature (Teece et al., 1997). However, we acknowledge that firms choose their collaboration strategy to devise a solution to a certain technological shortcoming (Mowery et al., 1996), and we believe that accounting for the effectiveness of enhancing the technological potential indicates a good measure of the success or failure of different collaboration strategies. By including this measure, we expect to derive additional insights on how firms can improve their technological capabilities through collaboration.

With respect to our concepts of simultaneous diversification and sequential adaptations of collaboration partner types in R&D alliances, we differentiate between eight simultaneous diversification and seven sequential adaptation strategies (see Figure 1). For the simultaneous diversification of collaboration partner types, the exclusive combinations of vertical, horizontal, and scientific collaboration compose the eight strategies. The sequential adaptation strategies are characterized by either remaining persistent within the current pattern or opening towards or shunning vertical, horizontal or scientific partner types.

Figure 1: Conceptual framework



Given the strong unbalanced nature of our panel dataset, we make use of the pooled cross-sectional structure of our data to estimate our models. We use robust clustered standard errors to account for the potential correlations of the errors, and we include a substantial set of control variables. For our first outcome measure that indicates the relative technological potential, we estimate probit models such that the dependent variable for the relative technological potential of a firm equals one if its technological potential is higher than the firms' average in a given period. The binary response models are estimated as follows:

$$y_i^* = x_i\beta + \varepsilon_i \tag{3.1}$$

$$y_i = 1[y_i^* > 0], \varepsilon_i \sim \mathcal{N}(0, \sigma^2)$$

where the binary variable y_i indicates the sign of the unobserved latent variable y_i^*.

For the equations that estimate firms' innovation performance, we apply pooled regression models with radical and incremental innovation performance as the dependent variables. These variables are measured as the ratio of the radical (incremental) innovative sales to the total turnover. Because these variables by definition range between 0 and 100, and because not all firms have innovative sales in each period, our data are characterized by corner solution outcomes around 0 (Winkelmann & Boes, 2006; Wooldridge, 2010). For our analysis, we use Tobit models to account for these censored dependent variables. With our approach, we are in line with previous empirical studies that faced similar data characteristics (Bakker & Knoben, 2014). As argued in Greene (2003), standard Tobit models require the assumption of homoscedasticity. As LR tests of the residuals indicate violations of the homoscedasticity assumption in our setting, we model the group-wise multiplicative heteroscedasticity by including firm size and industry dummies.[4] The Tobit models are estimated as follows:

$$InnoPerf_i^* = X'_{i,t-1}\beta + \epsilon_i, \qquad \epsilon_i \sim i.i.d. N(0, \sigma^2) \qquad (3.2)$$

$$InnoPerf_i = \begin{cases} InnoPerf_i^* \ \ if \ X'_{i,t-1}\beta + \epsilon_i > 0 \\ 0 \ otherwise \end{cases} \qquad (3.3)$$

where $InnoPerf_i$ represents the non-negative observable innovation performance variable; this variable captures the radical innovation and incremental innovation performance for the firm i. $InnoPerf_i$ corresponds to the latent dependent variable $InnoPerf_i^*$ if this variable is above zero and to zero otherwise. Finally, to avoid direct simultaneity, we run our analysis by allowing for time lags between the simultaneous diversification, sequential adaptation and output measures, as shown in Figure 1.

3.3 Measures

Dependent variables

We measure three different innovation outcomes to account for the different types of innovation objectives of firms. First, the *relative technological potential* (*RELTECHPOT*)

[4] We therefore estimated the heteroscedasticity-robust model by a maximum likelihood function in which we replace the homoscedastic standard error term σ with $\sigma_i = \sigma \exp(Z'\alpha)$ in the likelihood function.

captures reflections on pushing the technological capabilities of a firm above the industry average and thereby closer to the technological frontier of an industry (Teece et al., 1997; Tushman & Anderson, 1986). A dummy variable takes the value of one if the relative technological potential is above this threshold. Therefore, the level of the general technological potential of a firm reflects the level of scientific and technological knowledge available to it for conducting innovation activities (Kogut, 1988; Kogut & Zander, 1992; Mowery et al., 1996).

In addition, two further outcome variables indicate the firm's sales performance with innovative products and measure the commercial success of its innovation activities. In line with the previous literature (see, for instance, Laursen and Salter (2006)), we distinguish between radical and incremental innovation performance. Following Meuer et al. (2015), radical innovation performance (*RADICAL*) is measured as the firm's sales share of radical innovative products, i.e., products that are new to the firm, to the total turnover. Similarly, the incremental innovation performance (*INCREMENTAL*) is measured as the fraction of the firm's turnover with incremental innovative products, i.e., products that are significantly improved.

Main explanatory variables

As a central part of our conceptual model, we account for the firm's diversification and adaptation strategies to search for external sources of knowledge through external collaboration partners. Therefore, we include various variables to capture our concepts of simultaneous partner diversification and sequential partner adaptation.

As a starting point, we introduce the variable DIVERSIFICATION to capture the firm's simultaneous collaboration pattern. To construct this variable, we use information about firms' different R&D collaboration agreements with external collaboration partners such as suppliers, customers, clients, competitors, universities, and other research institutes. Following Belderbos et al. (2004a), we aggregate this information and create three dummy variables that are each equal to 1 if a firm collaborates with a specific partner type. More precisely, we differentiate between vertical (*VERT*, suppliers, clients or customers), horizontal (*HOR*, competitors), and institutional scientific partner types (*SCIE*). Then, the simultaneous diversification pattern (*DIVERSIFICATION*) is uniquely defined by eight different combinations as shown in Figure 1. Consequently, the simultaneous partner diversification variable represents the complementarities between different partner type structures and the diversification within a firm's collaboration pattern (see Figure 1).

However, we do not stop at the simultaneous pattern; we also take dynamic behavior into account. With respect to this second concept, the sequential partner adaptation (*ADAPTATION*) analyzes what happens if a firm changes its collaboration pattern between two points in time (t_0-4 and t_0-1). Thus, the sequential ADAPTATION accounts for a firm modifying or locking down its pattern between two periods (i.e., times t_0-4 and t_0-1). Accordingly, a sequential adaptation in the firm's collaboration pattern can be described by seven different sequential adaptation strategies: a firm can remain persistent within its pattern or it can open to or shun horizontal, scientific, and vertical partner types (see Figure 2).

Overall, the introduction of these two new concepts captures the diversification and sequential adaptation of firms' collaboration patterns, which will enhance our understanding of the mechanisms between external knowledge sourcing and the innovation outcomes of firms.

Further controls

In our analysis, we further control for various factors that may influence firms' innovation outcomes. We include a measure for the firm's R&D investments: they are measured as the firm's R&D expenditures relative to its total turnover (*RDINT*). This measure accounts for the firm's R&D activities, thereby reflecting its general absorptive capacity and ability to conduct innovative activities. The receipt of public support is indicated by a dummy (*PUBSUB*). A previous reception of a public grant signals relevant competences and capabilities to successfully conduct R&D projects to other partner firms, and hence, may affect innovation success.

Furthermore, we include the firm age (*FIRMAGE*) and (the log of) the firm size (*LNFIRMSIZE*) to capture relevant firm characteristics. Moreover, we include the squared term of the two previously mentioned variables to take a non-linear relationship into account (*FIRMAGE2, LNFIRMSIZE2).* In addition, we control for whether or not a firm belongs to a foreign group (*FOREIGN*), as foreign group members may show higher innovative performance due to spillovers from international group members. We also control for the foreign market activities of a firm. Highly export-oriented firms may be more innovative due to higher international competition than firms exclusively operating on a national market. We include a variable measuring the export share of the total turnover (*EXPORT*).

Moreover, seven industry-sector dummies account for the different propensities to innovate across sectors. Finally, we include six survey-year dummies in our set of control variables to control for time shocks.

3.4 Descriptive results

Relevant variables

Table 1 reports descriptive statistics about the relevant variables for our analysis. The table shows that on average, firms generate approximately 7.0 % of their total turnover with radical innovative products, whereas 8.2 % of the turnover can be attributed to incremental innovative products. Moreover, 50.8 % of the firms in our sample innovate, 37.6 % conduct R&D activities, and 14.2 % collaborate in R&D alliances. Among the firms in our sample, 8.6 % collaborate with partners from scientific institutes, 13.0 % collaborate with vertical partners, and 4.4 % collaborate with horizontal partners. On average, the firms in our sample are rather large (mean: 257 employees) and old (mean: 67 years). In addition, 85.1 % of the firms are SMEs. Further descriptive statistics of the industry and firm-size-class distribution are provided in Table 6 and Table 7 in Appendix.

Simultaneous partner diversification

After examining the descriptive results regarding the simultaneous partner diversification strategies in Table 2, we recognize that the predominant pattern in our sample is non-collaboration. After differentiating between firm size classes, the table shows that large firms collaborate more than SMEs. Diversification strategies that include vertical partners are frequently used, particularly within large firms. Moreover, large firms most frequently collaborate with scientific and vertical partners or all three partner types. Contrarily, SMEs are predominantly engaged in R&D alliances composed by scientific and vertical partner types or vertical partners alone.

Sequential partner adaptation

Focusing on sequential partner adaptation, our sample demonstrates that the most predominant strategy for firms is remaining persistent (see

Table **3**). This pattern appears particularly valid for SMEs, while large firms adapt their knowledge sourcing strategies more often. Overall, we observe the most frequent adaptations in R&D alliances towards opening up to or shunning vertical partner types.

Table 1: Descriptive statistics of the relevant variables.

	Variable	Obs.	Mean	S.D.	Min.	Max.
1	RADICAL	3993	6.951	13.665	0	100
2	INCREMENTAL	3993	8.208	15.580	0	100
3	RELTECHPOT	3993	0.522	0.500	0	1
4	R&D	3993	0.376	0.485	0	1
5	COLLABORATION	3993	0.142	0.349	0	1
6	INNO	3993	0.508	0.500	0	1
7	SCIENCE	3993	0.086	0.280	0	1
8	VERTICAL	3993	0.130	0.337	0	1
9	HORIZONTAL	3993	0.044	0.205	0	1
10	RDINT	3993	1.118	4.748	0	178.79
11	FIRMSIZE	3993	256.821	1749.612	1	43038
12	FIRMAGE	3993	67.401	42.146	2	614
13	EXPORT	3993	22.451	33.522	0	100
14	FOREIGN	3993	0.148	0.355	0	1
15	SUBSIDY	3993	0.059	0.235	0	1

Table 2: Descriptive statistics on simultaneous partner diversifications according to firm size classes.

Simultaneous DIVERSIFICATION	Full sample		Small-medium		Large firms	
STRATEGY: (S V H)	Freq.	Percent	Freq.	Percent	Freq.	Percent
0: (0 0 0)	3,429	85.88	3014	88.65	415	69.98
1: (0 0 H)	13	0.33	10	0.29	3	0.51
2: (0 V 0)	126	3.16	102	3.00	24	4.05
3: (S 0 0)	16	0.4	12	0.35	4	0.67
4: (0 V H)	74	1.85	56	1.65	18	3.04
5: (S 0 H)	8	0.2	7	0.21	1	0.17
6: (S V 0)	225	5.63	138	4.06	87	14.67
7: (S V H)	102	2.55	61	1.79	41	6.91
Total	3,993	100	3,400	100	593	100

Table 3: Descriptive statistics on sequential partner adaptations according to firm size classes.

		Full sample		Small-medium		Large firms	
Sequential ADAPTATION		Freq.	Percent	Freq.	Percent	Freq.	Percent
	0 persistent	3,322	83.20	2906	85.47	416	70.15
closing	1 horizontal	38	0.95	28	0.82	10	1.69
	2 scientific	38	0.95	29	0.85	9	1.52
	3 vertical	257	6.44	187	5.50	70	11.80
opening	4 horizontal	37	0.93	23	0.68	14	2.36
	5 scientific	44	1.10	33	0.97	11	1.85
	6 vertical	257	6.44	194	5.71	63	10.62
	Total	3,993	100	3,400	100	593	100

4 Empirical results

Table 4 presents the results of the regressions models, which reflect the role of simultaneous partner diversifications and sequential partner adaptations for different innovation outcomes. For the effects of simultaneous partner diversification, we find strong support for our first hypothesis, which indicates the presence of important selectivity effects. Precisely, our results indicate that certain simultaneous compositions of collaboration partners are more appropriate for specific innovation outcomes than others.

If firms intend to increase their relative technological potential (*PROBIT model*), we can state that scientific or horizontal partners are appropriate partner types in R&D alliances. However, to unfold the benefits, these partner types need to be complemented with vertical partners. Highly diversified collaboration patterns in R&D alliances that include collaborations with all three partner types are linked with the highest probability of increasing a firm's relative technological potential.

With respect to our innovation performance measures, our analysis highlights that a pure vertical collaboration without any complementary partner is positively associated with performance gains in radical and incremental innovation output. Interestingly, a pure horizontal collaboration is negatively linked to an incremental innovation outcome, which may indicate potential leaks of knowledge or product collusion problems in the output market.

Scientific and horizontal collaborations only exhibit positive effects on radical and incremental innovation performance if they are complemented with vertical partners. Highly diversified patterns in R&D alliances composed by collaborations with scientific, horizontal and vertical partners also show positive effects on both types of innovation performance outcome. Notably, we find that a collaboration in R&D alliances with scientific partners or horizontal partners needs to be complemented with other partner types (i.e., with vertical partners) to enhance the positive effect on both types of innovation performance. This result is in contrast to vertical collaboration, which does not need to be complemented with other partner types. Overall, these results confirm our expectations about the presence of important selectivity issues with respect to the simultaneous partner diversification (*Hypothesis 1*).

Second, for the role of sequential partner adaptations in R&D alliances for firms' innovation outcomes, in accordance with our expectations the results generally show that firms can benefit through a sequential change in collaboration patterns (*Hypothesis 2*). However, not all of the results point in the same direction, and hence, hypothesis two can only partly be supported. For instance, we see that ending a scientific collaboration is negatively linked to the probability of enhancing the relative technological potential of a firm. Despite this negative impact, we mainly find positive effects of adaptation on innovation outcomes compared to remaining persistent.

These ambiguous results motivate us to more closely examine the partner-specific adaptation effects (*Hypothesis 3*). In this vein, our analysis unveils positive effects of ending scientific and horizontal collaborations for incremental innovation performance, indicating that these types of collaboration may not be the most appropriate partner type to collaborate with if firms intend to incrementally innovate. Furthermore, our results show positive effects of opening a horizontal collaboration for radical innovation outcomes. Finally, collaborating with vertical partners is overall positively linked with all three innovation outcome measures and seems to be an essential source of knowledge in R&D alliances. Ultimately, these results support hypothesis three of this paper by indicating significant partner selectivity effects.

Table 4: Regression estimates for innovation outcomes accounting for simultaneous partner diversification and sequential partner adaptation.

		Innovation outcomes		
		Probit	Random Effects Tobit	
Explanatory variables		RELTECHPOT	RADICAL	INCREMENTAL
DIVERSIFICATION (S V H) 0:		(.)	(.)	(.)
	1: (0 0 H)	0.397	9.653	-21.842***
		(0.468)	(6.288)	(8.458)
	2: (0 V 0)	0.266	10.296***	11.265***
		(0.174)	(2.499)	(2.968)
	3: (S 0 0)	0.307	-2.569	-10.411
		(0.336)	(5.772)	(7.300)
	4: (0 V H)	0.544**	11.171***	16.148***
		(0.217)	(3.237)	(3.728)
	5: (S 0 H)	0.476	13.822	2.766
		(0.530)	(8.689)	(11.441)
	6: (S V 0)	0.672***	7.189***	7.074***
		(0.155)	(1.985)	(2.415)
	7: (S V H)	0.809***	8.497***	7.828**
		(0.255)	(2.804)	(3.397)
ADAPTATION 0: persistent		(.)	(.)	(.)
closing	1 horizontal	0.014	-1.792	12.616**
		(0.361)	(4.262)	(5.204)
	2 scientific	-0.447*	6.400	9.237*
		(0.254)	(4.066)	(4.857)
	3 vertical	-0.223	0.953	0.397
		(0.164)	(2.128)	(2.536)
opening	4 horizontal	-0.019	6.894*	4.721
		(0.272)	(3.521)	(4.425)
	5 scientific	0.169	2.055	1.711
		(0.242)	(3.642)	(4.246)
	6 vertical	0.357***	11.237***	16.543***
		(0.100)	(1.515)	(1.817)
	CONTROLS	[YES]	[YES]	[YES]
	TIME DUMMIES	[YES]	[YES]	[YES]
	INDUSTRY DUMMIES	[YES]	[YES]	[YES]
	No. of observations	3,993	3,993	3,993

Note: The standard errors are clustered at the firm level, as firms appear more than once in the sample. The time and industry dummies are jointly significant (not presented). ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

Firm size

In the next step of our analysis, we investigate the effectiveness of inter-organizational knowledge exchange structures that depend on the sizes of firms. Table 5 reports the results of simultaneous partner diversification and sequential partner adaptation after differentiating between SMEs and large firms.

Overall, our results demonstrate that the partner structure impacts the innovation performance differently according to the firm size (*Hypothesis 4)*. With regard to horizontal collaboration, pure horizontal collaboration represents an appropriate means for large firms to achieve high relative technological potential. However, this type of collaboration demonstrates negative effects on incremental innovation performance. Thus, although a horizontal collaboration is an essential source to gain technology potential, it comprises severe risks and threats for the economical commercialization if this collaboration engagement is undertaken to generate outcomes with only a minor degree of innovation novelty.

With respect to small firms, collaboration patterns that exclusively include vertical partner types are positively associated with higher relative technological potential, radical and incremental innovation performance, while this inter-organizational knowledge sourcing and transfer structure does not exhibit significant effects for large firms. In line with the full firm sample results, we cannot detect any statistically significant positive effect of a scientific collaboration if it is not complemented with other partner types for SMEs as well as for large firms. This finding highlights that this source of external knowledge alone enhances neither the relative technological potential of a firm nor its economical innovation performance. Consequently, this finding shows that scientific partners need complementary types of partners to exploit the knowledge received through scientific partners.

Next, we focus on the results of diversified patterns that are composed by more than one partner type. To begin with SMEs, our analysis shows that horizontal collaboration complemented with vertical partner types seems to be an effective external knowledge sourcing structure. This structure cannot only enhance the relative technological potential, it can also boost the economical innovation performance with radical and incremental innovative products. Moreover, if it is complemented with a vertical partner, a scientific collaboration is positively associated with higher relative technological potential and radical innovation performance. Notably, inter-organizational R&D alliances composed by highly diversified partner structures composed of all three partner types are positively linked with a higher relative technological potential as well as with higher radical and incremental innovation performance.

For large firms, collaboration constellations with scientific and vertical partner types positively affect the relative technological potential and incremental innovation performance. Interestingly, large firms generally do not benefit to the same extent from the complementarity effects created from external partner types to enhance the firms' technological potential and innovation performance as SMEs. This finding highlights the scarcity of resources in SMEs, and hence, it indicates that collaboration may be an appropriate means for SMEs to confront these problems.

In shedding light on the sequential partner adaptation, our study detects substantial firm size effects. For instance, closing down a scientific collaboration is negatively linked with the relative technological potential, but positively associated with incremental innovation performance for SMEs. For large firms, no significant effect is found for any of the outcome variables. Although a scientific collaboration is an important source for higher relative technological potential for SMEs, these results point to the difficulties SMEs face in exploiting knowledge from scientific collaborations particularly if this inter-organizational knowledge exchange is supposed to foster incremental innovations. Contrarily, if large firms adapt their collaboration patterns and open up to scientific partners, our results shows positive effects for the relative technological potential as well as for both types of innovation performance. These results indicate that large firms are able to create benefits from collaborations with scientific partners for any type of innovation outcome. Hence, this knowledge and learning channel to scientific partners constitutes an important source of the competitive advantage of large firms.

With respect to SMEs, sequential adaptations in the form of opening toward horizontal collaboration partners show a positive effect on the radical innovation performance. This finding indicates that SMEs can benefit from joint collaborations with competitors for radical innovation to establish new technologies or standards and to create new output markets for these radical innovations. The insignificant effects for this sequential adaptation strategy for large firms may derive from the fact that large firms have less need for other external partners to shape these output markets.

Another interesting effect of sequential adaptation related to horizontal collaboration concerns large firms: closing down horizontal partnerships is linked to increased incremental innovation performance. This result shows that collaborations with competitors may harm large firms if the associated innovation outcome is incremental. This possibility may be due to potential collusion in the subsequent product market, increased leakage of knowledge to competitors, or ineffective appropriation mechanisms. Overall, we can conclude that the above findings with respect to the firm size are generally consistent with hypothesis four.

Table 5: Regression estimates for the innovation outcomes accounting for simultaneous partner diversifications and sequential partner adaptations and differentiating between small-medium-sized and large firms.

		Innovation outcomes					
		SMALL MEDIUM FIRMS			*LARGE FIRMS*		
		Probit	Random Effects Tobit		Probit	Random Effects Tobit	
Explanatory variables		RELTECHPOT	RADICAL	INCREMENTAL	RELTECHPOT	RADICAL	INCREMENTAL
DIVERSIFICATION	0 (S V H)	(.)	(.)	(.)	(.)	(.)	(.)
	1: (0 0 H)	0.132	7.171	-18.252	0.000	14.562	-27.061**
		(0.549)	(8.639)	(11.859)	(.)	(10.004)	(11.011)
	2: (0 V 0)	0.370*	14.651***	13.994***	0.129	-1.899	-4.819
		(0.203)	(3.113)	(3.590)	(0.340)	(4.497)	(5.317)
	3: (S 0 0)	0.615	-5.676	-11.158	-0.858	-1.126	-16.821
		(0.431)	(7.131)	(8.874)	(0.699)	(9.912)	(11.853)
	4: (0 V H)	0.699***	15.747***	15.577***	0.142	-2.587	8.225
		(0.241)	(3.990)	(4.605)	(0.487)	(5.362)	(5.699)
	5: (S 0 H)	0.444	5.232	-8.320	0.000	47.442	29.370
		(0.564)	(9.728)	(12.745)	(.)	(32.416)	(36.158)
	6: (S V 0)	0.640***	9.135***	4.854	0.830***	4.268	8.290**
		(0.205)	(2.884)	(3.383)	(0.236)	(2.704)	(3.316)
	7: (S V H)	1.305***	8.999**	9.593**	0.493	5.015	0.649
		(0.306)	(3.924)	(4.503)	(0.390)	(3.942)	(4.910)

ADAPTATION	0 persistent						
	1 horizontal	0.311	-2.959	9.265	-0.265	5.058	16.098**
		(0.462)	(5.760)	(6.889)	(0.558)	(6.396)	(7.569)
closing	2 scientific	-0.632**	7.831	10.441*	0.223	-2.335	4.720
		(0.318)	(5.027)	(5.822)	(0.511)	(7.175)	(9.104)
	3 vertical	-0.350*	-1.577	1.275	-0.039	4.664	0.142
		(0.198)	(2.845)	(3.295)	(0.297)	(3.195)	(3.919)
	4 horizontal	0.045	9.830**	8.050	-0.235	6.067	0.353
		(0.324)	(4.972)	(6.199)	(0.489)	(4.976)	(5.906)
opening	5 scientific	-0.118	-3.752	-5.665	0.000	16.626***	20.200***
		(0.268)	(4.481)	(5.176)	(.)	(6.411)	(7.000)
	6 vertical	0.253**	12.230***	15.494***	0.846***	8.986***	15.089***
		(0.110)	(1.840)	(2.143)	(0.250)	(2.576)	(3.307)
	CONTROLS	[YES]	[YES]	[YES]	[YES]	[YES]	[YES]
	TIME DUMMIES	[YES]	[YES]	[YES]	[YES]	[YES]	[YES]
	INDUSTRY DUMMIES	[YES]	[YES]	[YES]	[YES]	[YES]	[YES]
	No. of observations	3,400	3,400	3,400	569	593	593

5 Discussions, implications and concluding remarks

5.1 Discussion

As a response to today's highly competitive and rapidly changing environment, which includes shorter product cycles and time to market, firms need to adapt effectively to meet these challenges (Bakker & Knoben, 2014; Mohammed & Nadkarni, 2011). One of the response strategies for many firms is to form strategic inter-organizational R&D alliances with external collaborating partners. This study extends the conceptual understanding of inter-organizational structures of external knowledge exchanges and technology transfers within R&D alliances. To that end, we introduce two new concepts, namely, simultaneous partner diversification and sequential partner adaptation.

The introduction of these concepts should help achieve a better evaluation of the managerial choices of strategies to organize external knowledge sourcing and transfers through collaboration to effectively meet specific innovation objectives. As we expected, these knowledge-sourcing strategies vary based on the firm size. By accounting for the effects of dynamic search behavior within R&D alliances, our study responds to calls for more research how firms organize their external searches for innovation (Bakker & Knoben, 2014; Dahlander & Gann, 2010; Kale & Singh, 2009; Laursen & Salter, 2014). In our framework, we argue that specific simultaneous diversification patterns of firms are more appropriate to achieving different types of innovation outcomes. In this vein, we expect that firms that manage to organize their external searches with the best potential complementarity mix between the focal firms' resources, capabilities, and innovation objectives and their partners' resources and know-how show superior performance.

As previous literature has noted, there is a lack of openness of firms to their external environment (Chesbrough, 2003b; Laursen & Salter, 2006). Hence, firms that over-focus on internal search activities may generally behave too persistently within their search processes.

This myopic and persistent behavior may limit the adaptations of firms to external changes in technology and markets. Therefore, we have introduced a dynamic framework suggesting that firms that effectively adapt their organizational knowledge structure of external linkages according to their current pattern and innovation objectives show superior performance outcomes.

We examine the role of simultaneous partner diversification on different innovation output measures to gain further insights on how external linkages to heterogeneous collaboration partner types affect innovation outcomes. Therefore, our study confirms and extends the previous research on the effects of complementarities between collaboration partner types (Belderbos et al., 2006). In particular, our results highlight the importance of selectivity in collaboration partner types according to specific innovation outcomes and the firm size. For instance, collaboration with scientific partners needs to be complemented to have positive effects on innovation outcomes. By collaborating with scientific partners, firms may gain access to new ideas, scientific workforces and new technology. However, to make these collaborations effective for innovation outcomes this knowledge and technology need to be complemented with other partner types.

This finding shows that although collaboration with science is an important source for the relative technological potential for SMEs and large firms, this collaboration type needs to be complemented with vertical partner (or vertical and horizontal partner) types to economically exploit radical and incremental innovation outcomes. This need may hint at ineffective appropriation mechanisms in the case of a purely scientific collaboration.

Similar characteristics appear to be valid for horizontal collaborations. Complemented horizontal collaborations with vertical (and scientific) partners are positively associated with innovation outcomes of either type. Along with pure scientific collaborations, pure horizontal collaborations are negatively linked with incremental innovation outcomes. This linkage indicates severe problems with this type of collaboration partner if it is used for innovation activities with only minor product novelty. The innovation monopoly, and hence, the producer rent of a pure horizontal collaboration may not be high enough for incremental innovation activities to fully cover involuntary outgoing spillovers and potential product collusion problems with competitors; these issues may explain the negative effects. These insights regarding horizontal collaboration enhance the discussions about opportunistic behavior versus learning in R&D alliances (Kale, Singh, & Perlmutter, 2000).

Contrary to scientific and horizontal collaborations, vertical collaborations do not need to be complemented with other partner types to exploit innovation performance. Our results particularly emphasize that SMEs can benefit through vertical collaboration; surprisingly, SMEs can also increase their technological potential by means of a vertical collaboration. In line with our expectations, firms do not face tremendous difficulties exploiting and exploring knowledge through collaboration channels with vertical partners.

Focusing on firm size effects, we can state that SMEs show more positive effects of partner diversification associated with innovation outcomes compared to large firms. These findings confirm and extend previous empirical studies (Beck & Schenker–Wicki, 2014) and show that SMEs can substantially benefit from the complementarities gained from external sources of knowledge in their innovation activities. Consequently, the means of partner diversification can allow SMEs to effectively bypass their lack of internal sources compared to large firms.

To examine how firms dynamically adapt their inter-organizational structure of knowledge sourcing and transfer in R&D alliances, we introduce the concept of sequential partner adaptation. Our results reveal that dynamic adaptation is an appropriate measure to confront problems related to path dependency and remaining too persistently within firms' previous knowledge sourcing strategies. In general, we found positive associations between closing down transfer channels from horizontal and scientific partners for incremental innovation performance. These findings demonstrate that those partner types may not provide the most appropriate knowledge sourcing channels to enhance incremental innovation performance. Furthermore, we found positive relationships between opening channels to horizontal partners and radical innovation performance, and between opening vertical channels and all types of innovation outcomes. One exception to these positive relationships concerns our finding for closing down channels to scientific partners. Here, we found negative correlations to the firms' relative technological potential, indicating that knowledge that is derived from scientific collaborations is an important prerequisite for superior technological potential.

Our analysis supports our expectations about the presence of major firm-size effects reflecting the sequential partner adaptations in R&D alliances. Contrary to SMEs, for large firms beginning a scientific collaboration is positively related to the relative technological potential and innovation performance with radical and incremental innovative products. Hence, knowledge sourcing through scientific partners represents an important source of innovation opportunities for large firms. As our results show, large firms can significantly benefit from installing these knowledge transfer channels to scientific partners. Apparently, they have the capabilities to create, manage and retain these new inter-organizational linkages effectively.

Furthermore, our analysis reveals that large firms are able to benefit through closing channels to horizontal partners in terms of incremental innovation performance. Thus, collaboration with competitors may harm large firms if this type of collaboration is associated with projects that only have incremental novelty. Potential collusion in the product output market and involuntarily leaking knowledge to competing firms may explain these results. Contrary to large firms, opening up a horizontal collaboration is positively correlated with radical innovation performance outcomes for SMEs. This correlation indicates that SMEs can benefit from joint innovation activities with competitors to establish new technologies and markets for radical innovations. Given our results, large firms may be more able to derive this result on their own. By reflecting this role of the inclusion and exclusion of horizontal collaboration in the knowledge exchange process in R&D alliances, our study provides new insights in a field where there is a call for more research concerning the potentially opportunistic behavior of competitors in the innovation process (Laursen & Salter, 2014). In summation, our study highlights the importance of simultaneous and sequential partner-type selections in R&D alliances and the importance of adapting collaboration strategies according to changing external environments.

5.2 Implications and concluding remarks

The earlier literature on R&D alliances has elaborated on the understanding of how firms organize their external innovation search activities (Katila & Ahuja, 2002; Laursen & Salter, 2006; Laursen & Salter, 2014). However, as suggested by Laursen and Salter (2006) and Bakker and Knoben (2014), more research is needed to better understand the performance implications when firms change their innovative search behavior over time. Our framework explores how sequential changes in firms' search strategies affect their innovation performance. Therefore, we follow Laursen and Salter (2006), who refer to this problem as a "key managerial challenge" (p. 147), and we investigate whether firms that adapt their search behavior over time to respond to major changes in the environment can exhibit better performance compared to those firms that remain persistent in the same search strategy. The present study identified appropriate simultaneous diversification and sequential adaptations strategies to achieve specific innovation outcomes. In this context, the findings of our study should help managers to develop effective re-configurations of firms' inter-organizational knowledge sourcing structures according to different innovation objectives.

Indeed, our analysis emphasizes that managerial decision makers should be aware of the risk of remaining too persistent and path-dependent within the same search activities. The attitude of non-adapting inter-organizational knowledge exchange strategies could lead to inferior performance. However, our analysis also highlights the need for an appropriate fit between the partners in R&D alliances in terms of their innovation objectives and firm sizes. Thus, a careful evaluation of the potential returns and risks of collaboration is required.

5.3 Future research and limitations

Given the nature of our data, we have to be careful about claims of causality. While establishing causality is crucial in order to verify theory, this was not the scope of our project. Furthermore, we strongly believe it is just as important to enhance theories based on correlations, if the later allow analyzing the dynamics that have thus far not received the needed attention in the literature (Arora et al., 2014). However, future avenues of research should account for the selection into collaboration in order to be able to derive stronger claims of causality.

Moreover, this study focuses on the sequential adaptation of the innovative search behavior of firms, and it can only partly capture a full understanding of dynamic firm behavior. Further improvements in data collection could allow researchers to follow a large set of firms over a longer timeframe, which would permit them to take long-term effects into account. Furthermore, having a longer timespan would allow researchers to consider whether experience with the same partner impacts the way firms choose to adapt their partner constellations. Future research could extend the understanding of which mechanisms moderate the adaptation of inter-organization knowledge structures in R&D alliances. For instance, further future studies could analyze the impact of different adaptation strategies across technological trajectories, as such strategies may be highly sector-specific (Fleming & Sorenson, 2001; Katila & Ahuja, 2002). In addition, further research on inter-organizational knowledge creation from different perspectives such as organizational learning, knowledge and intellectual property management is needed to attain an integrated understanding of how firms organize their searches for innovation.

Appendix

Table 6: Descriptive statistics, industry distribution.

Industry	Number of firms	Percent
1 Construction, mining, energy	496	12.42
2 Consumer goods (food, beverages, tobacco, textiles, clothing)	261	6.54
3 Intermediate goods (paper, printing, chemicals, pharmaceuticals, rubber, plastics, minerals, basic metals)	607	15.20
4 Investment goods (fabricated metals, machinery & equipment, electrical equipment, electronics and optical products, medical instruments, watches, vehicles, and other manufacturing)	1,203	30.13
5 Traditional services (trade, transportation, telecommunications)	750	18.78
6 Knowledge-based services (banking, insurance, information technology & services, technical commercial services)	503	12.60
7 Other services	173	4.33
Total	3,993	100

Table 7: Descriptive statistics, firm size distribution.

Size class	Size class distribution	Number of firms	Percent
1 Small-sized firms	1 – 49	1,918	48.03
2 Medium-sized	50 – 249	1,482	37.11
3 Large-sized	250 – max.	593	14.85
	Total	3,993	100

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