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The effects of internal technological diversity and external uncertainty on technological alliance portfolio diversity

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ABSTRACT

This research proposes internal and external determinants that influence the diversity of a firm's alliance portfolio. Focusing on technological aspects of the firm as well as investigating internal and external factors, we suggest that the internal technological diversity of the focal firm, as well as the technological uncertainty of the industry, affects the technological diversity of the alliance portfolio. The hypotheses are tested on a sample of U.S.-listed semiconductor firms' global R&D alliances from 1990 to 2010. We find that the internal technological diversity of a firm has a negative influence on its technological alliance portfolio diversity. However, technological alliance portfolio diversity seems unaffected by the uncertainty of the firm's environment. This study contributes to prior literature which has extensively studied the effects of alliance portfolio diversity on firm performance but has paid little attention to its determinants.

KEYWORDS

Alliance portfolio diversity; alliance; technological diversity; uncertainty

JEL CLASSIFICATIONS

D7; O32

1. Introduction

Strategic alliances are a valuable tool for firms to exchange technologies or jointly perform R&D with their partners and to spread the risks and costs of the innovation process (Hagedoorn 1993; Mowery, Oxley, and Silverman 1996). Firms in many high-tech industries are entering alliances with other firms on a regular basis, which often leads to them conducting more than one alliance at the same time, giving rise to what the literature refers to as the 'alliance portfolio'. The exact definition of what constitutes a firm's alliance portfolio in prior literature differs depending on the focus of the research. Research on alliance networks has found more network-centric definitions for the alliance portfolio such as the firm's egocentric alliance network (e.g. Baum, Calabrese, and Silverman 2000; Ozcan and Eisenhardt 2009), while research that has focused on a certain alliance characteristic only included partnerships that fit that characteristics and used definitions of alliance portfolios including only joint ventures or portfolios defined as only the international partnerships of a firm (e.g. Reuer, Park, and Zollo 2002; Reuer and Ragozzino 2006). Literature that focuses on the learning aspects of alliances often included also the firm's past alliances (e.g. Reuer, Park, and Zollo 2002). In the context of this study, the alliance portfolio is defined as the

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set of all currently active alliances with other firms (Bae and Gargiulo 2004). Following the focus on portfolios of alliances (Wassmer 2010), research has investigated various characteristics of alliance portfolios.

Understanding that the ultimate goal for a firm is not the alliance deal or the alliance portfolio itself, but rather to use the possibilities provided by the alliances, such as access to the resources of the alliance partners, to create innovation, previous literature has investigated how the alliance portfolio contributes to the performance of the firm. While literature on alliance portfolios first focused on the size of the portfolio, i.e. how many alliances the firm is taking part in, it has recognised that the size by itself is not a good predictor for firm performance (Wassmer 2010). Consequently, literature has investigated other portfolio characteristics such as breadth, efficiency and partner quality (e.g. Baum, Calabrese, and Silverman 2000; Gulati 1999; Stuart 2000). Recent literature has been especially interested in various measures related to the diversity of the alliance portfolio (Duysters et al. 2012; Oerlemans, Knoben, and Pretorius 2013; Van de Vrande 2013) and has defined the diversity based on both characteristics of the partners, e.g. partner type or technological resources of the partners, and characteristics of the alliance deals such as the mode of governance. Literature has, however, paid little attention to the factors that influence the alliance diversity itself. Alliance portfolio diversity, however, is not a fixed firm characteristic, but rather the reflection of a firm's strategy to actively influence and deal with its business environment (Golonka 2015). Bahlmann et al. (2012) suggest two solutions to actively adapt the diversity of the alliance portfolio to balance explorative and exploitative learning activities of the firm: firms can either try to balance diversity across different domains (dimensions) of diversity or assemble a suboptimal but stable 'core' portfolio of alliances and perform changes to the portfolio diversity in response to changing conditions by adjusting the 'crust' alliances sitting on top of the core portfolio. In a case study on Dutch start-ups, Tjemkes et al. (2014) showed how different, in terms of size and various diversity measures, configurations of alliance portfolios allow firms in the knowledge-intensive business service sector to develop innovation and bring it to the market. Investigating the determinants of alliance portfolio diversity also allows to extend the existing models linking alliance portfolio diversity and various dimensions of firm performance. Given that a key motive for firms pursuing strategic alliances is to increase various dimensions of performance, understanding what influences the diversity of alliance portfolios can provide new managerial insights how various factors, via the mediating effect on alliance portfolio diversity, affect the firms' financial and innovation performance.

Contributing to a, so far, little studied field within the literature on alliance portfolios (Golonka 2015), the objective of this study is to investigate internal and external determinants of alliance portfolio diversity. Focusing on technological aspects and the role of R&D alliances as tools to monitor technologies and access partner firms' knowledge (Hagedoorn 1993; Mowery, Oxley, and Silverman 1996), we defined technological alliance portfolio diversity as the diversity of the technological resources held by the partner firms in the alliance portfolio. Based on previous literature, which has seen alliances as 'a firm's adaptive behaviour to maintain a match between firm strategy and resource endowment on the one hand and changing environmental conditions on the other' (Hoffmann 2007), this study examines the effects of a firm's internal technological diversity, which is a reflection of the firm's resources and strategy, as well as of the uncertainty of the firm's environment on the technological diversity of its alliance portfolio. We theorise that an increasing internal technological diversity of the firm reduces the diversity of technologies held by the partner firms in its alliance portfolio while technological uncertainty increases the diversity. Our empirical analysis based on a sample of semiconductor firms confirms the relationship between internal technological diversity and technological alliance portfolio diversity but fails to find evidence for effects of technological uncertainty.

This study contributes to strategic alliance literature, which so far has analysed the determinants of alliance portfolio diversity using limited definitions and empirical settings, by investigating internal and external factors that affect the diversity of a firm's alliance portfolio defined in terms of technological diversity. Unlike previous literature which has mostly relied on surveys, the hypotheses of this study are tested using patent data over a longer time period.

The remainder of this paper is organised as follows: first, we discuss the relevant literature and develop hypotheses which link internal technological diversity and external technological uncertainty with alliance portfolio diversity. Second, we test our hypotheses using a data-set of U.S.-listed firms in the semiconductor industry. Finally, we present our empirical results and conclude with a discussion of implications, limitations and directions for future research.

2. Literature

In many high-tech industries, firms form alliances at an increasing rate and pursue multiple alliances at the same time, building up alliance portfolios (Lavie 2007). Literature on strategic alliances has followed this trend and has shifted its focus away from the single alliance towards a view that focuses on the interaction of the individual alliances and the characteristics and management of the portfolio (George et al. 2001; Parise and Casher 2003; Wassmer 2010). Within the alliance literature, in recent years, a number of studies have focused on alliance portfolio diversity, also sometimes referred to as alliance portfolio complexity. Alliance portfolio diversity research mainly concerns itself with the effects of diverse alliance portfolios on firm performance. Many of the studies found an inverted U-shaped relationship between alliance portfolio diversity and firm performance (e.g. de Leeuw, Lokshin, and Duysters 2014; Duysters et al. 2012; Jiang, Tao, and Santoro 2010; Oerlemans, Knoben, and Pretorius 2013). At lower levels of alliance portfolio diversity, positive effects are limited as partners provide resources that are similar to the one the focal firm already possesses. Too high levels of diversity, on the other hand, increase communication, monitoring and coordination costs and reduce the benefits of the access to diverse knowledge (Oerlemans, Knoben, and Pretorius 2013).

Previous studies have defined alliance portfolio diversity in a variety of ways such as partner type (de Leeuw, Lokshin, and Duysters 2014; Faems et al. 2010; Oerlemans, Knoben, and Pretorius 2013), modes of governance (Van de Vrande 2013), activity along the value chain (Bruyaka and Durand 2012; Duysters et al. 2012) and diversity of partners' technological resources (Srivastava and Gnyawali 2011; Vasudeva and Anand 2011). Firm performance has for the most part been measured as innovation performance (Faems et al. 2010; Sampson 2007; Van de Vrande 2013) or financial performance (Jiang, Tao, and Santoro 2010). The relationship between alliance portfolio diversity and firm performance has been empirically researched using data-sets spanning a range of industries such as semiconductors (Srivastava and Gnyawali 2011), telecommunication equipment (Sampson 2007), pharmaceuticals (Van de Vrande 2013), automobile (Jiang, Tao, and Santoro 2010) and fuel cell technology (Vasudeva and Anand 2011).

Unlike the number of studies on the effects of alliance portfolio diversity, only a limited number of empirical studies have focused on what affects the diversity of a firm's alliance portfolio. Duysters and Lokshin (2011) have investigated the alliance portfolio diversity, defined as geographical diversity as well as different types of alliance partners, of firms that are either classified as innovators, imitators or non-innovators. The study employed data from two consecutive Community Innovation Surveys performed in the Netherlands. Collins (2013) investigated the influence of social capital held by the top management team and by the firm itself on the industrial diversity of the alliance portfolios of 300 randomly selected firms from the Standard Poor's 500 list. Golonka (2015) used survey data to investigate how ICT firms' cooperation strategy, their proactiveness in forming cooperation and trust in the partners affect the diversity of their alliance portfolios in terms of geographic diversity, governance diversity and partner type diversity. While the studies described have used a number of different approaches to define alliance portfolio diversity, to our knowledge, no study has yet investigated the determinants of technological alliance portfolio diversity. Technological alliance portfolio diversity is a diversity measure directly based on the technological resources possessed by the partner firms in the alliance portfolio and has been shown to affect firms' innovation performance (Srivastava and Gnyawali 2011; Vasudeva and Anand 2011). Consequently, a better understanding of the factors affecting this diversity, as attempted by our study, will have not just academic but also practical implications.

3. Theory and hypotheses

Zaheer, Gulati, and Nohria (2000) have argued that the evolution of alliance networks is shaped by both internal and external forces while Hoffmann (2007) talks about the alignment of the firm's alliance portfolio with the external environmental conditions and internal resources and strategy. Following this thought, this paper hypothesises the effect of both internal and external factors on the diversity of firms' alliance portfolios.

In terms of internal factors, previous literature has stressed the importance of the firm's resources (Peteraf 1993; Wernerfelt 1984), which often determine the opportunities available to the firm (Penrose 1959). While the focus was originally placed on resources that are internal to the firm, later work has acknowledged that key resources can span firm boundaries and firms also access and employ the resources of their alliance partners (Dyer and Singh 1998; Lavie 2006). In other words, firms access and use internal knowledge, which it created through its own R&D activities as well as the externally sourced knowledge of its partners. While previous literature has not come to an agreement on whether the relationship between internal R&D and external knowledge sourcing is substitutive (Kang, Jo, and Kang 2015; Laursen and Salter 2006) or complementary (Cassiman and Veugelers 2006; Grimpe and Kaiser 2010), the relationship between the internal knowledge base and external knowledge has been previously investigated in the context of alliances. Among the previous studies that have investigated characteristics of the firm's internal knowledge base and alliance portfolios, a number of studies have focused on the breadth and diversity aspects (e.g. Srivastava and Gnyawali 2011; Wuyts and Dutta 2014; Zhang, Baden-Fuller, and Mangematin 2007). This paper adopts the internal technological diversity of the firm, an important characteristic of the internal knowledge base that reflects the R&D strategy of the firm, and investigates how it affects the diversity of the knowledge provided in the firm's alliance portfolio. Selecting technological diversity as the representative internal factor has also the added benefit of complementing the work of Srivastava and Gnyawali (2011), who investigated the effect of this diversity on the relationship between alliance portfolio diversity and innovation performance.

In terms of external factors, previous literature has linked alliance portfolio diversity and the uncertainty of the external environment of the firms. Ozcan and Eisenhardt (2009) showed how diversified alliance portfolios help firms to better handle environmental uncertainty. Similarly, Hoffmann (2007) argued that diverse alliance portfolios allow firms to better deal with high levels of uncertainty by increasing their strategic flexibility. While one stream of literature has investigated the positive impact of alliance portfolio diversity in dealing with the environment, another stream of previous research (e.g. Castro, Casanueva, and Galán 2014; Lavie and Singh 2012) has argued that firms and their alliance portfolios co-evolve in response to changes of the technological environment. More specifically, Koka, Madhavan, and Prescott (2006) hypothesised that an increasing uncertainty will lead to an increase in the range of partners in the portfolio and Tao, Jiang, and Santoro (2015) have investigated the effects of environmental jolts on several dimensions of alliance portfolio diversity.

3.1. *Internal technological diversity*

The resources available to a firm play a critical role in the innovation process as innovation is generally understood to be created by recombining existing resources (Ahuja and Lampert 2001; Fleming 2001; Kogut and Zander 1992). In today's high-tech industries, firms can no longer simply rely on a single product or technology to indefinitely sustain a competitive advantage. Constant innovation is the key for firms to stay ahead of their competition and survive. For successful innovation, not just the amount of resources held by a firm, but also their diversity is important. Due to limits of creating new ideas from a limited and constant set of knowledge, the existence of a more diverse range of resources allows a firm to increase the possibility of developing useful combinations (Katila and Ahuja 2002). Consequently, more diverse internal resources improve the firm's ability to innovate through resource recombination (Carnabuci and Operti 2013). A firm which does not possess diverse internal resources can follow two strategies to obtain them: either develop them through internal R&D or use external sourcing modes. Creating new knowledge internally is a difficult process that requires time and the investment of the limited resources of the firm and firms are often limited in their ability to internally produce diverse technologies (Hagedoorn and Schakenraad 1994). Internal R&D is also inflexible, increases the path dependency of the firm and makes it more difficult to move towards radically new or different technologies (Narula 2001). To overcome these limitations, firms take advantage of external sources of knowledge and access them through various strategies such as strategic alliances, mergers and acquisitions, joint ventures and venture capital investments (Schildt, Maula, and Keil 2005).

To gain access to the diverse knowledge and technological resources needed for recombination, firms with a low internal diversity will try to form relationships granting them access to the diverse knowledge and technologies of other firms, e.g. by assembling a technologically diverse alliance portfolio. With increasing internal resource diversity of a firm, the need to obtain diverse resources through external acquisition methods becomes less urgent. As they can already use their diverse internal resources to create innovation through the recombination of knowledge, firms see less value in the pursuit of access to external diverse resources due to two important factors: increased costs and changes in the perception of knowledge from outside the firm.

Increasing diversity, both internally and externally, leads to increasing costs. Technology diversification within the firm increased R&D costs (Granstrand 1998), resulting in less of the firm's limited resources being available to pursue other knowledge acquisition strategies. At the same time, increasing the diversity of an alliance portfolio increases complexity, resulting in higher managerial and coordination costs (Bruyaka and Durand 2012; Jiang, Tao, and Santoro 2010). This makes it difficult for firms to both internally and externally pursue high levels of resource diversity.

Additionally, relying on its diverse internal experiences and knowledge, firms may fall into a competency trap (Levitt and March 1988) which results in the firm becoming increasingly unwilling to pursue other options. Possessing already a diversified portfolio of technologies and knowledge, a firm might suffer from the 'not-invented-here syndrome' (Katz and Allen 1982). According to Lichtenthaler and Ernst (2006), it affects the preference for outside knowledge and can lead firms to wrongly evaluate and neglect external technology. The reduced willingness of firms possessing a diversified base of technical resources to acquire external resources has also been demonstrated by Srivastava and Gnyawali (2011).

Another possible explanation is that as a firm diversifies its internal technological portfolio, it gains knowledge and expertise in a wider range of fields. This knowledge allows the firm to better identify technologies and knowledge that can supplement and complement its internal resources. Consequently, such a more experienced firm would pursue a strategy of a more focused external technology acquisition by selecting only the most promising alliance partners (Rothaermel and Hill 2005). However, one could make the counter-argument that such increased knowledge as the result of a more diverse internal knowledge base raises the firm's absorptive capacity, i.e. its capacity to recognise the usefulness of externally acquired knowledge, to assimilate it and to apply it towards the firm's business (Cohen and Levinthal 1990). In other words, the firm would be better equipped to handle and profit from diverse alliance portfolios and would be more likely to pursue a strategy of diversifying its portfolio of alliances. The knowledge of various technological fields is, however, just one of possible sources of absorptive capacity. Previous literature has used factors such as R&D intensity (Cohen and Levinthal 1990) and the relative relationship between the firm and its knowledge source (Lane and Lubatkin 1998) as indicators of firm's absorptive capacity and our empirical study controls for these effects. All of the above leads us to the following hypothesis:

> Hypothesis 1: The level of a firm's internal technological diversity is negatively related with the technological diversity of its alliance portfolio.

3.2. *External uncertainty*

High-tech industries are often turbulent and characterised by a high level of uncertainty. Previous literature has investigated a range of internal and external uncertainties (Folta 1998). For firms in high-tech industries, uncertainties related to changes in the key technologies of the industry, i.e. technical uncertainty (Gilsing, Vanhaverbeke, and Pieters 2014; Goerzen 2007; Van de Vrande, Vanhaverbeke, and Duysters 2009), are of great concern as firms' existing knowledge and technologies might become obsolete due to technology shifts (Koka and Prescott 2008). The technological uncertainty has two effects on firms: first, it increases the pressure to innovate and second, it requires firms to identify technological options to be prepared for when the current capabilities and technologies are no longer sufficient to successfully compete in the industry.

In unstable environments, firms are found to be more likely to exhibit strategic reorientation (Lant, Milliken, and Batra 1992) and the uncertainty of the environment raises the necessity for firms to innovate at an increasing rate in order to survive (Rowley, Behrens, and Krackhardt 2000). Robertson and Gatignon (1998) demonstrated that to cope with the pressure to innovate under the condition of high technological uncertainty, firms are more likely to employ technological alliances rather than just rely on internal R&D.

Being open to external sources of technology allows firms to increase the number of technological opportunities (Laursen and Salter 2006). When the uncertainty is high, firms find it difficult to predict which technologies will allow it to sustain or gain a competitive advantage in the future. Such effects can be mitigated by the use of real options (Tao, Jiang, and Santoro 2015). Real options are investments in non-financial assets that provide the firm opportunities to respond to future events (Reuer and Tong 2005). A small investment into the real option is done immediately; however, the choice to continue with a larger investment or not take up the option is taken at a later point. At this point in time, the firm might possess more information to make the final decision (Bowman and Hurry 1993). An example of real options would be to conduct pilot tests or exploratory R&D on a small scale, before committing large amounts of the firm's resources into manufacturing facilities or commercialisation (Ziedonis 2007). In terms of innovation and environmental uncertainty, firms will create real options to be able, depending on the direction the industry is taking, to choose between different technologies. Kogut (1991) has investigated firms' use of joint ventures to create real options, which they can later take up or defer. Alliances are another external knowledge acquisition mode which allows firms to learn about opportunities from their partners (Vassolo, Anand, and Folta 2004). With increasing uncertainty, firms will try to create a larger number of options to react to the changing trends of technology, which will be reflected in an increasing technological diversity of its alliance portfolio.

The increasing pressure to innovate in an uncertain environment and the firm's use of alliances to create real options lead us to the following hypothesis:

> Hypothesis 2: The level of external uncertainty is positively related with the technological diversity of a firm's alliance portfolio.

4. Methodology

4.1. *Data and sample*

For our empirical analysis, we have compiled a data-set of firms in the semiconductor industry. The semiconductor industry is a high-tech industry that is known for its propensity to patent (Hall and Ziedonis 2001) and networks of innovators (Kapoor and McGrath 2014). We began by identifying U.S.-listed firms with an Standard Industrial Classification (SIC) Code of 3674 (Semiconductors and Related Devices) from the Compustat North America database and collected information such as sales and R&D expense data for the 1990–2010 period. This time period was chosen to ensure a sufficient number of suitable samples. While firms in the semiconductor industry are very active in forming alliances, many of the alliances focus on manufacturing or other services. Additionally, the semiconductor industry is dynamic and due to the constraints and filtering process described below, some firms only provided observable characteristics in a smaller number of observation years.

In the next step, we obtained information on the U.S. patents granted to each of the firms by the United States Patent and Trademark Office (USPTO). The matching between the firms and its patents was performed using the matching data compiled by the Coleman Fung Institute for Engineering Leadership at UC Berkeley (Fierro 2014). Due to the fact that one of the independent variables as well as an important control variable is based on patents, we decided to exclude all firms which had not been granted any patents. This left us with a sample of 171 U.S. semiconductor firms which had been granted at least one patent during the observation period. For each of those 171 firms, we compiled a list of strategic alliances they entered from 1990 to 2010 using information from the Thomson Reuters SDC Platinum database (Schilling 2009), which we matched with the previously obtained Compustat firm data using the CUSIP (Committee on Uniform Securities Identification Procedures) number assigned to each firm in both databases. Alliances before 1990 were not considered due to doubts about the completeness of the alliance data in the database (Schilling 2009). Using the provided alliance activity code, we decided to only include alliances which contained an R&D component, i.e. we excluded all alliances focusing purely on marketing, manufacturing or various services. Some of the alliances were formed between three or more firms and we have converted such alliances into sets of dyadic alliances. Due to the fact that not all of the semiconductor firms formed R&D-focused alliances during the sample period, at this point, the number of firms in the sample was reduced to 88 firms. These 88 semiconductor firms engaged in a total of 1,123 R&D-focused alliances with 632 different partner firms. The next step was to transform the list of alliance deals into the alliance portfolios of the 88 firms. As the SDC database does not contain complete information on when a given alliance ended, we followed previous studies assumed an alliance duration of three years (Schilling and Phelps 2007; Srivastava and Gnyawali 2011) when compiling the firms' alliance portfolios. For each of the 632 alliance partners, we obtained information on the patents granted using again the Fung Institute's patent data files. We were unable to find patent information for 188 of the partner firms. These 188 firms without patents were either undisclosed partners or firms which had not been granted any patents by the USPTO. For each of the firms in our sample, we now calculated the technological diversity of the alliance portfolio for each year in which the firm had at least one active alliance. Due to the fact that, as mentioned above, some of the alliance partners had no patent information, at this point, the sample was further reduced by excluding all firms whose alliance portfolios did not include at least one patent. This had to be done as without patents, we are unable to calculate the dependent variable of this study.

The final sample contains observations from 68 distinct firms. Further accounting for the fact that many of these 68 firms in our sample did not exist for the whole observation period due to being incorporated later than 1990 or exiting the industry before 2010, and also excluding observations with missing values, our final data-set contains 403 firm year observations.

4.2. Measures

4.2.1. Dependent variable

The dependent variable, *Alliance portfolio diversity*, is the technological diversity of the alliance portfolio. Technological diversity has often been measured using patent class data (e.g. Huang and Chen 2010; Miller, Fern, and Cardinal 2007). We follow previous literature (Lin, Chen, and Wu 2006; Quintana-García and Benavides-Velasco 2008; Rao, Vemuri, and Galvin 2004) in adopting a diversity measure based on the Herfindahl Index. In the field of alliance portfolio research, the use of the Herfindahl Index in combination with patent class data to measure technological alliance portfolio diversity has previously been used in studies of Srivastava and Gnyawali (2011) and Vasudeva and Anand (2011). Our measure is defined as:

$$\text{Alliance portfolio diversity} = \tfrac{N}{N-1}\left(1 - \textstyle\sum_i p_i^2\right)$$

where N is the total number of patents held by the alliance partners and p_i is the proportion of the alliance partners' patents in the technical field i. The factor $N/(N-1)$ is a correction for the bias introduced to Herfindahl Index-based measurements, especially when they are based on a small sample size. The bias is corrected following the formula suggested by (Hall 2005). Due to the high number of individual patent classes in the USPTO patent classification system, which leads to some classes having a very low technological distance, we utilised a patent classification system based on Hall, Jaffe, and Trajtenberg (2001), which resulted in the patents being classified into one of the 38 different fields. Due to the high depreciation rate of technological knowledge in high-tech industries (Park, Shin, and Park 2006), we only included patents applied for by the alliance partners within the five years before the alliance deal.

4.2.2. Independent variables

The operationalisation for the independent variable *Technological diversity* followed a similar bias-corrected Herfindahl Index-based approach as the dependent variable. It is based on the patents applied for by the focal firm in the five years before the observation year. For the classification, we used the same 38 categories and calculated the diversity using the formula given above.

Technological uncertainty, which is external to the firm, is often measured using the year-to-year changes in patenting activity on the industry level. Goerzen (2007) measured the percentage change in the number of patents of the industry between two years. A similar approach was used by Gilsing, Vanhaverbeke, and Pieters (2014) who measured the relative change in the number of industry patents for a given year compared to the average of the three preceding years. Instead of basing a measure on the total patenting activity, Van de Vrande, Vanhaverbeke, and Duysters (2009) introduced a measure based on the change of patenting activity in the patent classes that are most relevant for a given industry. To calculate the independent variable *Uncertainty*, we followed the procedure described in Van de Vrande, Vanhaverbeke, and Duysters (2009). We began by identifying all the USPTO patent classes in which the focal firms in our sample had been granted patents during the observation period and narrowed the list down to the 22 classes which accounted for 80 per cent of the patents. For each of the classes, we now calculated the total number of U.S. patent

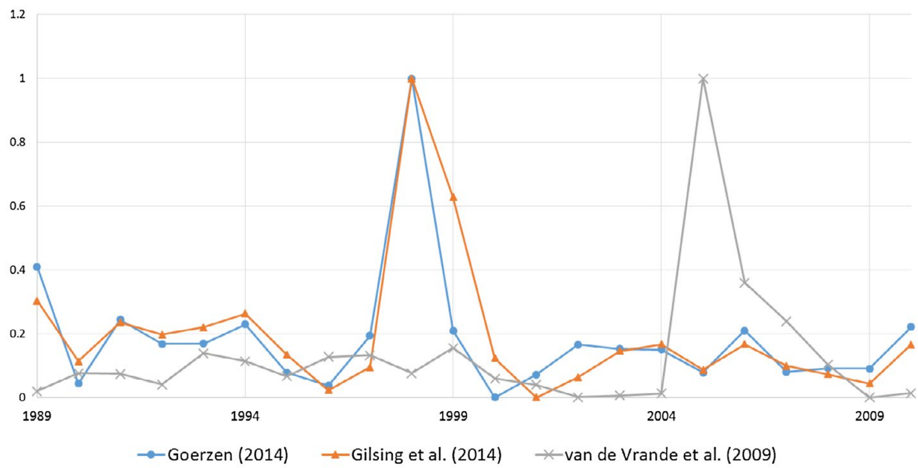

Figure 1. A comparison of various uncertainty measures.

applications per observation year and calculated the Pearson correlation coefficient ρ for each pair of subsequent yearly patent distributions. We define *Uncertainty* as $1 - \rho$ and lag the variable by one year. The firms in our sample account for roughly 50 per cent of all granted patents within the 22 key patent classes that were applied for during the observation period. The calculation of the variable revealed relatively small year-to-year differences, but a large uncertainty in the year 2005. This prompted us to also calculate the uncertainty following the above-mentioned approaches of Goerzen (2007) and Gilsing, Vanhaverbeke, and Pieters (2014). A comparison of the results of these measures is given in Figure 1. The spike in the patent class-based measure is due to especially a massive change in the patenting activity within US Patent Class 257, which covers active solid-state devices such as transistors. This spike is not seen in the other two measures which are based on the changes of the total number of patents. These two measures, however, exhibit a spike in 1998, which is the result of a general large increase in U.S. patents that year.

4.2.3. *Control variables*

Our empirical analysis includes a range of different control variables: portfolio size, similarity, R&D intensity, firm size, firm age as well as a number of time dummy variables. First, we control for the size of the alliance portfolio with the variable *Portfolio size*, defined as the number of alliances in the alliance portfolio in the observation year. The similarity of the focal firm's patent portfolio and the patent portfolio of the alliance partners is an important control variable as it might influence the alliance portfolio diversity in a number of different ways: on the one hand, an increasing similarity between the knowledge and resources of the focal firm and its partners increases absorptive capacity (Cohen and Levinthal 1990) and allows the focal firm to better access, transfer and incorporate the resources of its partners. This might result in firms pursuing more diversified portfolios. On the other hand, similar knowledge of focal firm and partners can increase the chance for redundancy and decrease the value of having a diversified portfolio. We calculate *Similarity* for each year and firm by calculating the Pearson correlation coefficient between the distribution of patents granted to both the focal firm and the firms in its alliance portfolio during the last five years based on the patent classification of Hall, Jaffe, and Trajtenberg (2001). As a firm's absorptive capacity in previous literature is often also approximated by the firm's R&D intensity, we define *R&D intensity* as the firm's R&D expenses in a given year divided by the firm's total sales of the same year. Another variable that might have an effect on the firm's alliance portfolio is its size. We define *Firm size* as the sales in each observation year. Due to very high inter-firm differences, we log-transformed *Firm size*. We also controlled for *Firm age*, defined as the number of years between the establishment of the firm and the observation year. Semiconductor firms can be distinguished by their approach to manufacturing. Some larger firms such as Intel Inc. have their own manufacturing facilities which are often referred to as 'fab', while other firms follow a 'fab-less' business model and focus on the design of semiconductors but outsource the manufacturing to other firms. While we have specifically excluded alliances which just focus on manufacturing from our dataset, the choice of business model of the semiconductor firms might affect their alliance decisions. Consequently, we have included a control variable *Fab*, which takes the value of 1 when the firm manufactures in-house and 0 if it follows the fab-less business model. We also introduced a series of year dummy variables.

4.3. *Method*

Our dependent variable, *Alliance portfolio diversity*, is continuous and limited to the [0,1] range. Without considering this characteristic, the predicted values could fall outside this range. For this reason, the dependent variable was logit transformed (Baum 2008; Warton and Hui 2011). As logit transformation does not work on values that are exactly 0 or 1 (which represent around 5 per cent of all observations), the variable was first transformed to avoid these values using the following equation suggested by Smithson and Verkuilen (2006), where N is the sample size:

$$\mathrm{APD}' = \left[\mathrm{APD} * (N-1) + \frac{1}{2}\right] / N$$

Our unbalanced panel data was then analysed using a linear regression model, both assuming random and fixed effects.

5. Results

Table 1 shows a summary of the descriptive statistics and the correlations among the variables used in our study. There are no high correlations between any of the variables. Nevertheless, in order to check for the presence of any multicollinearity problem, we performed an additional variance inflation factor (VIF) test. The results of this VIF test are shown in Table 2 and the low values (average of 1.78) indicate that we do not have any problems with multicollinearity.

Table 3 contains the results of our regression analysis using a random effects model. Model 1 contains all the control variables used in our study. The coefficients for *Similarity* and *Firm size* are statistically significant, i.e. we find that similar alliance portfolios tend to be more diverse and also larger firms tend to have more diverse alliance portfolios. Similar portfolios raise absorptive capacity and allow the firm to take better advantage also of diverse knowledge while large firms possess more resources to deal with the increasing complexity of managing highly diversified portfolios. Firm age is shown to be significant in three out of

Table 1. Descriptive statistics and correlations matrix.

	Variables	Min	Max	Mean	SD	1	2	3	4	5	6	7	8
1.	Similarity	0.01	0.99	0.52	0.27	1							
2.	Portfolio size	1	81	6.62	11.60	0.32	1						
3.	Firm size	0.57	43,623	3,170.63	6,556.97	0.21	0.43	1					
4.	R&D intensity	0.01	24.06	0.29	1.23	0.09	−0.05	−0.28	1				
5.	Firm age	2	59	22.29	12.61	0.18	0.24	0.36	−0.08	1			
6.	Technological diversity	0	1	0.75	0.16	0.19	0.18	0.09	0.04	0.16	1		
7.	Uncertainty	0.00	0.01	0.01	0.02	0.05	−0.05	0.07	0.22	0.01	−0.06	1	
8.	Alliance portfolio diversity	0	1	0.78	0.20	0.26	0.29	0.13	−0.03	0.02	0.01	0.01	1

Table 2. VIF test results.

Variables	VIF
Similarity	1.19
Portfolio size	1.37
Firm size	1.59
R&D intensity	1.19
Firm age	1.27
Fab	1.34
Technological diversity	1.12
Uncertainty	1.09
Average	1.27

Table 3. Regression results for alliance portfolio diversity (random effects model).

	Model 1		Model 2		Model 3		Model 4	
Variables	Coefficient	(SE)	Coefficient	(SE)	Coefficient	(SE)	Coefficient	(SE)
Control variables (at time t)								
Similarity	0.847***	(0.213)	0.870***	(0.211)	0.838***	(0.214)	0.865***	(0.212)
Portfolio size	0.007	(0.006)	0.006	(0.006)	0.007	(0.006)	0.006	(0.006)
Firm size	0.121*	(0.066)	0.117*	(0.066)	0.114*	(0.066)	0.113*	(0.066)
R&D intensity	0.012	(0.044)	0.015	(0.043)	0.006	(0.045)	0.011	(0.044)
Firm age	−0.015	(0.010)	−0.017*	(0.010)	−0.016	(0.010)	−0.017*	(0.010)
1990s dummy	0.705***	(0.145)	0.716***	(0.144)	0.706***	(0.145)	0.719***	(0.144)
Independent variables								
Technological diversity$_{t-1}$			−1.219***	(0.410)			−1.199***	(0.411)
Uncertainty$_{t-1}$					1.670	(2.384)	1.149	(2.362)
Constant	0.222	(0.416)	1.112**	(0.510)	0.235	(0.415)	1.104**	(0.509)
Fab dummy	Included		Included		Included		Included	
Number of observations	403		403		403		403	
R^2 (overall)	0.197		0.204		0.202		0.202	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

the four models. We originally included year dummies controlling for each observation year, but found that all year dummies for years in the 1990s were significant, which prompted us to create a new dummy variable, which takes the value 1 if the observation year is in the 1990s. This new control variable also solved a multicollinearity problem that exists when all years are controlled for, as the uncertainty levels are also distinct for each given year.

Table 4. Regression results for alliance portfolio diversity (fixed effects model).

	Model 1		Model 2		Model 3		Model 4	
Variables	Coefficient	(SE)	Coefficient	(SE)	Coefficient	(SE)	Coefficient	(SE)
Control variables (at time t)								
Similarity	0.751***	(0.227)	0.753***	(0.234)	0.734***	(0.227)	0.740***	(0.224)
Portfolio size	0.001	(0.007)	−0.002	(0.006)	0.001	(0.006)	−0.001	(0.006)
Firm size	0.283**	(0.111)	0.266**	(0.110)	0.269**	(0.112)	0.255**	(0.110)
R&D intensity	0.023	(0.047)	0.024	(0.046)	0.0134	(0.048)	0.017	(0.047)
Firm age	−0.088***	(0.021)	−0.092***	(0.021)	−0.090***	(0.021)	−0.093***	(0.021)
Independent variables								
Internal diversity$_{t-1}$			−1.580***	(0.462)			−1.555***	(0.464)
Uncertainty$_{t-1}$					2.378	(2.410)	1.801	(2.379)
Constant	1.270*	(0.659)	2.654***	(0.765)	1.387**	(0.670)	2.721**	(0.770)
1990s dummy	Included		Included		Included		Included	
Number of observations	403		403		403		403	
R^2 (within)	0.197		0.225		0.199		0.226	
R^2 (between)	0.002		0.001		0.001		0.001	
R^2 (overall)	0.019		0.014		0.016		0.012	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Model 2 tests our Hypothesis 1, which predicted a negative influence of the internal resource diversity on the diversity of the alliance portfolio. The coefficient for *Technological diversity* (−1.219, $p < 0.01$) is negative and highly significant in Model 2 as well as in Model 4 (−1.199, $p < 0.01$), the full model. This strongly supports our Hypothesis 1. Model 3 tests Hypothesis 2, which predicted that increasing technological uncertainty leads to firms building up more diverse portfolios. The coefficient for *Uncertainty* is neither significant in Model 3 nor in Model 4. We have retested Model 3 using the uncertainty definitions of Goerzen (2007) as well as of Gilsing, Vanhaverbeke, and Pieters (2014), but in both cases (not shown in Table 3) failed to obtain statistically significant results. In summary, our empirical analysis did not support our Hypothesis 2.

The results for the fixed effects model, which are presented in Table 4, are very similar to the results of the random effects model. Again we find significance of the Similarity, Firm size and Firm age control variables. We also find support for our Hypothesis 1 but fail to support Hypothesis 2 using all three different definitions of *Uncertainty* (Table 4 only shows our baseline using the uncertainty definition of Van de Vrande, Vanhaverbeke, and Duysters (2009)).

5.1. *Robustness test*

We also conducted an additional robustness test to rule out possible problems stemming from a 'reverse causality', i.e. the possibility that the internal technological diversity is not the cause of technological alliance portfolio diversity but its effect. To address this problem, we reversed the temporal order of our independent variable and dependent variable for Hypothesis 1. Specifically, we set *Technological diversity [t + 1]* as the dependent variable, *Alliance portfolio diversity [t]* as the independent variable and performed our regression analysis following the same procedure as for the original analysis. The results of the reverse-order regression analysis are shown in Table 5 and we do not find any statistically significant relationships between the two lagged variables.

Table 5. Reverse causality test (regression results for technological diversity$_{t+1}$).

Variables	Model 1 (fixed effects)		Model 2 (random effects)	
	Coefficient	(SE)	Coefficient	(SE)
Control variables (at time t)				
Similarity	0.154**	(0.067)	0.156**	(0.066)
Portfolio size	−0.001	(0.002)	−0.002	(0.002)
Firm size	−0.095***	(0.030)	−0.058**	(0.026)
R&D intensity	−0.011	(0.014)	−0.004	(0.013)
Firm age	0.006	(0.006)	0.011*	(0.006)
Independent variables				
Alliance portfolio diversity $_t$	0.097	(0.095)	0.084	(0.093)
Constant	1.491***	(0.170)	0.997***	(0.237)
Fab dummy			Included	
Year dummies	Included		Included	
Number of observations	389		389	
R^2 overall	0.0041		0.0755	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

6. Discussion

This study investigates internal and external factors that affect the diversity of a firm's alliance portfolio. Specifically, focusing on technological aspects, we examined the effects of internal technological diversity and technological uncertainty on the technological diversity of alliance portfolios. We tested our hypotheses on a sample of U.S.-listed semiconductor firms.

Our empirical results confirm that increasing internal diversity of the technological resources held by a firm negatively affects the diversity of its portfolio. In other words, firms that cover a wide range of technological fields within the firm are less likely to follow the same strategy in building their alliance portfolio. This result falls in line with a stream of research advocating for organisational ambidexterity. Ambidextrous organisations balance and pursue both exploration and exploitation (Raisch et al. 2009). Literature has acknowledged that this balancing does not just happen within a certain mode of operation such as internal activities and external alliance activities, but also between different modes (Rothaermel and Alexandre 2009; Russo and Vurro 2010; Stettner and Lavie 2014). Diversification and variation can be interpreted as exploration of new possibilities, in contrast to exploitation, which is a focus on existing competencies (Lavie, Stettner, and Tushman 2010; March 1991). This relates to the firms in our sample as firms that focus on exploration within the firm's boundary, i.e. have a high internal technological diversity, achieve boundary crossing ambidexterity by limiting their external technology acquisition to focus on a smaller range of technologies. On the other hand, firms who focus on specific capabilities of their non-diverse internal knowledge complement this internal exploitation focus by having a diverse alliance portfolio, which can be seen as more exploration oriented.

We also hypothesised that the technological diversity of a firm's alliance portfolio is affected by the technological uncertainty, i.e. the environment in which the firm operates. Our hypothesis was based on the idea that increasing uncertainty makes it difficult for the firm to predict which technologies will become the next driving force of the industry and will support the firm's competitive advantage. Consequently, we expected firms to build up a range of options by increasing the access to a more diverse range of technologies through their alliance portfolios. However, we failed to find empirical evidence for such effect. Recently, Tao, Jiang, and Santoro (2015) investigated how firms in the telecom industry adapt their alliance portfolios to environmental jolts. They focused on two large-scale disruptions to the firm's environment: the 1996 US Telecommunications Act and the 2000 dot.com crisis. While they were able to find evidence for changes of the alliance portfolio size as well as for changes to the alliance portfolio's functional and governance diversity, they found no evidence of changes in the partner diversity as a reaction to the changing environment. Their partner diversity measure was based on the partners' industrial background (as indicated by their SIC codes). Such partner diversity measures serve as a proxy for the resources and capabilities offered by the partner firms and thus are closely related to the approach of our study, in which we define the alliance portfolio diversity based on the technological resources of the partners, measured by their patents. Together, the results of Tao, Jiang, and Santoro (2015) and of this study indicate that alliance portfolio resource diversity is unaffected by year-to-year changes of the external uncertainty as well as by larger environmental jolts. Our comparison of different measures for external uncertainty has also shown that the indicated uncertainty differs depending on whether the measures are based on all patents of an industry or just a selection of the most important ones. This opens up the question on how to best measure uncertainty. Previous literature has shown a long-running debate on whether uncertainty can be measured objectively, as we have done in this study, or should be treated as a perceptual measure, i.e. the important factor is how the firm, or, respectively, its managers, sees and evaluates the external uncertainty (e.g. Milliken 1987; Snyder and Glueck 1982). It might well be that the change in resource-oriented dimensions of alliance portfolio diversity does not depend on objective, but rather subjective factors.

This study contributes to the research on strategic alliances, especially the research focused on the concept of alliance portfolio diversity. Previous research has extensively investigated the effects of alliance portfolio diversity on firm performance in a variety of settings but has paid little attention to investigating factors influencing the diversity. We extend previous research on this topic (Duysters and Lokshin 2011; Golonka 2015) which has recently begun to investigate the determinants of alliance portfolio diversity. Specifically, we contribute by following a technological perspective and defining alliance portfolio diversity in terms of the diversity of the technological resources held by the firms in the alliance portfolio. This dimension of alliance portfolio diversity is important as the access to partners' resources is one of the key reasons for firms to enter into strategic alliances. Our study investigated the effects of both internal (internal resource diversity) and external (technological uncertainty) determinants on this alliance portfolio diversity. The choice of internal resource diversity as an independent variable also allows us to complement the research of Srivastava and Gnyawali (2011). They investigated the moderating effect of internal resource diversity on the relationship between alliance portfolio diversity and innovation performance. Our research complements this by allowing to investigate a mediating effect: internal resource diversity directly affects alliance portfolio diversity, which in turn affects innovation performance. Our investigation of environmental uncertainty complements previous work of Tao, Jiang, and Santoro (2015), who investigated how firms adapt their alliance portfolios after environmental jolts, by researching changes in alliance portfolio diversity in response to the year-by-year variation of the uncertainty in the firms' environment over longer time periods. Further setting our research apart from previous studies of the determinants of alliance portfolio diversity, which had mostly relied on survey results, our study employs alliance and patent data and empirically tests its hypotheses on a data-set with a longer time duration.

As previous research has consistently demonstrated, the diversity of a firm's alliance portfolio has direct implications for its financial and innovation performance. Consequently, it has stressed the need for managers to be aware of the composition of their alliance portfolios. Our study further contributes to the understanding of this diversity by explaining the effects of internal resource diversity, which can be affected by a firm's spending on internal R&D.

7. Limitations and future research

While providing important insights into the determinants of alliance portfolio diversity, our study has some limitations, which we hope will be overcome by future research in this field: first, as the focus of this paper is on the determinants of alliance portfolio diversity, we have only considered alliances as external technology sourcing strategy. In practice, there are other options available to the firm such as corporate venture capital (CVC) investments and M&As. However, research has shown that firms in industries characterised by strong technological change prefer flexible sourcing instruments and, e.g., prefer alliances over M&A (Hagedoorn and Duysters 2002). Nevertheless, future research could incorporate other possibilities for firms to obtain technologies and create real options. Second, this study follows a number of prior studies (e.g. Srivastava and Gnyawali 2011; Vasudeva and Anand 2011) and adopted a technological perspective in defining alliance portfolio diversity as well as internal resource diversity based on patents. Patent-based indicators can suffer from possible variations of propensity to patent over time or between different industries (Pavitt 1985) and the fact that they disregard innovations that are not patented (Kleinknecht, Van Montfort, and Brouwer 2002). In a similar fashion, the use of alliance data from the SDC Platinum database presents a limitation. While the database is regarded as one of the most inclusive one, it does not capture all alliance deals and some entries contain estimated information, e.g. on the date of alliance announcement. Future research could try to supplement the available data with data from other sources or use other, more specialised databases. This study uses a single-industry data-set from the semiconductor industry as a representative high-tech sector. We hope that future research will extend our understanding of the determinants of alliance portfolio diversity by adopting a greater variety of definitions and empirical settings to further increase the validity and applicability of the results.

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References

Ahuja, G., and C. M. Lampert. 2001. "Entrepreneurship in the Large Corporation: A Longitudinal Study of How Established Firms Create Breakthrough Inventions." *Strategic Management Journal* 22 (6–7): 521–543.

Bae, J., and M. Gargiulo. 2004. "Partner Substitutability, Alliance Network Structure, and Firm Profitability in the Telecommunications Industry." *Academy of Management Journal* 47 (6): 843–859.
Bahlmann, M., A. Alexiev, B. Tjemkes, and A.-P. de Man. 2012. "Between Learning and Competence: The Effect of Alliance Portfolio Diversity on Learning Equilibrium." In *Proceedings of the 9th International Conference on Innovation and Management*, edited by G. Duysters, A. de Hoyos, and K. Kaminishi, 98–110. Wuhan: Wuhan University of Technology Press.
Baum, C. F. 2008. "Stata Tip 63: Modeling Proportions." *Stata Journal* 8 (2): 299.
Baum, J. A., T. Calabrese, and B. S. Silverman. 2000. "Don't Go It Alone: Alliance Network Composition and Startups' Performance in Canadian Biotechnology." *Strategic Management Journal* 21 (3): 267–294.
Bowman, E. H., and D. Hurry. 1993. "Strategy through the Option Lens: An Integrated View of Resource Investments and the Incremental-choice Process." *Academy of Management Review* 18 (4): 760–782.
Bruyaka, O., and R. Durand. 2012. "Sell-off or Shut-down? Alliance Portfolio Diversity and Two Types of High Tech Firms' Exit." *Strategic Organization* 10 (1): 7–30.
Carnabuci, G., and E. Operti. 2013. "Where Do Firms' Recombinant Capabilities Come from? Intraorganizational Networks, Knowledge, and Firms' Ability to Innovate through Technological Recombination." *Strategic Management Journal* 34 (13): 1591–1613.
Cassiman, B., and R. Veugelers. 2006. "In Search of Complementarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition." *Management Science* 52 (1): 68–82.
Castro, I., C. Casanueva, and J. L. Galán. 2014. "Dynamic Evolution of Alliance Portfolios." *European Management Journal* 32 (3): 423–433.
Cohen, W. M., and D. A. Levinthal. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35: 128–152.
Collins, J. D. 2013. "Social Capital as a Conduit for Alliance Portfolio Diversity." *Journal of Managerial Issues* 25 (1): 62–78.
Duysters, G., K. H. Heimeriks, B. Lokshin, E. Meijer, and A. Sabidussi. 2012. "Do Firms Learn to Manage Alliance Portfolio Diversity? The Diversity-performance Relationship and the Moderating Effects of Experience and Capability." *European Management Review* 9 (3): 139–152.
Duysters, G., and B. Lokshin. 2011. "Determinants of Alliance Portfolio Complexity and Its Effect on Innovative Performance of Companies." *Journal of Product Innovation Management* 28 (4): 570–585.
Dyer, J. H., and H. Singh. 1998. "The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage." *Academy of Management Review* 23 (4): 660–679.
Faems, D., M. De Visser, P. Andries, and B. Van Looy. 2010. "Technology Alliance Portfolios and Financial Performance: Value-enhancing and Cost-increasing Effects of Open Innovation." *Journal of Product Innovation Management* 27 (6): 785–796.
Fierro, G. 2014. "Processing USPTO Patent Data." Coleman Fung Institute for Engineering Leadership.
Fleming, L. 2001. "Recombinant Uncertainty in Technological Search." *Management Science* 47 (1): 117–132.
Folta, T. B. 1998. "Governance and Uncertainty: The Trade-off between Administrative Control and Commitment." *Strategic Management Journal* 19 (11): 1007–1028.
George, G., S. A. Zahra, K. K. Wheatley, and R. Khan. 2001. "The Effects of Alliance Portfolio Characteristics and Absorptive Capacity on Performance." *The Journal of High Technology Management Research* 12 (2): 205–226.
Gilsing, V., W. Vanhaverbeke, and M. Pieters. 2014. "Mind the Gap." *Technological Forecasting and Social Change* 81: 351–362.
Goerzen, A. 2007. "Alliance Networks and Firm Performance: The Impact of Repeated Partnerships." *Strategic Management Journal* 28 (5): 487–509.
Golonka, M. 2015. "Proactive Cooperation with Strangers: Enhancing Complexity of the ICT Firms' Alliance Portfolio and Their Innovativeness." *European Management Journal* 33: 168–178.
Granstrand, O. 1998. "Towards a Theory of the Technology-based Firm." *Research Policy* 27 (5): 465–489.

Grimpe, C., and U. Kaiser. 2010. “Balancing Internal and External Knowledge Acquisition: The Gains and Pains from R&D Outsourcing.” *Journal of Management Studies* 47 (8): 1483–1509.
Gulati, R. 1999. “Network Location and Learning: The Influence of Network Resources and Firm Capabilities on Alliance Formation.” *Strategic Management Journal* 20 (5): 397–420.
Hagedoorn, J. 1993. “Understanding the Rationale of Strategic Technology Partnering: Nterorganizational Modes of Cooperation and Sectoral Differences.” *Strategic Management Journal* 14 (5): 371–385.
Hagedoorn, J., and G. Duysters. 2002. “External Sources of Innovative Capabilities: The Preferences for Strategic Alliances or Mergers and Acquisitions.” *Journal of Management Studies* 39 (2): 167–188.
Hagedoorn, J., and J. Schakenraad. 1994. “The Effect of Strategic Technology Alliances on Company Performance.” *Strategic Management Journal* 15 (4): 291–309.
Hall, B. H. 2005. “A Note on the Bias in Herfindahl-type Measures Based on Count Data.” In *Patents, Citations and Innovations*, edited by M. Trajtenberg and A. B. Jaffe. Boston, MA: MIT Press.
Hall, B. H., A. B. Jaffe, and M. Trajtenberg. 2001. “The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools.” National Bureau of Economic Research Working Paper. N. B. o. E. Research.
Hall, B. H., and R. H. Ziedonis. 2001. “The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979–1995.” *The RAND Journal of Economics* 101–128.
Hoffmann, W. H. 2007. “Strategies for Managing a Portfolio of Alliances.” *Strategic Management Journal* 28 (8): 827–856.
Huang, Y.-F., and C.-J. Chen. 2010. “The Impact of Technological Diversity and Organizational Slack on Innovation.” *Technovation* 30 (7–8): 420–428.
Jiang, R. J., Q. T. Tao, and M. D. Santoro. 2010. “Alliance Portfolio Diversity and Firm Performance.” *Strategic Management Journal* 31 (10): 1136–1144.
Kang, K. H., G. S. Jo, and J. Kang. 2015. “External Technology Acquisition: A Double-edged Sword.” *Asian Journal of Technology Innovation* 23 (1): 35–52.
Kapoor, R., and P. J. McGrath. 2014. “Unmasking the Interplay between Technology Evolution and R&D Collaboration: Evidence from the Global Semiconductor Manufacturing Industry, 1990–2010.” *Research Policy* 43 (3): 555–569.
Katila, R., and G. Ahuja. 2002. “Something Old, Something New: A Longitudinal Study of Search Behavior and New Product Introduction.” *Academy of Management Journal* 45 (6): 1183–1194.
Katz, R., and T. J. Allen. 1982. “Investigating the Not Invented Here (NIH) Syndrome: A Look at the Performance, Tenure, and Communication Patterns of 50 R & D Project Groups.” *R&D Management* 12 (1): 7–20.
Kleinknecht, A., K. Van Montfort, and E. Brouwer. 2002. “The Non-trivial Choice between Innovation Indicators.” *Economics of Innovation and New Technology* 11 (2): 109–121.
Kogut, B. 1991. “Joint Ventures and the Option to Expand and Acquire.” *Management Science* 37 (1): 19–33.
Kogut, B., and U. Zander. 1992. “Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology.” *Organization Science* 3 (3): 383–397.
Koka, B. R., R. Madhavan, and J. E. Prescott. 2006. “The Evolution of Interfirm Networks: Environmental Effects on Patterns of Network Change.” *Academy of Management Review* 31 (3): 721–737.
Koka, B. R., and J. E. Prescott. 2008. “Designing Alliance Networks: The Influence of Network Position, Environmental Change, and Strategy on Firm Performance.” *Strategic Management Journal* 29 (6): 639–661.
Lane, P. J., and M. Lubatkin. 1998. “Relative Absorptive Capacity and Interorganizational Learning.” *Strategic Management Journal* 19 (5): 461–477.
Lant, T. K., F. J. Milliken, and B. Batra. 1992. “The Role of Managerial Learning and Interpretation in Strategic Persistence and Reorientation: An Empirical Exploration.” *Strategic Management Journal* 13 (8): 585.
Laursen, K., and A. Salter. 2006. “Open for Innovation: The Role of Openness in Explaining Innovation Performance among U.K. Manufacturing Firms.” *Strategic Management Journal* 27 (2): 131–150.

Lavie, D. 2006. "The Competitive Advantage of Interconnected Firms: An Extension of the Resource-based View." *Academy of Management Review* 31 (3): 638–658.
Lavie, D. 2007. "Alliance Portfolios and Firm Performance: A Study of Value Creation and Appropriation in the U.S. Software Industry." *Strategic Management Journal* 28 (12): 1187–1212.
Lavie, D., and H. Singh. 2012. "The Evolution of Alliance Portfolios: The Case of Unisys." *Industrial and Corporate Change* 21 (3): 763–809.
Lavie, D., U. Stettner, and M. L. Tushman. 2010. "Exploration and Exploitation within and across Organizations." *The Academy of Management Annals* 4 (1): 109–155.
de Leeuw, T., B. Lokshin, and G. Duysters. 2014. "Returns to Alliance Portfolio Diversity: The Relative Effects of Partner Diversity on Firm's Innovative Performance and Productivity." *Journal of Business Research* 67 (9): 1839–1849.
Levitt, B., and J. G. March. 1988. "Organizational Learning." *Annual Review of Sociology* 319–338.
Lichtenthaler, U., and H. Ernst. 2006. "Attitudes to Externally Organising Knowledge Management Tasks: A Review, Reconsideration and Extension of the NIH Syndrome." *R&D Management* 36 (4): 367–386.
Lin, B.-W., C.-J. Chen, and H.-L. Wu. 2006. "Patent Portfolio Diversity, Technology Strategy, and Firm Value." *Engineering Management, IEEE Transactions on* 53 (1): 17–26.
March, J. G. 1991. "Exploration and Exploitation in Organizational Learning." *Organization Science* 2 (1): 71–87.
Miller, D. J., M. J. Fern, and L. B. Cardinal. 2007. "The Use of Knowledge for Technological Innovation Within Diversified Firms." *Academy of Management Journal* 50 (2): 307–325.
Milliken, F. J. 1987. "Three Types of Perceived Uncertainty about the Environment: State, Effect, and Response Uncertainty." *Academy of Management Review* 12 (1): 133–143.
Mowery, D. C., J. E. Oxley, and B. S. Silverman. 1996. "Strategic Alliances and Interfirm Knowledge Transfer." *Strategic Management Journal* 17 (S2): 77–91.
Narula, R. 2001. "Choosing between Internal and Non-internal R&D Activities: Some Technological and Economic Factors." *Technology Analysis & Strategic Management* 13 (3): 365–387.
Oerlemans, L. A., J. Knoben, and M. W. Pretorius. 2013. "Alliance Portfolio Diversity, Radical and Incremental Innovation: The Moderating Role of Technology Management." *Technovation* 33 (6–7): 234–246.
Ozcan, P., and K. M. Eisenhardt. 2009. "Origin of Alliance Portfolios: Entrepreneurs, Network Strategies, and Firm Performance." *Academy of Management Journal* 52 (2): 246–279.
Parise, S., and A. Casher. 2003. "Alliance Portfolios: Designing and Managing Your Network of Business-partner Relationships." *Academy of Management Executive* 17 (4): 25–39.
Park, G., J. Shin, and Y. Park. 2006. "Measurement of Depreciation Rate of Technological Knowledge: Technology Cycle Time Approach." *Journal of Scientific and Industrial Research* 65 (2): 121.
Pavitt, K. 1985. "Patent Statistics as Indicators of Innovative Activities: Possibilities and Problems." *Scientometrics* 7 (1–2): 77–99.
Penrose, E. T. 1959. *The Theory of the Growth of the Firm*. New York: Wiley.
Peteraf, M. A. 1993. "The Cornerstones of Competitive Advantage: A Resource-based View." *Strategic Management Journal* 14 (3): 179–191.
Quintana-García, C., and C. A. Benavides-Velasco. 2008. "Innovative Competence, Exploration and Exploitation: The Influence of Technological Diversification." *Research Policy* 37 (3): 492–507.
Raisch, S., J. Birkinshaw, G. Probst, and M. L. Tushman. 2009. "Organizational Ambidexterity: Balancing Exploitation and Exploration for Sustained Performance." *Organization Science* 20 (4): 685–695.
Rao, P., V. Vemuri, and P. Galvin. 2004. "The Changing Technological Profile of the Leading ICT Firms: Evidence from US Patent Data, 1981–2000." *Industry and Innovation* 11 (4): 353–372.
Reuer, J., K. M. Park, and M. Zollo. 2002. "Experiential Learning in International Joint Ventures: The Roles of Experience Heterogeneity and Venture Novelty." In *Cooperative Strategies and Alliances*, edited by F. J. Contractor and P. Lorange, 321–346. Oxford: Pergamon.
Reuer, J., and R. Ragozzino. 2006. "Agency Hazards and Alliance Portfolios." *Strategic Management Journal* 27 (1): 27–43.

Reuer, J., and T. W. Tong. 2005. "Real Options in International Joint Ventures." *Journal of Management* 31 (3): 403–423.

Robertson, T. S., and H. Gatignon. 1998. "Technology Development Mode: A Transaction Cost Conceptualization." *Strategic Management Journal* 19 (6): 515–531.

Rothaermel, F. T., and M. T. Alexandre. 2009. "Ambidexterity in Technology Sourcing: The Moderating Role of Absorptive Capacity." *Organization Science* 20 (4): 759–780.

Rothaermel, F. T., and C. W. Hill. 2005. "Technological Discontinuities and Complementary Assets: A Longitudinal Study of Industry and Firm Performance." *Organization Science* 16 (1): 52–70.

Rowley, T., D. Behrens, and D. Krackhardt. 2000. "Redundant Governance Structures: An Analysis of Structural and Relational Embeddedness in the Steel and Semiconductor Industries." *Strategic Management Journal* 21 (3): 369–386.

Russo, A., and C. Vurro. 2010. "Cross-boundary Ambidexterity: Balancing Exploration and Exploitation in the Fuel Cell Industry." *European Management Review* 7 (1): 30–45.

Sampson, R. C. 2007. "R&D Alliances and Firm Performance: The Impact of Technological Diversity and Alliance Organization On Innovation." *Academy of Management Journal* 50 (2): 364–386.

Schildt, H. A., M. V. Maula, and T. Keil. 2005. "Explorative and Exploitative Learning from External Corporate Ventures." *Entrepreneurship Theory and Practice* 29 (4): 493–515.

Schilling, M. A. 2009. "Understanding the Alliance Data." *Strategic Management Journal* 30 (3): 233–260.

Schilling, M. A., and C. C. Phelps. 2007. "Interfirm Collaboration Networks: The Impact of Large-scale Network Structure on Firm Innovation." *Management Science* 53 (7): 1113–1126.

Smithson, M., and J. Verkuilen. 2006. "A Better Lemon Squeezer? Maximum-likelihood Regression with Beta-distributed Dependent Variables." *Psychological Methods* 11 (1): 54.

Srivastava, M. K., and D. R. Gnyawali. 2011. "When Do Relational Resources Matter? Leveraging Portfolio Technological Resources for Breakthrough Innovation." *Academy of Management Journal* 54 (4): 797–810.

Stettner, U., and D. Lavie. 2014. "Ambidexterity under Scrutiny: Exploration and Exploitation via Internal Organization, Alliances, and Acquisitions." *Strategic Management Journal* 35 (13): 1903–1929.

Stuart, T. E. 2000. "Interorganizational Alliances and the Performance of Firms: A Study of Growth and Innovation Rates in a High-technology Industry." *Strategic Management Journal* 21 (8): 791–811.

Snyder, N. H., and W. F. Glueck. 1982. "Research Notes. Can Environmental Volatility Be Measured Objectively?" *Academy of Management Journal* 25 (1): 185–192.

Tao, Q. T., R. J. Jiang, and M. D. Santoro. 2015. "Expand or Retrench? Alliance Portfolio Adaptation to Environmental Jolts." *International Journal of Business Environment* 7 (1): 79–97.

Tjemkes, B. V., E. H. de Pinéda, M. D. Bahlmann, A.-P. de Man, and A. S. Alexiev. 2014. "Open Innovation and KIBS Start-ups: Technology-and Market-based Alliance Portfolio Configurations." In *Open Innovation through Strategic Alliances*, edited by R. Culpan, 191–217. New York: Palgrave Macmillan.

Van de Vrande, V. 2013. "Balancing Your Technology-sourcing Portfolio: How Sourcing Mode Diversity Enhances Innovative Performance." *Strategic Management Journal* 34 (5): 610–621.

Van de Vrande, V., W. Vanhaverbeke, and G. Duysters. 2009. "External Technology Sourcing: The Effect of Uncertainty on Governance Mode Choice." *Journal of Business Venturing* 24 (1): 62–80.

Vassolo, R. S., J. Anand, and T. B. Folta. 2004. "Non-additivity in Portfolios of Exploration Activities: A Real Options-based Analysis of Equity Alliances in Biotechnology." *Strategic Management Journal* 25 (11): 1045–1061.

Vasudeva, G., and J. Anand. 2011. "Unpacking Absorptive Capacity: A Study of Knowledge Utilization from Alliance Portfolios." *Academy of Management Journal* 54 (3): 611–623.

Warton, D. I., and F. K. Hui. 2011. "The Arcsine is Asinine: The Analysis of Proportions in Ecology." *Ecology* 92 (1): 3–10.

Wassmer, U. 2010. "Alliance Portfolios: A Review and Research Agenda." *Journal of Management* 36 (1): 141–171.

Wernerfelt, B. 1984. "A Resource-based View of the Firm." *Strategic Management Journal* 5 (2): 171–180.

Wuyts, S., and S. Dutta. 2014. “Benefiting from Alliance Portfolio Diversity the Role of past Internal Knowledge Creation Strategy.” *Journal of Management* 40 (6): 1653–1674.
Zaheer, A., R. Gulati, and N. Nohria. 2000. “Strategic Networks.” *Strategic Management Journal* 21 (3): 203.
Zhang, J., C. Baden-Fuller, and V. Mangematin. 2007. “Technological Knowledge Base, R&D Organization Structure and Alliance Formation: Evidence from the Biopharmaceutical Industry.” *Research Policy* 36 (4): 515–528.
Ziedonis, A. A. 2007. “Real Options in Technology Licensing.” *Management Science* 53 (10): 1618–1633.