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ALLIANCE PORTFOLIO DIVERSITY AND INNOVATION OUTCOMES: DOES TECHNOLOGY MANAGEMENT MATTER?

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ABSTRACT

In this paper we test whether the use of a set of technology management tools (TM-tools), a specification of alliance portfolio capability, influences the relationship between alliance portfolio diversity and a firm's innovation outcomes. Based on a sample of South African firms we first confirm the inverted U-shaped relation between alliance portfolio diversity and a firm's innovation outcomes found by earlier research. We also show that the shape of this inverted-U differs for incremental and radical innovation outcomes. Subsequently, we test the moderating effect of the use of TM-tools on this relationship, for which find a strong positive moderating effect. In particular, for firms intensively using TM-tools the negative effect of high levels of alliance portfolio diversity on innovation outcomes turns into a positive effect. This suggests that the use of formal technology management practices is beneficial to manage highly diverse alliance portfolios.

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1. INTRODUCTION

One of the latest sprouts of the alliance literature focuses on portfolios of alliances [69]. It is shown that the prevalence of alliance portfolios is increasing over time [43] and that the characteristics of portfolios, such as their diversity, impact on a firm's (innovation) outcomes above and beyond what can be expected by the presence of the sum of individual alliances [22], [56]. Such findings fit the general idea that the inter-organizational relationships and (ego centric) networks within which organizations are embedded have important consequences for their outcomes.

Moreover, several studies have shown us that performance heterogeneity among firms is not only the result of the impact of the characteristics of their network [63] and network ties [61] but also a consequence of variation in managerial action directed at these ties [57]. In recent years a vast body of literature developed describing and analyzing the skills and abilities needed to manage inter-organizational ties (so-called alliance management capability). A recent literature review on alliance management [34] concluded that a vast majority of scholarly work has focused on the management of single inter-organizational relationships. The same study observed that many firms are connected to a set of partners, an alliance network or portfolio, which brings new managerial challenges [29]. First, an organization needs to assess to what extent the composition of its alliance portfolio is in fit with its strategic needs. Second, while building its portfolio, it has to deal with competition that might grow between individual partners in the portfolio. Third, it has to ensure that the synergetic benefits that accrue from complementary alliances in its portfolio are actually reaped by the firm [35: p. 57].

Based on these arguments, it is useful to take a portfolio approach to the management of a firm's set of inter-organizational relationships and to develop an alliance portfolio capability [60]. In particular, this approach becomes relevant when an organization collaborates on technological matters with a diverse set of actors. In that case, the firm is confronted with an inflow of diverse knowledge resources, which could, if not properly organized and managed, negatively impact on its innovation outcomes, due to, for example, a lack of knowledge identification and coordination devices [20]. Although there are a number of studies investigating the effects of a firm's alliance portfolio diversity on its subsequent innovation outcomes, with a few notable exceptions [28], [59], [60], there are hardly any large scale empirical studies on alliance portfolio management in general and on the influence of alliance portfolio management on this relationship in particular [48], [71]. Therefore, there is a need to fill this gap in our knowledge [35] and answer the call for more research on this topic.

To achieve just that, this paper studies the impact of alliance portfolio diversity on innovation outcomes, and the moderation of this relation by the use of a set of technology management tools (TM-tools). The choice to focus on ego networks is made because a set of direct relations is better known to and can be actively managed by firms, whereas this is far less the case for indirect ties or the position of firms in the overall network structure. TM-tool use is an especially applicable specification of what [59] label as alliance portfolio coordination because it helps in identifying, selecting and combining relevant technologies in the hands of a diverse set of external actors, with which the focal firm has technological collaborations [55]. Therefore, we put forward the following research question: *"What is the effect of alliance portfolio diversity on a firm's innovation outcomes, and what is the effect of the use of TM-tools on this relationship?"*
By answering this question, we build on and contribute to the literature in two distinct ways. First, we contribute to alliance portfolio (management) literature by showing that the negative effects of high levels of portfolio diversity on innovation outcomes can be counteracted by conscious and focused managerial efforts. Preceding studies

predominantly focus on the development of capabilities and management functions aiming for the improvement of the functioning of *individual* alliances, but say relatively little about which managerial interventions allying firms put in place to profit from externally acquired knowledge and information acquired from a *set* of inter-organizational ties. Studying the impact of the use of technology management tools in the context of a variety of technological collaborations with different types of partners will increase our understanding of the performance impacts of managerial action.

Second, we contribute to increasing the generalizability of empirical findings in alliance portfolio diversity literature by studying the performance effects of alliance portfolios of firms in non-western context, that is, in South Africa. This economy is of special interest because for a long time it was isolated from the world economy, inhibiting the wide-spread formation and the proper functioning of domestic and international inter-organizational relationships. In the post apartheid era, the South African government consciously strived for a re-connection to the world economy and it was one of the first countries in the world adopting the system of innovation policy approach. The formation of relationships between different parts of the innovation system and with other parts of the world economy was stimulated to foster technological and economic development. Replicating the performance effects of alliance portfolios in this empirical context would clearly add to the generalizability of these findings.

1.   THEORY AND HYPOTHESES

2.1   Alliance Portfolio Diversity

Diversity is generally defined as: "the distribution of differences among the members of a unit with respect to a common attribute X" [27]. This attribute can be many things, for example tenure, gender, or network ties. Diversity is, therefore, a unit-level and multi-dimensional concept. Further specifying the concept, Harrison and Klein [27] distinguish between separation (composition of differences in position or opinion regarding values, beliefs, or attitudes), disparity (vertical differences for example in terms of status or expertise), and variety (composition of differences in kind, source or category of knowledge or experience) among unit members. In this paper, the emphasis lies on variety, because we focus on the different knowledge bases possessed by different types of domestic and international external organizations that are accessed through technological collaborations. This means that we assume: (a) that unit members (i.e. external actors) differ on categorical attributes, in our case, on the type of actor and the types of knowledge they bring to the technological collaboration and their geographical location; (b) units (i.e. alliance portfolios) differ in the extent to which their members are distributed across these categories. In a next section, the different types of actors and the different knowledge bases they possess are delineated, but first we turn to the organizational unit of relevance: the alliance portfolio of a firm.

The literature distinguishes alliance portfolios and alliance networks. Alliance portfolios are commonly defined as sets of alliances, thus concerning the ego-network including a firm's direct ties, whereas alliance networks also includes the ego-networks of the alters [10]. In this study, we opt for the former definition because it is most commonly used in the alliance portfolio literature [6], [18], [40]. Consequently, alliance portfolio diversity is defined as the distribution of differences reflecting variety in characteristics of a focal firm's direct alliance partners [10]. The direct ties taken into account are technological collaborations with a wide range of domestic and international external actors (e.g. buyers, suppliers, universities, research labs) in which partner firms actively work together on the development of technologically new or strongly improved products, processes and services.

Diversity in the alliance portfolio is the result of linking with different types of actors possessing different types of knowledge located in different geographical areas. Collaborating with organizations such as universities and research labs gives access to fundamental knowledge and the possibility to conduct high quality research [39]. Suppliers possess knowledge related to production processes and input characteristics that could lead to process innovation, cost reduction or product innovation [62], whereas buyers can be sources of new product ideas as is evidenced in the medical instruments and software industry [67]. Collaborations with competitors gives access to industry-specific knowledge and a possibility to share, for example, research facilities [36] and consultants and private research organizations can be valuable sources, for example because they offer engineering capabilities or marketing knowledge helping in commercializing innovations [64], [65].

2.2 Alliance Portfolio Diversity and the Innovation Outcomes of Firms

There is a small but growing literature on the innovation outcome implications of firms' linkage in diverse alliance portfolios. The dominant perspective is that there is an inverted U-shaped relationship between a firm's level of alliance portfolio diversity and its innovation outcomes [19], [40]. Interestingly, three partly overlapping theoretical explanations grounding this non-linear relationship can be found in the literature.

Resource Based View argument. Arguments derived from the Extended Resource Based View of the firm [41] point at the benefits of having a highly diverse set of alliances to innovation. In this theoretical perspective, alliance portfolio diversity refers to the diversity of network resources possessed by partners, which can, through inter-organizational ties, be accessed by a focal firm. The effect thereof on a firm's innovation outcomes takes place through four mechanisms [42]. First, a more diverse set of alliances provide access to a wider variety of complementary assets required to turn innovation projects into commercial success [22]. These external complementary and specific resources contribute to innovation outcomes because they supplement the firm's resources with resources that are not available internally. Second, a more diverse set of partners reduces the risk of knowledge redundancy and increases the probability that new knowledge and information is accessed, which can lead to higher and novel innovation outcomes [6]. Third, a firm can create value by combining resources of distinct partners, and thus profit from synergies that are not available from any individual partner in its portfolio. Finally, if a focal actor relies on inter-organizational links with actors of the same type, there are no mechanisms for iterative and diverse learning feedback with respect to an innovation [58]. In this argument a diverse set of actor in the alliance portfolio serves as a sounding board for the focal actor.

There are, however, downsides to highly diverse alliance portfolios impacting negatively on firms' innovation outcomes as well. Highly diverse alliance portfolios can lead to information overflow. Koput [38] presents three related reasons why information overflow has negative performance effects: (a) an absorptive capacity problem: there are too many ideas to manage and to choose from; (b) a timing problem: the inflowing knowledge and ideas come at the wrong time or in the wrong place to be fully exploited; (c) the attention allocation problem: because there are too many ideas, few of these ideas are given the attention needed to implement them. Put differently, in the case of high alliance portfolio diversity the cognitive limits of the innovating firms are more easily reached, which has negative performance effects because efficient solutions to portfolio challenges are not reached.

Organizational economics argument. Organizational economists and resource-based theorists agree on the possible cross alliance benefits of portfolios, but the former use

cost arguments to substantiate their position [7]. On the one hand, the cost-reducing impact of collaboration with suppliers leads, for example, to increased R&D effort under cooperation with competitors, which in turn might lead to higher innovation outcomes [2]. On the other hand, informed by transaction cost economics logic, it is argued that collaborating with a larger set of diverse actors increases complexity, coordination, communication, knowledge processing, and monitoring costs of these hybrid governance structures, while at the same time lowering benefits. Moreover, high levels of alliance portfolio diversity may increase the probability of opportunism, for example resulting in unobserved and unintended knowledge spillovers [14]. Collaboration with a moderately diverse set of partners can therefore be argued to be most beneficial.

In sum, increasing levels of alliance portfolio diversity leads to cost reduction effects and cross alliance synergetic benefits up to a certain point after which the costs of processing and managing a highly diverse set of knowledge and information possessing actors becomes too costly.

Internationalization argument. In the economic geography literature it is argued that geographical proximity eases the transfer of tacit knowledge in particular. Because this type of knowledge is difficult to imitate, firms with collaborations with a diverse set of local actors have comparative knowledge advantages resulting in higher innovation outcomes. More recently, however, this line of reasoning has been challenged [37], building on the argument that the probability that an innovating firm can find all required or new knowledge locally is not very high. Consequently, the importance of inter-regional linkage for innovation is more emphasized. This argument is further specified by scholars who pointed at the importance of internationalization of alliance portfolios [44]. The more innovating firms collaborate with a diverse set of international partners, the higher their innovation outcomes because these alliances provide flexibility, adaptability to global market conditions, and reduction of risk and uncertainty [44]. More specifically, international technological collaborations with diverse partners provide new sources of technologies, resources and ideas, which can be used to generate new and improved products and services. However, collaborating with a too diverse set of international partners has a number of liabilities impacting negatively on innovation outcomes. Examples of these liabilities are: (a) greater investments are needed to facilitate interaction; (b) due to different appropriability regimes undesired spillover may occur; and (c) cultural and institutional differences may hamper trust-building, commitment and knowledge exchange. Overall, these liabilities reduce effective technological collaboration, which impairs the firm's innovation outcomes.

The three theoretical arguments presented in the above all lead to our first hypothesis:

Hypothesis 1. There is an inverted U-shaped relationship between a firm's level of alliance portfolio diversity and its level of innovation outcomes.

There is reason to believe, however, that not all types of innovation outcomes are equally affected by alliance portfolio diversity. On the one hand, it can be argued that the production of technologically new products and services asks for a greater diversity of the alliance portfolio. Because more radical innovations combine relatively new knowledge resources, access to dissimilar (external) knowledge is an important condition [25]. Greater portfolio diversity may reduce a firm's inclination to capitalize on or to be locked into its prior knowledge and enables firms to keep track of new technical advances [70]. Moreover, acquiring diverse, non-redundant knowledge through technology alliances can foster the development of new insights and solutions and facilitates experimentation with new combinations, resulting in novel innovations [1]. These arguments lead to the conclusion that as compared to the generation of more incremental innovations, the

production of more radical innovations is conditioned upon the access to a more diverse set of alliances. In other words and other things being equal, the value of alliance portfolio diversity that maximizes innovation outcomes is assumed to be higher for more radical innovations.

Moreover, the magnitude of the short-term outcome implications of incremental and radical innovations is likely to differ as well. The inflow of more diverse knowledge not only brings novelty to the firm, but also an increasing probability of failure and lower adoption rates in the market. Put differently, the short-term performance impact for the focal firm from more incremental innovations tends to be higher in comparison to more radical innovations due to the fact the former innovations are more proximate, predictable and less risky [71]. Due to these characteristics, the features of incremental innovations can be more easily recognized and appreciated by external users generating a higher probability of short-term sales, whereas more radical innovations are more alien to users and take more time to get diffused.

Hypothesis 2. For radical innovation outcomes (as compared to incremental innovation outcomes): (a) the level of alliance portfolio diversity that maximizes respective innovation outcomes will be higher; and (b) the maximum of the short-term innovation outcomes will be lower.

2.3   The Role of Technology Management

In the previous sections, it is assumed that the innovation outcomes of all firms are equally influenced by alliance portfolio diversity. Innovation and knowledge transfer processes in which multiple (external) partners are involved are, however, difficult organizational activities due to the complexities and uncertainties related to technological innovation in general and the complexity of assessing multiple knowledge flows across organizational boundaries in particular. It is therefore unlikely that the capabilities to assess inflows of knowledge acquired from a selected set of actors are evenly distributed across firms. In particular, the technology management tools used by firms to identify and select technologies hold by external partners can be argued to moderate the relationship between alliance portfolio diversity and innovation performance.

In this study, the use of technology management tools in the context of multiple collaborations is regarded as a dimension of alliance portfolio capability. Until recently, the ability to manage alliances mainly dealt with single alliances [29], [35]. Although it is advantageous to know how to manage dyads, many organizations are involved in a set of alliances. As Hoffman [29] maintains, shifting from a single to a portfolio of alliances brings a number of new managerial challenges. Following Kale and Singh [35: p. 57], a distinction can be made between alliance capability (aiming at managing single alliances) and alliance portfolio capability. The latter concept refers to a firm's ability to manage its set of alliances as a portfolio and comprises of the development and implementation of a portfolio strategy, the monitoring and coordination of the alliance portfolio, and the institutionalization of multi-alliance management [30].

Thus far very few academics have paid attention to the investigation of the effects of (dimensions of) alliance portfolio management on alliance and firm performance [29] as most studies are conceptual [43] or descriptive. Moreover, it is virtual impossible to empirically research the impacts of all dimensions of alliance portfolio management in one study. In this paper, therefore, we focus on a specific set of alliance management activities relevant in the context of technological collaboration and stressed by several scholars [18], [54]. We focus on managerial tools enabling capturing, sharing and

leveraging information and knowledge across an alliance portfolio. Technology management tools are managerial routines suitable for these purposes.

Technology management can be defined as the capability to stimulate the effective use of technical knowledge and skills to develop new products and processes, the improvement of existing technology, and the generation of new knowledge and skills [32]. Cetindamar et al. [12] have suggested that technology management comprises of five generic activities: *identification* of technologies which are or may be of relevance to the organization; *selection* of technologies that should be supported by the organization; *acquisition* and assimilation of selected technologies; *exploitation* of technologies, and; *protection* of knowledge and expertise. Especially, identification (e.g. technology and market scanning) and selection (technology forecasting and monitoring) are relevant activities as they facilitate the understanding of the inflow of knowledge through technological collaborations and enables firms to benefit from complementarities across and between internal and external knowledge sources [11]. Typical identification and selection activities conducted are technology audits (analyzing the current technological capabilities of the firm, competitor analysis (identification of the current competitive position of the organization), and technological forecasting (getting an overview and understanding of future technological options and their implications) [24].

The confrontation of the outcomes of the technology audits on the one hand, and the market & industry analyses and technology forecasts on the other hand, results in knowledge about the size and nature of a technology gap (the gap between the characteristics of the current internal and extern knowledge bases and external and future technological demands) . Based on this knowledge, the organization can plan its technological activities or adjust the composition of its alliance portfolio.

The moderating effect of TM-tool use. We propose that the use of TM-tools will moderate the effect of alliance portfolio diversity on innovation outcomes of firms. We argued in hypothesis one that the overall relationship between alliance portfolio diversity and innovation outcomes was curvilinear. The question remains, however, how does this relationship differ when the use of TM-tools varies?

A higher use of TM-tools allows firms to better perceive the availability and quality of external knowledge resources held by their alliance partners and, due to the link with internal technology monitoring, allows firms to make a better judgment of the (potential and synergetic) value of these resources in the context of the technology base of their own organization. These TM activities are especially valuable when the diversity of a firm's alliance portfolio increases, because in that case by nature very different knowledge and information comes from different alliance partners has to be recognized, valued and processed [59]. Moreover, utilizing more TM-tools allows firms to exploit complementarities between internal and external technology bases more fully, which is an especially valuable activity in the context of high levels of alliance portfolio diversity as well. In other words, utilizing many TM tools allows firms to benefit from high levels of alliance portfolio diversity by facilitating the recognition of valuable external resources across their alliances and combining those with internal resources resulting in better and more novel products and, ultimately, in higher levels of innovation performance. For low levels of TM-tool use, the relationship between alliance portfolio diversity and innovation outcomes is hardly affected, because the lower diversity level of the acquired external knowledge does not pose major processing problems.

A micro theoretical foundation of the moderating influence of the use of TM-tools can be derived from the literature on cognitive complexity [16], a concept developed in group and team research in the field of organizational psychology, but also applied to the

context of technological collaboration [66]. It can be described as "the complexity of the knowledge structures in a cognitive system, and the sophistication of those cognitive structures that are used for organizing and storing cognitive contents" [15]. A high level of cognitive complexity is a result of two related cognitive processes: differentiation (i.e., distinguishing many distinct dimensions or having many ideas) and integration (i.e., combining dimensions and ideas in many ways) and thus reflects the complexity with which knowledge and information about the environment is represented in cognitive systems of managers. There is ample empirical evidence from different scientific fields that higher levels of cognitive complexity are positively associated with (organizational) performance [49].

Applying the cognitive complexity logic to the context of alliance portfolio diversity, it can be argued that higher levels of alliance portfolio diversity confront organizational members with a higher number of interrelated situational cues. After all, higher diversity levels reflect more different collaboration partners who transfer different types of knowledge. The application of technology management tools help the organizational members involved to build more complex representations enabling them to make sense out of the knowledge received. Moreover, it helps them to value this knowledge and come to decisions on how to apply and combine it with the firm's internal knowledge base, subsequently leading to superior innovations that perform better in the market. In particular, the combined use of internal and external technology audits, and competitor analysis creates the most complex representations, which enables firms to reap the most out of their alliance portfolio. The above lines of reasoning leads to hypothesis 3:

H3: The relationship between alliance portfolio diversity and firm's innovation outcomes is positively moderated by the use of technology management tools.

2.   EMPIRICAL APPLICATION

3.1   Data

The theoretical ideas put forward in the previous sections will be tested by utilizing data of the South African Innovation Survey 2001 (SAIS2001). The SAIS2001 questionnaire was based on the European Community Innovation Survey, but adapted to the South African context. The population of firms in the survey consisted of all South African firms in manufacturing, services, and wholesale with 10 or more employees that conducted economic activities in the period 1998-2000. As a sampling frame the Reedbase Kompass database was used. This database contains 16,931 South African firms with a known number of employees. In SAIS 2001 stratified sampling was used as the sampling technique. The population of South African firms was divided into three different size classes (strata). Taking the number of employees as an indicator of the size of a firm, the following three strata were distinguished: Stratum 1: firms with 11 to 20 employees; Stratum 2: 21-50 employees, and; Stratum 3: more than 50 employees.

The survey was mailed to, in total, 7,339 firms of which 8.4% (N=617) returned the survey. This is a low figure, but not uncommon for organizational level questionnaire research, which often yields relatively low response rates [4]. Nevertheless, the fact that a large group of firms did not respond raises the question whether or not the data might suffer from sample bias. Therefore, a telephonic non-response analysis among 462 firms was conducted. Questions were asked about specific reasons not to respond and about some key firm characteristics, like for example R&D activity. The response to the non-response survey was very high (90%). Amongst others, non-responding firms were asked whether they had technological innovations in the period 1998-2000 and with what frequency they conducted R&D. As the same information was gathered in the written questionnaire as

well, a comparison of the response and the non-response group could be made. The results of this comparison can be found in table 1. As can be derived from this table, the comparison between respondents and non-respondents revealed no statistically significant differences.

Variable	Respon-dents	Non-respondents	Diffe-rence	Signifi-cance
Continuity of R&D activities				
More or less continuously R&D	37%	40%	3%	
Occasionally R&D	29%	29%	0%	0.46[a]
No R&D	34%	31%	-3%	
Firms with technological innovations	54%	58%	4%	0.17[b]

Table 1: Non-response analysis

a: Mann-Whitney U-test
b: Phi-test

To further substantiate the representativeness of the data, population estimates of our survey have been compared with estimates produced by Statistics South Africa. All estimates based on the SAIS-database were very close to the population estimates. In particular, our population estimate of the annual growth of employment in the period 2000-2003 is 1.2%. This is exactly the same figure as the estimate provided by Statistics South Africa. Based on the non-response analysis and the comparison of population estimates, the response group can be considered as representative of the total population of South African firms, which implies that the data is likely to be unbiased despite the relatively low response rate.

As noted in the above, the SAIS 2000 database contains information on 617 firms. In this research, a subset of 419 firms will be analyzed. This subset has been created by selecting only firms that reported to conduct innovation activities. This selection has been made because many of the questions, for example about technological alliances and technology management, were only asked to firms that indicated to conduct at least some innovation activities. Moreover, this selection is completely in-line with the theoretical mechanisms we aim to research, since these all assume that firms are trying to get access to resources that help them to be(come) innovative. Important to emphasize, however, is that not all of these firms were necessarily engaged in alliances nor were these firms necessarily successful in putting new products and/or services on the market. Therefore, our sample demarcation does not imply any selection on either the dependent or the main independent variable.

3.2   Measurements

Innovation outcomes. To operationalize a firm's innovation outcomes, we used self-reported measures of innovativeness that were developed for the Community Innovation Survey (CIS) [8]. First, managers were asked whether or not their firms had introduced new or improved products or services in the previous two years (1998-2000). A two year period was chosen to avoid bias resulting from measuring accidental innovation. For firms that indicated to have done so, their innovation outcomes was determined by asking what percentage of the firm's turnover in 2000 was generated by these innovative products and services (identical to: [40]). The novelty of the innovations was determined by differentiating between turnover generated by: (a) products or services that were technologically improved versions of existing ones or (b) were technologically new to the

market. This measurement is in line with generally accepted definitions of incremental and radical innovation and prior research has shown that this perception based measure of innovation outcomes is highly reliable and correlates heavily with other (objective) measures of innovation outcomes [25].

Alliance portfolio diversity. The SAIS 2001 database contains data about the types of alliance partners a firm has (8 types are distinguished: buyers, suppliers, competitors, consultants, research institutes, universities, own group, and open category labeled 'other') and whether these alliances are with domestic and/or international partners. Respondents were asked the following question: *"Innovation in partnership is working actively and together with other partners on the development of technologically new or strongly improved products, services, and processes. Most of the times, but not always, costs and revenues are shared in these partnerships. Between 1998-2000, did your firm participate in such partnerships with organizations located in South Africa/foreign countries"*. Important to note is that this question refers to alliances maintained in the period 1998-2000, whereas the measures of innovation outcomes pertain to the year 2000 only. This lag has been introduced to capture the fact that it takes some time before the resources obtained through alliances find their way into innovative products and/or services. Doing so reduces the problems of endogeneity and reverse causality and thereby strengthens the internal validity of the study.

Next, firms were asked to indicate with which type of partners knowledge was exchanged. In total, a firm can maintain 16 different types of alliances (the abovementioned 8 types of actors times 2 geographical scopes). Alliance portfolio diversity is calculated by dividing the number of different types of ties maintained by the firm by the maximum possible amount of different ties (in this case 16) and squaring the result of this division. It is important to note that this measure is not indicating alliance portfolio size. More diverse portfolios purely signal that a more diverse set of external actors from different geographical areas are part of the ego network of the firm.

The result of this simple calculation is a diversity score with a value between 0 (least complex) and 1 (highest diversity) that has a convex relationship with the number of different alliances maintained by the firm. We chose this specification because it corresponds to Blau's index of heterogeneity which has been used frequently in the alliance literature to measure portfolio diversity [18]. Other specifications, such as linear and concave ones, can be found in the literature as well (e.g. [40]). Therefore, the effects of different specifications of the diversity function are discussed in the robustness checks section of this paper.

Use of TM-tools. The SAIS 2001 database contains information about the types of technology management tools (TM-tools) that an innovating firm uses. In correspondence to the theoretical definition of the concept firm internal, external (market), and technology monitoring TM-tools were distinguished. With regard to internal TM-tools firms are asked whether they utilize: 1) technological audits of the own organization, 2) core competence assessment of the own organization, 3) intellectual property audits, and 4) project portfolio management. Regarding external, market oriented, TM-tools 5) competitor analysis, 6) industry analysis, and 7) market analysis are distinguished. Finally, firms are asked whether they utilize 8) technology monitoring, 9) technology forecasting, and 10) competitive technological intelligence as measures of the utilization of technology monitoring TM-tools.

In total 10 different TM-tools are distinguished. The variable 'use of TM-tools' is a count variable that captures the amount of different TM-tools that a firm uses and therefore varies between 0 (no TM-tools) and 10 (maximum TM-tools).

Control variables. Several control variables were included in the analyses. First, we control for the use of codified external knowledge sources by the firms because these can constitute another source of external knowledge (besides alliances), which could influence innovation outcomes on the one hand, and substitute for the use of alliances on the other [52]. To construct this variable we utilized questions about the extent to which firms judged the use of patents, electronic databases, and professional literature to be important for their innovation activities (on a scale of 0 to 3). The answers to these three questions were condensed into a single measure with the help of factor analysis, which revealed that the three questions indeed reflect a single concept, use of codified knowledge sources (α=0.761).

Moreover, a firm's internal capacity to generate and process knowledge is also likely to impact on its innovation outcomes [13]. Therefore, the R&D intensity of a firm is controlled for by including a measure that captures the percentage of personnel of a firm involved in R&D activities.

Another control variable that we included is a count variable for the number of different types of bottlenecks to innovation that a firm has experienced over the last two years. Ten potential bottlenecks are distinguished ranging from economic risks to knowledge shortages and institutional rigidities. However, no single firm indicates that they experienced all 10 types of bottlenecks; resulting in a variable with a range from 0 to 9. This variable aims to capture the hampering factors to the firm innovation activities, potentially pushing a firm to seek cooperation partners to overcome existing bottlenecks [19].

Moreover, we control for firm size by including the natural logarithm of the amount of full-time employees that a firm has in the analysis. Several studies have found that inter-organizational network activity and innovation outcomes are size-dependent. Size indicates amongst others resource endowment and it is argued that larger size enables firms to maintain a larger set of alliances and is conducive for outcomes.

We include dummy variables for exporting firms and for foreign owned (versus South-African) firms. Including export as a control variable is informed by the notion that exports might serve as a means to get access to novel information and technological knowledge not available in the domestic market [33]. Foreign ownership was included as a control variable because firms in emerging economies often highly benefit from technological knowledge available from their international headquarters and research labs [31]. We also included a count variable that captures the number of 2-digit NACE-sectors in which a firm is active to represent its level of diversification, which might influence both the firm's alliance portfolio diversity as well as its innovation outcomes [50]. Finally, we control for differences between sectors by including dummy-variables for different Pavitt-sectors.[1]

Descriptive statistics for all of these variables can be found in table 2 and bivariate correlations are reported in table 3. Table 2 reveals that the average percentage of turnover from incremental innovations is about 17% whereas for radical innovations this is roughly 7%. For both types of innovation the full range of the scale (from 0 to 100%) is covered by the firms in our dataset. There are no firms in our dataset that obtain the maximum score on the alliance portfolio diversity scale. The average alliance portfolio diversity is 0.06, which corresponds to 4 types of alliances (out of the possible 16). With regard to the use of TM-tools, the firms in our dataset again cover the full scale (0 to 10), with the average firm utilizing a little below three different TM-tools.

Table 3 (in the Annex) shows that all bivariate correlations are relatively low as are the Variance Inflation Factors presented in table 2. Based on these results, we conclude that there are no problems of multicollinearity in our dataset.

Variable	Mean	S.D.	Min	Max	VIF
% turnover from incremental innovations	16.90	23.69	0	100	n.a.
% turnover from radical innovations	7.13	17.99	0	100	n.a.
alliance portfolio diversity	0.06	0.12	0	0.88	1.73
technology management tools	2.79	3.11	0	10	2.01
use of codified knowledge sources	0.00	1.00	-0.61	4.37	1.75
R&D intensity	0.04	0.09	0	0.82	1.16
innovation bottlenecks	1.02	1.97	0	9	1.25
size (ln)	4.68	1.70	0	10.31	1.31
foreign owned firm	0.16	0.36	0	1	1.04
exporting firm	0.65	0.48	0	1	1.15
firm diversification	1.34	0.75	1	8	1.11
Pavitt sector 2	0.27	0.44	0	1	1.51
Pavitt sector 3	0.13	0.33	0	1	1.20
Pavitt sector 4	0.16	0.37	0	1	1.38
Pavitt sector 5	0.28	0.45	0	1	1.52

Table 2: Descriptive statistics

3.3   Methods

For both measures of innovation outcomes that we use as dependent variables, the score lies between 0 and 100 by definition. The most appropriate method to analyze such left and right censored data is a Tobit analysis. Moreover, the data for both measures of innovation outcomes is also highly skewed to the left. As a result, it is very likely that the assumption of a normal distribution of the residuals that is made in a Tobit analysis is violated. In order to deal with this problem we have log-transformed the dependent variable [53].

In order to test the moderating effects of TM-tools on the relationship between alliance portfolio diversity and innovation outcomes, several interaction variables have to be entered into the models. In order to prevent any multicollinearity problems between the main effects and the interaction effects we have mean centered the variables before calculating the interaction terms. Moreover, we performed several robustness checks to make sure multicollinearity does not influence our results (see robustness checks section). To prevent any biases from heteroskedasticity problems we utilized the Huber/White robust specification of standard errors.

Earlier research has shown that there is bi-directional relation between interorganizational alliances and firm performance. Firms with more alliances perform better and better performing firms attract more alliance partners. Even though this simultaneous causality has, to our knowledge, not been proven to hold for alliance portfolio diversity in particular, endogeneity might be an issue in our data. Besides introducing the time-lag between the measurement of innovation outcomes and alliance portfolio diversity we also estimated instrumental variables regressions.[2] The instruments are marginally relevant (a first stage F-statistic of 9.08 [5]), but Hausman specification tests indicate that the efficient model also yields consistent results. This conclusion is corroborated by Wu-Hausman and Durbin-Wu-Hausman tests [5] which do not reject the null-hypothesis that the regressor (alliance portfolio diversity) is exogenous. Therefore,

the results of the Tobit regression that we report are unlikely to be biased as a result of simultaneous causality problems.

	% turnover from incremental innovations			% turnover from radical innovations		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	-0.27	-0.03	-0.19	-2.13**	-2.01**	-2.84***
alliance portfolio diversity (APD)	-	15.16***	48.71***	-	21.84***	63.26***
APD^2	-	-17.24***	-102.33***	-	-46.69***	-145.37***
Technology management tools (TM)	-	-	0.75***	-	-	0.73***
TM * APD	-	-	-7.07***	-	-	-8.83***
TM * APD^2	-	-	13.57***	-	-	17.77***
use of codified knowledge sources	1.23***	0.76***	0.27***	1.14***	0.80***	0.49***
R&D intensity	3.58**	3.02*	1.40	4.64**	4.01**	3.49***
innovation bottlenecks	0.23***	0.16***	0.01	0.31***	0.24**	0.12
size (ln)	0.14*	0.04	-0.13**	-0.12	-0.17	-0.32**
foreign owned firm	0.94***	0.71**	0.48**	0.66	0.51	0.36
exporting firm	0.19	0.03	-0.08	0.68	0.53	0.53
firm diversification	-0.10	-0.11	-0.26**	0.08	-0.04	0.02
Pavitt sector 2	-0.54	-0.69*	-0.74***	-0.99*	-1.26**	-1.32***
Pavitt sector 3	0.23	0.16	-0.19	0.06	0.01	-0.42
Pavitt sector 4	-0.07	-0.19	-0.65***	-0.26	-0.46	-0.75
Pavitt sector 5	-0.45	-0.36	-0.67***	-0.85	-0.83	-1.12**
# of observations	419	419	419	419	419	419
# of left-censored observations	202	202	202	303	303	303
# of right censored observations	4	4	4	5	5	5
Log-likelihood	-618.00	-599.11	-462.94	-422.85	-413.19	-381.19
Log-likelihood reduction (on AIC)	-	18.89***	136.17***	-	9.66***	32.00***
Model significance (F-test)	0.000	0.000	0.000	0.000	0.000	0.000
Sigma	2.32	1.80	1.45	3.29	3.17	2.80
McKelvey & Zavoina's Pseudo R-square	37.00%	43.60%	70.15%	19.10%	21.40%	30.20%

*: p<0.10, **: p<0.05, ***: p<0.01 (Based on a Huber/White robust specification of standard errors)

Table 4: Estimation results

3.   RESULTS

The results of the estimations of the Tobit models are presented in table 4. For both dependent variables, that is, two types of innovation outcomes, three different models have been estimated. First, models with only the control variables were estimated (models 1 and 4). These models establish a baseline against which the other models can be evaluated. Second, the alliance portfolio diversity variables (both linear and squared) were added to the model (models 2 and 5). Finally, the moderating effect of the use of TM-tools has been introduced into the models (models 3 and 6).

Both of the baseline models (models 1 and 4) are highly significant and have relatively high levels of explanatory power for firm-level models (respectively 37% and 19%).[3] The findings for both models are highly consistent. The use of codified external knowledge sources and the level of internal R&D are positively associated with a both firm's level of

incremental as well as radical innovation outcomes. The same holds for the number of innovation bottlenecks that firms encounter, which is also positively associated with a firm's innovation outcomes. On the one hand, this reflects the notion that the fewer innovation activities a firm exhibits, the less likely the chance that it will encounter any problems. So encountering bottlenecks is a sign of conducting relatively high levels of innovation activities. On the other hand, experiencing more bottlenecks invokes more external search attempts. The main difference between the two models is that foreign owned firms have higher levels of incremental innovation outcomes as compared to domestic firms, whereas no such difference is found for radical innovation outcomes.

Subsequently, we added the alliance portfolio diversity variables (models 2 and 5). This addition leads to a highly significant improvement of the models in terms of log-likelihood reduction, estimation accuracy (represented by sigma (i.e. the estimated standard error of the residuals)), and of variance explained. The results regarding the control variables remain largely unchanged.

The coefficients for the alliance portfolio diversity variables (linear and squared) are both highly significant and have the signs that correspond to the predicted inverted U-shape. To get a clear insight into the exact shape of the relation between alliance portfolio diversity and a firm's innovation outcomes we plotted this relationship for both types if innovation outcomes in Figure 1. The enhance comparability between the two effects for incremental and radical innovation outcomes the effects have been standardized.
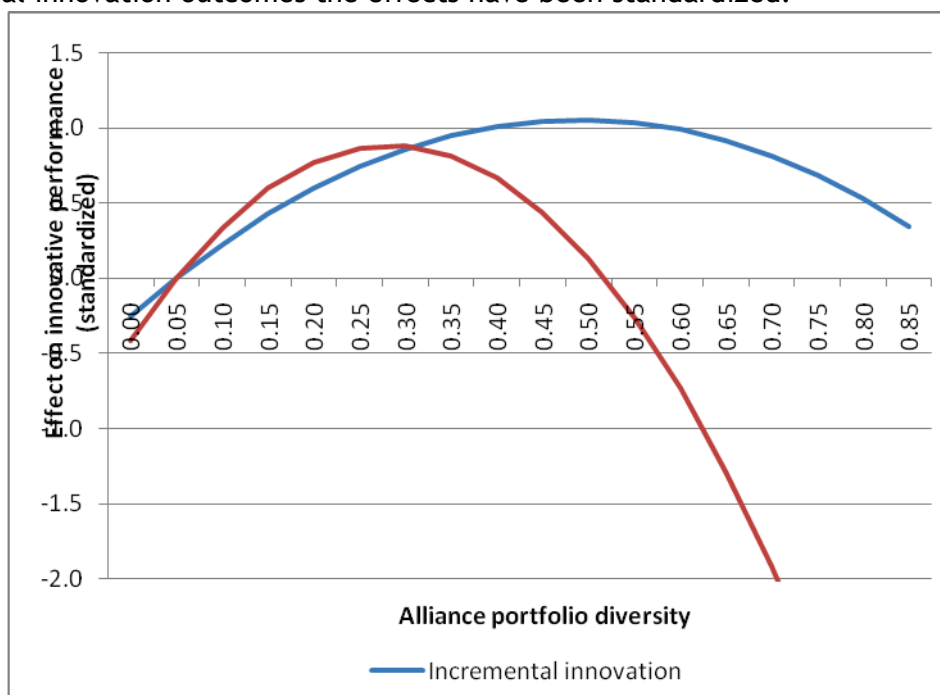
Figure 1: Alliance portfolio diversity and innovation outcomes

This figure clearly shows an inverted U-shape relationship for both types of innovation outcomes. It could be the case, however, that the model predicts the down-sloping part of the curve, but that this part is not statistically significant. To investigate this issue, we estimate models where the alliance portfolio diversity variables are replaced with a set of dummies.[3] Both for radical and incremental innovation outcomes, the benchmark is set for alliance portfolio diversity values around the tipping point. Dummies are created for firms without any alliances, for firms with some alliances but below the tipping point, and for firms with more diverse alliance portfolios than the tipping point. The results of these analyses show that for incremental innovation, the downward sloping part of the curve is

not statistically significant. So for this type of innovation outcomes diminishing returns to diversity are found, but no negative effects of very high levels of alliance portfolio diversity are observed. For radical innovation outcomes, however, the downward sloping part of the function is statistically significant. So for radical types of innovation, there truly are negative returns to very high levels of alliance portfolio diversity. In sum, for incremental innovation hypothesis 1 is partially confirmed, whereas for radical innovation it is fully confirmed.

Figure 1 also shows that the optimal level of alliance portfolio diversity differs between the types of innovation outcomes. The optimal level is lower for radical innovation outcomes (0.25) than for incremental innovation outcomes (0.42). Given our non-linear specification of alliance portfolio diversity these numbers correspond to maintaining 7 (radical innovation) respectively 10 (incremental innovation) different types of partners. These levels are highly similar to those reported by [19] and [40]. Even though we find a significant difference in the optimal level of alliance portfolio diversity between incremental and radical innovation, the difference is opposite to hypothesized leading to a rejection of hypothesis 2a. Interestingly, our own calculations based on the results reported by [40] reveal that in their sample the optimal level of portfolio diversity is also higher for incremental as for radical innovation outcomes. So despite the fact that theoretical arguments predict a higher optimum for radical innovation outcomes, the available empirical evidence suggests the opposite. We will get back to this counter-intuitive finding in the discussion section.

Furthermore, the height of the two optima in terms of performance implications does not significantly differ. Even though the estimated maximum performance impacts do differ (incremental = 27.9, radical 12.7), which is in line with the second part of hypothesis, this difference is not statistically significant (p = 0.26). This finding implies a rejection of hypothesis 2b as well.

Finally, the interaction terms between alliance portfolio diversity and the use of TM-tools were entered into the model (models 3 and 6) again resulting in a significant improvement of the models (see table 4). The pseudo R-square of the incremental innovation model rises to almost 70%, whereas that of the radical innovation model climbs up to a respectable 30%. Again, the log-likelihood reductions are highly significant and the estimations become more accurate (reflected in the lower sigma).

The newly added moderating effects are highly statistically significant and have the signs that are in correspondence with those predicted in hypothesis 3. However, it is hard to interpret the coefficients directly, which is why the relation between alliance portfolio diversity and a firm's radical innovation outcomes has been plotted in Figure 2. This picture is virtually identical for radical and incremental innovation outcomes, which is why these are not plotted separately. For reasons of clarity, only the lines for firms without TM-tools applied and for firms with the maximum use of TM-tools are depicted.

What emerges from Figure 2 is completely in-line with the predicted effects. Especially in the higher ranges of alliance portfolio diversity utilizing TM-tools is highly beneficial for firms. The negative effect of high levels of portfolio diversity is not only dampened, but even turns into a strong positive effect. It should be noted however, that the switching point at which the relation turns from an inverted-U into a regular-U shape lies at about 8 TM-tools. Given the fact that the range of the TM-tool variable runs up to 10, these are indications that intensive usage of TM-tools is required to really benefit from high levels of alliance diversity. Using the internal, the external, and the technology auditing forms of TM is required in this regard.

On the lower part of the portfolio diversity domain, the differences are less pronounced or even insignificant. One could interpret this as evidence that firms do not need TM-tools to deal with low to moderate levels of alliance portfolio diversity. Nevertheless, these findings provide strong support for hypothesis 3 which is therefore confirmed.

Robustness Checks
Several robustness checks have been performed to assess the sensitivity of the results to changes in model specifications.

Different specifications of alliance portfolio diversity. In our analyses, we have adopted a convex relation between the number of different types of alliances a firm maintained and its alliance portfolio diversity. Even though this is the dominant specification that is used in the literature, different specifications can be made as well. In order to test the sensitivity of the results to changes in this specification we also applied a linear specification and a concave specification of the relation between the number of alliance types a firm has and its level of alliance portfolio diversity. Regressing these different specifications of alliance portfolio diversity on innovation outcomes, leads to almost identical results as compared to the ones obtained with the convex specification of alliance portfolio. This clearly indicates that our findings are robust to such changes in the specification of this independent variable.

Moreover, the specification of alliance portfolio diversity that we used pools two types of diversity, namely in partner type and in geographical reach. To assess whether doing so might influence the results we have also constructed alliance portfolio measures based on domestic and international alliances separately. Replicating our estimations with these separate measures leads to identical results showing that our results are robust to this change and indicating that pooling these two kinds of diversity does not influence our results.
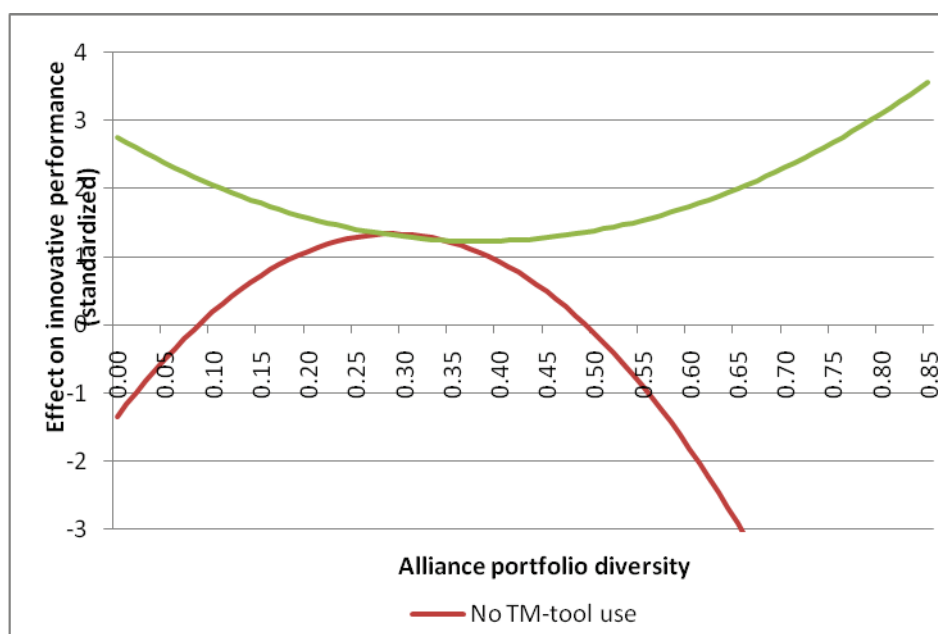

Figure 2: The moderating effect of TM-tool use

Different specifications of dependent variable. Besides the log-transformed percentage of sales derived from innovative products and services, several different specifications of the dependent variable have been used to test the robustness of the results. We estimated the Tobit models on the non-log-transformed percentage of sales from innovative products

and services data and on a binary variable that simply indicated whether the firm had any innovative sales at all (identical to: Duysters & Lokshin, forthcoming). The results were highly robust to these changes in specification.

Estimation on random sub-samples. Models with moderation effects are sensitive to multicollinearity and heteroskedasticity issues. In order to minimize these problems we have utilized robust standard errors and mean centered all variables before calculating the interaction terms. Nevertheless, it is sometimes argued that the estimated coefficients of, in particular, the interaction effects can be very sensitive to mutations in the underlying dataset [21]. In order to assess this sensitivity we estimated the model for both incremental and radical innovation outcomes on 20 randomly drawn sub-samples of our dataset (as suggested by [21]). Each sub-sample contained approximately 50% of the observations of the full dataset. For each of these 20 sub-samples results were obtained that are virtually identical to those reported in table 4. Therefore, we conclude that our results are highly robust to changes in the underlying dataset and are not biased due to multicollineairy or heteroskedasticity issues.

5.   DISCUSSION AND CONCLUSION

From the findings discussed in the above we derive several contributions. First and foremost, we contribute to the alliance (portfolio) management literature by showing that the use of TM-tools focusing at the identification and selection of external technological knowledge strongly impacts on the relationship between alliance portfolio diversity and a firm's innovation outcomes. Previous alliance (portfolio) management literature has shown that it is beneficial for organizations to have an alliance function and/or a dedicated alliance manager [17], [34], [47] but basically black-boxed the actions that alliance managers or functions undertake. Our findings show that organizations that want to make the most out of alliance portfolio diversity should conduct three types of actions, namely mapping the internally available knowledge, scanning the external environment for valuable knowledge, and making forecasts about future technological trajectories and developments. Instead of being overflowed by the diversity of cues coming in from their diverse portfolios, firms that intensively use TM-tools are able to absorb and process these cues thereby spurring them to higher levels of innovation outcomes.

In other words, our findings point at the importance of organized managerial action and the formalization of technology management. This is in line with results found in the latest best practice study by the Product Development & Management Association in which it is reported that firms with the highest outcomes use a high number of formal tools simultaneously [3]. The finding is also somewhat counter-intuitive, however, as scholars argue that high levels of formalization are negatively related to technological innovation and knowledge production [45], which signals that high levels of formalization are detrimental to innovation. It might be that the object of formalization plays a crucial role in this regard. For example, formalization directed at outcomes might have negative effects, whereas formalization focusing on behavioral aspects (e.g. identification and selection) might improve or fasten the creation of innovations [9].

Second, our findings add to the generalizability of the relation between alliance portfolio diversity and innovation outcomes. On a general level, our findings show that also in a non-western, across industry and non high-tech context there is strong evidence for the hypothesized inverted U-shaped relation. As such, our findings show that the theoretical arguments underlying this hypothesis are also valid outside of the contexts in which they had so far been tested.

On a more fine-grained level, however, we reveal that the difference in the level of alliance portfolio diversity that is optimal for radical versus incremental innovation outcomes is exactly the opposite of hypothesized; for incremental innovation outcomes, the optimal level of alliance portfolio diversity is higher. Since there is more empirical support for this counter-hypothesized finding [23], [40], it cannot be attributed to particularities of the research context.

A possible explanation might be that more diverse alliance portfolios are especially conducive to incremental types of innovative performance because incremental innovation implies that dominant designs already have emerged. In such contexts, firms mainly use alliance portfolios for fine-tuning and coordinating new products and services in a step-by-step way, which is easily inspired by a diverse set of external actors [40]. Radical innovation, on the contrary, involves the development and exchange of new technologies. This has two implications for alliance portfolio diversity. First, radical innovation performance is the result of the introduction and acceptance in the market of a firm's new product(s) and service(s) that extends its competencies significantly [68]. The generation of such products and services preceding this performance asks for novel types of knowledge often not available in the innovating firm and only possessed by a limited number of specialized external actors, such as specific universities or lead-users [46]. In other words, the creation of more radical innovations requires emphasis on access to scarce capabilities and expertise, the possession of which is unequally distributed by residing in the hands of only a very few partners or of partners of a specific type. Second, the exchange of resources required for radical innovations requires deeper ties as compared to incremental innovation for which rather superficial ties are often sufficient [51]. However, maintaining deeper ties is also more demanding in terms of resources and managerial attention, thereby severely limiting the number of deep ties a firm can maintain [26]. As a result, only maintaining a limited set of (deep) ties and focusing all attention to those ties is likely to be a beneficial strategy for the generation of radical innovation.

Related to the above, one should take into account that many firms simultaneously produce incremental and radical innovative outcomes [71]. Because both types of innovative outcomes are influenced differently by alliance portfolio diversity organizations face a tradeoff in determining the level of alliance portfolio diversity. Maximizing it for incremental innovations has negative consequences for radical innovation and vice versa. As such, we should be cautious with interpreting the effects for the different types of innovation outcomes in isolation.

Besides the contributions of this research, several limitations apply. First, the operationalization of alliance portfolio complexity does not allow us to identify individual alliances, but only the existence of alliances with certain types of actors. This approach, which is adopted from the European Community Innovation Survey and has been used in most earlier research on the topic of alliance portfolio diversity as well [19], [40], was applied because the data collection problems become exceedingly large when firms are asked about (characteristics of) individual alliances. In order to be able to collect large scale data and, thereby, derive more externally valid results, we chose the research approach discussed in the above. Nevertheless, replication with more detailed alliance portfolio data seems a fruitful next step in this kind of research.

Another limitation lies in the causality claims that can be made on the basis of our analyses. Despite the time-lag between the measurements of alliance portfolio diversity and a firm's innovation outcomes our data remains cross-sectional. Without observing changes in one variable being followed in time by changes in another variable a causal chain is impossible to establish. A similar concern can be voiced regarding the role of TM-

tools. One could argue that TM-tools simply reflect a fixed ability of firms to transfer innovation inputs to innovation outputs and that they do not reflect time-varying activities that can be directly influenced through managerial action. Even though we have discussed earlier that our data shows that TM-tool use is significantly different from having organizational functions dedicated to TM-activities, observing changes in TM-tool activities over time and relating these to subsequent changes in innovation outcomes is required to provide grounds for causal claims.

Despite these limitations, the main conclusion of this paper, that the role of TM-tools strongly moderates the inverted U-shaped relation between alliance portfolio diversity and innovation outcomes, is robust and adds interesting insights to the literatures on alliance portfolios and alliance portfolio management in particular.

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NOTES

1: We also estimated models with firm level sales and employment growth as control variables. Because these variables were: a) insignificant in all models, and b) not available for all firms in our sample, we only report and discuss the models without these control variables.
2: Given the fact that we utilize survey data, the choice of instrumental variables is rather limited. We used (in all possible different combinations) the number of bottlenecks to innovation, whether the firm received innovation subsidies from the government or not (dummy) and whether the firm exports or not (dummy).
3: We report the McKelvey & Zavoina's Pseudo R-square because this measure closely represents the R-square yielded by an OLS.

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Annex

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1 alliance portfolio diversity	-											
2 technology and innovation management tools	0,58**	-										
3 use of codified knowledge sources	0,53**	0,58**	-									
4 R&D intensity	0,11*	0,20**	0,16**	-								
5 innovation bottlenecks	0,26**	0,39**	0,38**	0,20**	-							
6 size (ln)	0,27**	0,30**	0,22**	-0,16**	0,10*	-						
7 foreign owned firm	0.04	0.05	-0.03	-0.04	0.00	0.06	-					
8 exporting firm	0,23**	0,20**	0,20*	0.09	0,11*	0,22**	0,14**	-				
9 firm diversification	0.24**	0.18**	0.22**	-0.01	0.10*	0.18**	0.02	0.13*	-			
10 Pavitt sector 2	0,10*	0.01	-0.01	-0,10*	0.00	0,25**	0.02	0,11**	0.04	-		
11 Pavitt sector 3	0,16**	0,13**	0,15**	0,12*	0.10	0,14**	0.00	0,18**	0.04	0,26**	-	
12 Pavitt sector 4	0.01	0,10*	0.03	0.03	-0.02	-0.03	0.03	-0.04	0.01	-0,26**	-0,17**	-
13 Pavitt sector 5	-0,12*	-0,11*	-0,10*	-0.04	-0.06	-0,19**	0.03	-0,11*	0.01	-0,38**	-0,24**	-0,27**

*p<0.05, **p<0.01

Table 3: Bivariate correlations