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Different dimensions of knowledge in cooperative R&D projects of university scientists

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ABSTRACT

An increasing speed of new knowledge generation and a growing specialization of individuals in specific fields make cooperative R&D projects indispensable to stay abreast of the latest technological developments. However, studies targeting this field of research have almost exclusively focused on industrial cooperation projects, neglecting the importance of academic R&D collaboration.

We attempt to address this research gap by investigating completed R&D cooperation projects of 376 German professors of the chemical and biological sciences. Based on their evaluation, we can distinguish between successful and less successful projects mainly involving explicit or tacit knowledge. We further characterize these groups by identifying significant group differences regarding trust, the interdependency between partners, the frequency of communication and the closeness of partners. Overall, our study presents new empirical evidence that the codification of knowledge plays an important role for the success of cooperative R&D projects.

1. Introduction

An increasing speed of new knowledge generation leads to a growing specialization of individuals in specific fields and subfields of knowledge (Berends et al., 2006). This development makes cooperative R&D projects an indispensable instrument to stay abreast of the latest technological trends—especially in R&D intensive fields, such as the chemical or biotechnological sector (Carayannopoulos and Auster, 2010). Against this background, cooperation represents an important way of sourcing external knowledge. While industrial R&D often emphasizes the "D" and focuses on incremental innovations (e.g. improving the efficiency of production facilities), academic institutions emphasize the "R", concentrating on basic research. Looking at the innovation process, academic research can thus be placed in front of the front end. While the front end usually starts with the first consideration of an opportunity (Kim and Wilemon, 2002), basic research is not performed with a specific opportunity or application in mind (Bade et al., 2007). Cooperation with academia can thus aid in the search for new inventions and provide important stimuli for developing radical innovations (Fabrizio, 2009; Todtling et al., 2009), especially when a broad range of external sources is taken into consideration (Chiang and Hung, 2010).

In line with this reasoning, empirical studies could show that the number of R&D partnerships increased over the last decades (Hagedoorn, 1996; Hagedoorn, 2002; Roijakkers and Hagedoorn, 2006). Responding to the growing importance of cooperation, an extensive amount of literature on cooperative projects in general, and corresponding success factors in particular, has emerged. Many studies have put a special emphasis on structural and organizational factors. These included, for instance, the size of the organization (Rothaermel and Deeds, 2004), complementarity in resources of the cooperating organizations (Yang et al., 1999), the alliance experience of the partners (Hoang and Rothaermel, 2005) or alliance scope and governance (Jiang and Li, 2009), and their respective influence on performance or success. Other studies have focused on personal aspects and interpersonal connections, such as teamwork (Hoegl et al., 2004; Mudambi et al., 2007), the role of promotors (Hauschildt and Kirchmann, 2001) leadership (Curran et al., 2009; Faerman et al., 2001; Kleyn et al., 2007) or cultural aspects (Kanzler, 2010).

In contrast, comparatively few studies have addressed the role different dimensions of knowledge (i.e. tacit and explicit) play in cooperation. This holds all the more true for the context of academic cooperation projects. As Chompalov et al. (2002, p. 750) note: "[…] organizational studies have largely ignored scientific interorganizational collaborations as objects of inquiry […]". Almost all existing studies that analyze tacit and explicit knowledge in cooperative R&D projects rely solely on industrial sources for their data acquisition. In our opinion, this represents a major shortcoming, as the work environment of academic and industrial scientists substantially differs (e.g. Bruneel et al., 2010). Universities and companies have

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fundamentally different cultures and are perceived to have distinct social, cultural and economic roles (Cyert and Goodman, 1997; Meyer-Krahmer and Schmoch, 1998; Van Dierdonck and Debackere, 1988). While the primary goal of universities is the creation and dissemination of knowledge, companies provide products and services within a highly competitive environment (Cyert and Goodman, 1997). As a consequence, time horizons and the methods of validation and reward differ considerably (Lopez-Martinez et al., 1994). Acting under strong competitive pressure, companies mostly need to consider time in terms of meeting short-term goals. In contrast, the time horizons in the academic world are often much longer and less well defined (Cyert and Goodman, 1997). Not surprisingly, academic scientists perceive the short-term orientation of their industrial counterparts to be a major barrier for successful interaction (Meyer-Krahmer and Schmoch, 1998; Schmoch, 1997). In addition, the cultural differences between universities and industry can manifest themselves in deviating goals, languages and assumptions. For instance, many university scientists are driven by recognition and reputation in the scientific community. In contrast, the hierarchical superior often represents the critical constituent for managers (Cyert and Goodman, 1997). Furthermore, university scientists usually aim at making research results accessible to the public, while companies try to capture and exclusively use the intellectual property (Hall et al., 2001). Additionally, the nature and content of the partners' work differs substantially (Cyert and Goodman, 1997; Hurmelinna, 2004). According to Pavitt, "one of the main purposes of academic research is to produce codified theories and models that explain and predict natural reality" (Pavitt, 1998). On the other hand, industrial research mostly aims at concrete applications in the form of products, processes or services (Cyert and Goodman, 1997). Consequently, companies might have to face complex, ambiguous and abstract knowledge where they look for simple and concrete solutions to problems. In light of these differences between industry and academia, it seems to be a worthwhile endeavor to expand the scope of existing research beyond industry's perspective and assess the point of view of academic scientists. They might have different perceptions of the importance of factors potentially relevant for knowledge sharing. As recently demonstrated by a meta-analysis of van Wijk et al. (2008), it is very important to consider contextual characteristics when analyzing organizational knowledge. Accordingly, our study contributes to the existing literature by focusing on the so far under-researched context of academic cooperation projects, explicitly focusing on the role of different knowledge dimensions. To this end, we analyze academic cooperation projects with regard to the associated knowledge and factors relevant for sharing this knowledge. Our main objective is to identify differences between successful and less successful projects involving either predominantly tacit or explicit knowledge.

In the next section, the distinction between tacit and explicit knowledge will be illustrated and studies drawing on this distinction in analyzing cooperation projects will be highlighted. Building on these, hypotheses on the factors of relational trust, dependency of partners and tie strength will be derived. Followed by a description of the research design, results of our survey will be presented and analyzed. The paper concludes with a critical discussion of the results and points at future research opportunities.

2. Knowledge dimensions and their role in cooperation

2.1. Tacit and explicit knowledge

Although literature lacks a clear consensus about the definition of knowledge, many researchers from the field of innovation management follow the classical philosophical definition that views knowledge as justified true belief. However, as the truth of beliefs might be difficult to assess or prove, this work defines knowledge less strictly as justified belief. Although often used interchangeably, knowledge should be delineated from information to allow for a clear understanding of the terms. First, knowledge is always subjective and thus related to an individual's experiences, values, beliefs and commitment (Alavi and Leidner, 2001; Davenport and Prusak, 2000). Second, knowledge is associated with a specific purpose and is related to human action. It has been processed with a certain goal and is often of limited use when applied to differing goals (Cook and Brown, 1999). Third, knowledge is a synthesis of multiple sources of information over time and is always bound to a specific context (Rowley, 2007). These aspects emphasize the subjective nature of knowledge and support the idea of a tacit dimension—first introduced by Michael Polanyi as early as 1958 (Polanyi, 1958). The concept of tacit knowledge was later complemented by the explicit dimension to form the widely accepted distinction between tacit and explicit knowledge.

Building on the notion that individuals seem to know more than they can explain (Polanyi, 1966), tacit knowledge is characterized by a personal quality that makes it hard to formalize or communicate. It is rooted in an individual's values, beliefs, experiences and involvement in a specific context (Nonaka, 1994). The nature of tacit knowledge impedes its processing, sharing and storage in a systematic and logical way (Rehäuser and Krcmar, 1996). However, the same nature makes tacit knowledge more valuable and likely to yield a sustainable competitive advantage, as it is not easily imitated by competitors (Zander and Kogut, 1995). The value of tacit knowledge for high-tech industries, such as biotechnology, could be demonstrated (Zucker and Darby, 1996; Zucker and Darby, 2001; Zucker et al., 2002). In contrast, explicit knowledge refers to knowledge that can be articulated and transmitted in a formal, systematic language. It can be easily processed, transmitted and stored using (electronic) media. This characteristic allows for capturing the knowledge in records of the past, such as libraries or archives (Rehäuser and Krcmar, 1996). Explicit knowledge can thus be regarded as sequential knowledge (*then and there*), contrasting the simultaneous character (*here and now*) of tacit knowledge (Nonaka and Takeuchi, 1997). While the codification of knowledge facilitates its sharing, it simultaneously increases the risk of encouraging imitation (Kogut and Zander, 1992).

2.2. Knowledge in R&D cooperation projects

A literature review reveals that comparatively few studies specifically address the role of tacit and explicit knowledge in cooperation projects. Most of these studies target the impact on knowledge transfer or sharing, as it is closely associated with the overall performance of cooperation projects (Dhanaraj et al., 2004).

Analyzing 137 alliance cases in high-tech industries, Chen (2004) finds that knowledge transfer performance is positively affected by explicitness and a firm's absorptive capacity. Furthermore, the author can show that trust has a positive effect on knowledge transfer performance. In a survey involving firms from more than 15 industries, Cummings and Teng (2003) could show that articulability, embeddedness, knowledge and norm distance (i.e. the degree of shared organizational culture and value systems) as well as transfer activities affect knowledge transfer success. Dhanaraj et al. (2004) examine the influence of tacit and explicit knowledge on the performance of international joint ventures (IJVs). Their results show a positive effect of tie strength, trust, and shared values and systems on the transfer of tacit knowledge. Furthermore, they can demonstrate a positive relationship between explicit knowledge and IJV performance. Reagans and McEvily (2003) studied how different features of networks affect knowledge transfer using data from a contract R&D firm. They could find that social cohesion and network range facilitate knowledge transfer with a stronger effect than the strength of ties between people. Janowicz-Panjaitan and Noorderhaven (2009) stress the importance of operating-level boundary spanners for tacit knowledge sharing across organizational boundaries.

In a longitudinal case study approach, Hadjimanolis (2006) investigated a collaboration project between a medium-sized firm and an academic research group. He finds that a close proximity of the partners permitted the transmission of tacit knowledge. However, difficulties were caused by the limited previous exposure of the firm researchers to scientific literature—a finding related to the concept of absorptive capacity (Cohen and Levinthal, 1990). Difficulties in the transfer of tacit knowledge are also described by Inkpen and Pien (2006) in their case study of a Chinese–Singaporean alliance to build and manage an industrial park. Niedergassel et al. (2006) as well as Bröring and Herzog (2008) discuss organizational approaches to enhance the transfer of tacit knowledge in the context of Open Innovation.

Knowledge acquisition in university–industry collaboration was also recently investigated by Sherwood and Covin (2008). Based on the answers of 104 industry managers, they could show that partner familiarity and communication between the partners′ technology experts predict the acquisition of knowledge. Furthermore, they could demonstrate that the successful acquisition of tacit knowledge (but not explicit knowledge) is predicted by partner trust. The study of Santoro and Bierly (2006) represents one of the most relevant works for this study. Investigating partnerships between industrial firms and university research centers (URCs), they could show that the type of knowledge transferred (i.e. tacit vs. explicit) moderated the impact of different facilitators of knowledge transfer. Specifically, they could identify social connectedness, trust, IP policies, technological relatedness and technological capability as factors influencing the transfer of knowledge. However, Santoro and Bierly (2006) point out that a key limitation of their study lies in the principal focus on the industrial firm, neglecting the university′s perspective. They note that "future work should also examine the key facilitators of knowledge transfer from the university research center′s perspective". We therefore explicitly focus on academic cooperation projects, taking into account the university scientist′s view to enlarge our understanding of the role tacit and explicit knowledge play in cooperation.

3. Hypotheses

As indicated in this paper′s introduction, some fundamental differences between the academic and industrial contexts exist. Against this background, it seems to be important to analyze whether any dissimilarities in drivers of knowledge sharing in cooperation projects result from the differing contexts. In a first step, it appears to be reasonable to focus on selected drivers, which have been shown to be of major importance in previous studies that did not focus on the academic setting. In a second step, it is then necessary to evaluate in how far the context of academic cooperation projects might affect the impact of these drivers.

With regard to important factors influencing knowledge sharing in and between organizations, van Wijk et al. (2008) conducted a meta-analytic review of 75 studies. In their analysis, they classified the factors into three categories: knowledge, organizational and network characteristics. Considering knowledge characteristics, our study specifically builds on the discussed distinction between tacit and explicit knowledge. Organizational characteristics are addressed by focusing on universities as the analytical setting. However, the emphasis of our study lies on the network characteristics. While several important influencing factors can be identified in this category (e.g., Dyer and Hatch, 2006; Whittington et al., 2009), van Wijk et al. (2008) point out in their analysis that "given the large effect sizes we found for tie strength and trust, relational capital is arguably the most important network-level driver of knowledge transfer both within and across organizations". In light of these results, it seems reasonable to analyze these factors more closely and investigate in how far their influence might differ in an academic setting. We furthermore include the factor "interdependency of partners" in our analysis, as it might be of particular relevance when tacit and explicit knowledge are differentiated. Having identified the major drivers to be investigated, it furthermore seems necessary to assess in how far the academic context might influence the action of these drivers. To this end, potential particularities of academic cooperation projects will be discussed for each selected driver in the following and will be used to deduct specific hypotheses. The formulation of the hypotheses is built on a classification of cooperation projects into successful and less successful projects with tacit or explicit knowledge as the predominant form of knowledge involved.

3.1. Relational trust

Trust is an important factor for success in inter-organizational cooperation (Das and Teng, 1998; Gulati, 1995). It can be regarded as "the belief that an exchange partner would not act in self-interest at another′s expense" (Uzzi, 1997, p. 43). Transaction costs can be lowered by high levels of trust as less safeguards against opportunistic behaviour are required (Gulati, 1995). It can thus facilitate knowledge sharing as it builds a sense of security that the partner will not exploit the knowledge beyond the intended level (Dhanaraj et al., 2004). Accordingly, the willingness to share knowledge will be higher, resulting in a better overall project performance. Furthermore, trust can influence the transactive memory system (i.e. a system that combines individual knowledge with collective awareness about who knows what), which, in turn, can influence knowledge sharing (Huang, 2009). As indicated in the introduction, the primary goal of academic institutions is the creation and dissemination of knowledge. Furthermore, university scientists usually aim at making research results accessible to the public (Hall et al., 2001). Working in an environment that encourages open discussion and dialogue, most scientists share common goals and are motivated by the ability to do high-quality, curiosity-driven research (Jindal-Snape and Snape, 2006). Cooperating and sharing knowledge with others thus lies at the very heart of the work of academic scientists. Considering these particularities, we should expect that the academic environment is characterized by higher levels of trust between cooperating partners, as the academic system as a whole can only function when the actors cooperate and exchange their knowledge. In conclusion, the overall levels of trust in our study can expected to be higher when compared to previous studies that were conducted in industry.

Notwithstanding this reasoning, trust should be of special importance when it comes to sharing tacit knowledge. Tacit knowledge constitutes the most valuable resource of academic scientists. They often face competition for the first publication of research results in a prestigious journal or for the allocation of research grants. While explicit knowledge is mostly published and shared with the scientific community, tacit knowledge is important for academic scientists to ensure an advantage in the competition for scientific merits and research funding in the long run. Accordingly, sharing this knowledge with others should require exceptionally high levels of trust. Furthermore considering the findings of previous studies that trust is of special importance for sharing tacit knowledge (Dhanaraj et al., 2004; Santoro and Bierly, 2006;

Sherwood and Covin, 2008), we hypothesize:

H1a. Successful cooperation projects with tacit knowledge as the predominant form of knowledge will show a higher degree of trust than less successful ones.

H1b. Successful cooperation projects with explicit knowledge as the predominant form of knowledge will not show a higher degree of trust than less successful ones.

3.2. Interdependency of partners

The principle motivation of most university scientists to enter into a R&D cooperation project is to gain access to a partner's knowledge base. Furthermore, for the successful establishment and realization of a cooperation project, the motivation of the partners (Niedergassel et al., 2007) and reciprocal incentives are needed. As Cantner and Meder (2007) could show, a higher reciprocal incentive value enhances the probability of a cooperation substantially. We reason that a high interdependency of the partners offers a form of reciprocal incentive, as both partners need each other to accomplish their respective goals.

In how far might the influence of the interdependency of partners be affected by the academic setting? One key issue that comes into play at this point are the substantially different incentive systems of industry and academia. In contrast to industrial scientists, academic scientists are forced to share their (explicit) knowledge with the scientific community. While the often cited paradigm 'publish or perish' might sound very harsh, the academic reality is nevertheless characterized by a high pressure on scientists to publish their research results. Universities and their scientists are often evaluated by using the number of publications, dissertations, patents or invited lectures as output variables to measure scientific productivity (Geuna and Martin, 2003). These evaluations are in turn used to distribute funding and develop research strategies. Given these considerations, we expect that the interdependency of partners is not strongly associated with cooperation success when primarily explicit knowledge is involved, as scientists are usually used to sharing their explicit knowledge with external parties.

However, this might be different for tacit knowledge. Another particularity of the academic environment might be of importance for this knowledge dimension: a high autonomy of researchers to determine their research agenda. In industry, scientists are often forced to cooperate with external partners due to market developments, changes in the competitive landscape or budgetary constraints. On the contrary, there are little possibilities to force academic scientists into cooperation projects. Academic scientists are usually allowed to design their own research projects and freely choose the partners for cooperation. In this context, it can be expected that the scientists in this study are only willing to share their tacit knowledge if they really have to, i.e. if they are highly dependent on their cooperation partner. Accordingly, we hypothesize:

H2a. Successful cooperation projects with tacit knowledge as the predominant form of knowledge will show a higher degree of interdependency between the partners than less successful ones.

H2b. Successful cooperation projects with explicit knowledge as the predominant form of knowledge will not show a higher degree of interdependency between the partners than less successful ones.

3.3. Tie strength

It has been shown that the ease of knowledge transfer can be affected by the strength of interpersonal connections, often referred to as tie strength (Hansen, 1999; Levin and Cross, 2004; Reagans and McEvily, 2003; Uzzi, 1997). This also suggests an influence on the overall performance of cooperation projects. Tie strength has mostly been considered to have a component relating to the frequency of communication and a component relating to the closeness of individuals (Hansen, 1999; Marsden and Campbell, 1984; Reagans and McEvily, 2003). It is, however, still unclear in how far tie strength affects the sharing of knowledge in regard to the different dimensions of knowledge. Analyzing 120 new product development projects in a large electronics company, Hansen (1999) concluded in his study that strong ties facilitate the transfer of tacit knowledge more than that of explicit knowledge. Furthermore, he could show that weak ties speed up the completion time of projects when the involved knowledge is rather explicit. In contrast, the results of Reagans and McEvily (2003) indicate that it is easier to share both explicit and tacit knowledge in a strong tie and more difficult to transfer both dimensions of knowledge in weak ties. They further argue that it is inefficient to use strong ties to transfer explicit knowledge, as they could better be used to transfer tacit knowledge.

As discussed in Section 3.2, academic scientists can usually choose rather freely whether they want to cooperate with a certain external partner or not. Accordingly, one would expect that scientists mostly cooperate with partners they are highly dependent on or have a good relationship with. Through the mechanism of self-selecting cooperation partners, the overall level of tie strength can thus expected to be higher than in industrial cooperation projects. Another aspect that might exert an influence on the level of tie strength in the academic setting is the fact that professors are usually highly specialized and stay in their field of research for long time spans. In contrast to the short-term perspective often prevailing in industry, the long-term perspective in the academic setting should enable university scientists to establish and continually nurture high-quality relationships, leading to high levels of tie strength between cooperation partners. As this situation exists irrespective of the knowledge involved in selected cooperation projects, we hypothesize:

H3. Successful cooperation projects will show a higher degree of tie strength than less successful ones, both for tacit and explicit knowledge as the predominant dimension of knowledge.

4. Research design

4.1. Research setting

Studying R&D collaborations of university scientists is not purely academic, but can have further far-reaching implications for research policy. This can be attributed to two major trends: a continuing growth of collaborative research and a redefined role of publicly funded R&D (Chompalov et al., 2002). Bibliometric studies have shown that collaboration in academic research, both domestic and international, has been rising steadily over the last decades (Godin and Gingras, 2000; Hicks and Katz, 1996). As the generation of new knowledge becomes more and more complex, researchers from different areas of expertise increasingly work together to accomplish their goals. Smith and Katz (2000) could show that the level of institutional cooperation is exceptionally high in the natural sciences, leading to an outstanding importance of collaboration in this field. Analyzing cooperation projects in the natural sciences thus promises to yield interesting results with a high relevance for research policy. We therefore chose to focus on the fields of chemical and biological sciences in our study. Aiming at a comprehensive survey, we compiled a list of all German professors of the chemical and biological sciences. The final list covered a range of more than 60 universities and contained 2430 individuals—1274 chemists and 1156 biologists.

4.2. Data collection and measures

A standardized online questionnaire was developed over two stages. First, a literature review was performed to identify adequate constructs. Existing scale items from previous studies were used where applicable and adapted to the context of academic cooperation projects. Regarding the degree of knowledge codification, we employed the scale of Hansen (1999, 2002), and Hansen et al. (2005), respectively. Project success was measured using a modified two-item scale originally developed by Keim (1997). Santoro and Bierly (2006) measured the trust firms had in their university partners using a modified measure of Saparito et al. (2004). We adapted their four-item measure to determine the degree of trust between the cooperating partners. The dependency of the interacting partners was measured using a modified two-item scale developed by van den Ven and Chu (1989). Following Hansen (1999), we aimed to measure tie strength asking for the frequency of communication and the closeness of the cooperating partners.

Second, a pretest was performed by sending the questionnaire to selected university scientists. Including their suggestions, some questions were removed, others reformulated or added (see Appendix for an overview of the used items and constructs; the original questionnaire contained additional items not presented in this paper). All scientists were approached by personalized emails. A reminding email was sent out after 18 days. The survey was terminated 50 days after first approaching the target group. Overall, we could obtain 827 responses, representing a response rate of 34%. 235 datasets were eliminated due to incomplete answers or lack of cooperating activities. Furthermore, another 195 datasets were excluded from the analysis as the respondents reported the involvement of industrial partners. As this study explicitly focuses on the academic setting, we only included cooperation projects involving academic partners. This reduction resulted in a final sample size of $N=397$. To avoid a bias towards highly successful projects, the respondents were asked to evaluate their last completed collaborative R&D project regarding the different aspects of interest.

5. Analysis and results

Unidimensionality of constructs was assessed employing exploratory factor analysis. We further used Cronbach's alpha to evaluate the reliability of the measures. Factor loadings and Cronbach's alphas are reported in the Appendix. Construct unidimensionality could be shown for all constructs. We used the average variance extracted (VE) to assess construct validity. The construct *tie strength* showed a comparably low Cronbach's alpha of 0.55. As this value does not meet the threshold generally considered sufficient (Hair et al., 2006), we decided to examine the two underlying items (*frequency of communication* and *closeness*) separately. While this approach complicates a comparison of our results with other studies, it nevertheless promises to result in new findings concerning the role of communication and closeness in cooperation projects. With regard to the other constructs, *dependency* and *success* show a VE above 0.50. The constructs *degree of tacitness* and *relational trust* show values slightly below 0.50. To maintain the richness of the measures, we decided not to further purify these constructs. As proposed by Fornell and Larcker (1981), we assessed the discriminant validity of the constructs by comparing the VE percentages with the square of the correlation estimates. All VE estimates fulfilled the criterion of being greater than the squared correlation estimates, supporting good evidence of discriminant validity (Hair et al., 2006). The goodness-of-fit measures for the overall model can be considered acceptable (GFI=0.985; AGFI=0.975; RMR=0.094).

To test our hypotheses, we divided the total sample into subgroups. Basically, we want to distinguish between successful and less successful projects with explicit or tacit knowledge as the predominant form of knowledge involved. We therefore developed a matrix with the degree of knowledge codification and the degree of success as axes (see Fig. 1).

Based on the employed 7-point scales, we considered a value of 4 to be neutral and used this value for partitioning the sample (cases that included the exact value of 4,0 were included in the "high" groups). Four subgroups emerge:

- Group A is characterized by a project success below expectations and explicit knowledge as the predominant form.
- Group B represents projects with an outcome above expectations and explicit knowledge as the predominant form.
- Group C is formed by projects with an outcome above prior expectations and tacit knowledge as the predominant form.
- Group D includes projects less successful than expected that were based on tacit knowledge as the predominant form.

After partitioning the sample into subgroups, we conducted *t*-tests to test the developed hypotheses. Table 1 displays the mean values, standard deviations and results of hypotheses testing.

Hypotheses 1a and 1b predict that we should expect group differences in the degree of trust between groups C and D, but not between groups A and B. Regarding the mean values, group B shows the highest value of all groups, slightly above the value of group C. Both groups A and D (i.e. the groups covering the less successful projects) show lower mean values, albeit still on a comparatively high level. Surprisingly, the *t*-tests do not support Hypotheses 1a and 1b. We cannot find a significant difference in the levels of trust between successful and less successful projects when primarily tacit knowledge is involved. However, a significant difference exists in terms of relational trust when explicit knowledge dominates in the cooperation projects. Contradicting our expectation, these results suggest that trust seems to be of special importance in cooperation projects mainly involving explicit knowledge. At the same time, the high levels of trust in the less successful groups also indicate that a high level of trust does not guarantee the success of a cooperation project.

Hypothesis 2a stated that successful cooperation projects involving mainly tacit knowledge will show a higher degree of interdependency between the partners than less successful ones.

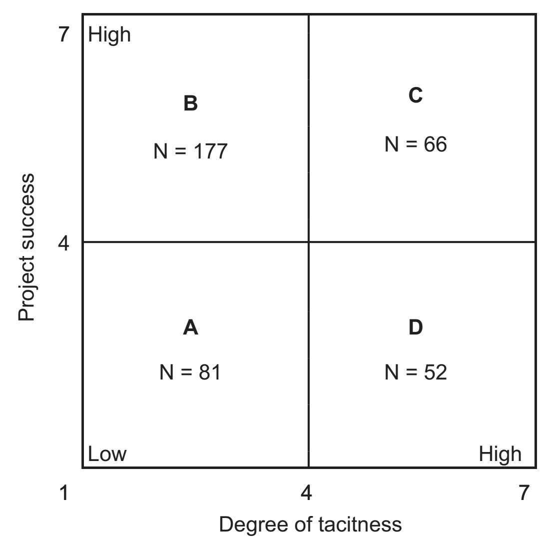

Fig. 1

Table 1
Mean values, standard deviations and results of *t*-tests.

	Group				Hypothesis	Results of *t*-tests
	A	B	C	D		
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)		
Degree of tacitness	2.93 (0.90)	2.84 (0.81)	5.02 (0.62)	5.04 (0.66)	–	–
Success	3.65 (0.60)	5.45 (0.67)	5.14 (0.60)	3.68 (0.53)	–	–
Relational trust	5.66 (1.06)	6.00 (0.87)	5.89 (1.05)	5.53 (1.18)	H1a: C > D H1b: A=B	B > A*
Dependency	4.83 (1.57)	5.18 (1.42)	5.55 (1.52)	4.78 (1.60)	H2a: C > D H2b: A=B	C > D**
Frequency of communication	3.52 (1.41)	3.99 (1.31)	3.92 (1.50)	3.29 (1.55)	H3: A,D < B,C	C > D* B > A**
Closeness of partners	4.58 (1.28)	4.85 (1.31)	5.02 (1.28)	4.46 (1.32)	H3: A,D < B,C	C > D*

Notes: $^{*}p < 0.05$; $^{**}p < 0.01$. S.D.=standard deviation.

Thus, we should expect a significant difference between groups C and D. Group C shows the highest mean value of all groups. Furthermore, the *t*-test reveals that group C significantly differs from group D regarding the degree of interdependency between partners, supporting Hypothesis 2a. Similarly, our data also lends support to Hypothesis 2b, stating that there should not be any significant differences in projects involving mainly explicit knowledge. These finding indicate that a high degree of interdependency could be associated with the successful outcome of cooperation projects, especially when tacit knowledge dominates the projects.

Hypothesis 3 expected that successful cooperation projects will show a higher degree of tie strength than less successful ones, regardless of the predominant dimension of knowledge. Due to the results of our factor analysis, we cannot test for a difference in tie strength. However, we can test for differences in the underlying items *frequency of communication* and *closeness of partners*. In line with the reasoning of Hypothesis 3, one could expect differences between groups B and A and groups C and D. Regarding the frequency of communication, group B shows the highest mean value, slightly above group C. Furthermore, the *t*-tests show that group B significantly differs from group A and group C significantly differs from group D. Accordingly, the frequency of communication seems to be of importance for project success, regardless of the type of knowledge involved. Regarding the closeness of partners, the *t*-tests reveal a different result. Here, we can only find significant differences between groups C and D, i.e. for the projects mainly involving tacit knowledge. Furthermore, it is interesting to note that the successful projects involving tacit knowledge (group C) show the highest mean value of all groups regarding the closeness of partners. These results suggest that the closeness of partners seems to be especially relevant in projects dominated by tacit knowledge.

6. Discussion and conclusion

In our paper, we set out to analyze differences in successful and less successful R&D cooperation projects of academic scientists, with a special focus on the role of different dimensions of knowledge. To this end, we asked university professors from the chemical and biological sciences to evaluate their last completed cooperative R&D project. More specifically, we investigated in how far successful and less successful projects mainly involving tacit or explicit knowledge differ in regard to *trust*, *dependency*, *frequency of communication* and *closeness of partners*.

Regarding the degree of trust, we reasoned that the overall level of trust in cooperation projects should be higher in the academic setting, compared to similar studies conducted in industrial settings. The results show that even in the less successful projects (groups A and D) very high levels of relational trust can be found. The mean value of all groups is 5.8, on a 7-point scale. In comparison, the mean value was 3.8 in Santoro and Bierly's (2006) study of university–industry collaborations and 4.73 in Sherwood and Covin's (2008) analysis of university–industry alliances. We believe that the obtained results can be attributed to the specific characteristics of the academic environment. Academic cooperation projects are, in contrast to their industrial counterparts or university–industry partnerships, seldom established under the influence of external forces such as market developments or competitive pressure. University scientists often enjoy the freedom to simply refrain from establishing a cooperation project when the (expected) level of trust appears to be too low.

With respect to the different knowledge dimensions, the study's results contradicted the developed hypotheses. The group covering successful projects involving explicit knowledge (group B) shows the highest mean value of all groups, differing significantly from the group with less successful projects. In contrast, no significant difference in the level of trust can be found between successful and less successful projects dealing with tacit knowledge. While we reasoned that trust should be of special importance when primarily tacit knowledge is involved in the projects, it turned out that it seems to be especially relevant when explicit knowledge dominates the projects. These results might indicate that competition between research groups plays a more prominent role in academia than expected. As briefly discussed before, it is extremely important for the reputation of academic scientists to be the first to publish research results in prestigious journals. The intense degree of competition for the first publication of research results has been demonstrated in a study of Hagstrom (1974), who found that only 38% of the academic scientists in his sample had never been anticipated by others. In light of these considerations, university scientists might be particularly afraid of knowledge spillovers in cooperation projects. As these spillovers might occur more easily when the involved knowledge has an explicit character, exceptionally high levels of trust might be required for cooperation projects involving explicit knowledge to be successful. Furthermore, cooperating partners in an industrial setting frequently use formal (non-disclosure) agreements and contracts to secure their intellectual property and impede unintended knowledge flows. In contrast, cooperation projects in academia are often based on mutual trust and informal arrangements rather than on contractual agreements. While van Wijk et al. (2008) could already demonstrate in their comprehensive meta-analysis that trust is of major importance for intra- and inter-organizational knowledge sharing, our results further add to our understanding by showing that both knowledge and organizational characteristics seem to affect the role trust plays in cooperation projects.

Considering the interdependency between the project partners, our results support both Hypothesis 2a and 2b. Successful projects involving tacit knowledge significantly differ from the less successful ones regarding the interdependency between partners. In contrast, no significant differences can be observed in successful and less successful projects involving mainly explicit knowledge. These findings can be interpreted drawing on the idea of reciprocal incentives. As it can be the source of competitive advantage, a cooperation partner would naturally be reluctant to disclose and share tacit knowledge. However, when the interdependency is high, both partners can also expect to gain tacit knowledge from the other. Thus, a reciprocal incentive for sharing knowledge exists in this situation, which in turn could be a reason for higher project success. If predominantly explicit knowledge is involved, the reluctance to share should be lower, as explicit knowledge is easily accessible and transmittable. Especially for university scientists, the (intended) sharing of explicit knowledge is an essential part of their everyday activities and a cornerstone of the academic system as a whole. Consequently, as explicit knowledge is less of a competitive advantage, cooperation partners should be willing to share even if they are not highly interdependent. Accordingly, it can be observed that the interdependency between partners is lower in the successful projects involving explicit knowledge. One should further note that the mean values of all groups are comparatively high. Again, this finding might be attributable to the academic context. While scientists in industry are often forced into cooperation projects by external influences, academic scientists enjoy a high level of freedom when it comes to the decision to cooperate. Accordingly, university scientists might only be willing to establish cooperation projects in the first place when they can expect a high degree of interdependency, indicating a good fit of the partners and building the foundation for reciprocal incentives to disclose knowledge and cooperate.

Looking at the construct of *tie strength*, we decided to analyze the underlying items *frequency of communication* and *closeness of partners* separately. With regard to the frequency of communication, we could demonstrate that successful projects significantly differed from less successful projects, regardless of the predominant type of knowledge. Slightly different results emerged for the closeness of partners. Here, a significant difference between successful and less successful cooperation projects could only be demonstrated for those projects involving mainly tacit knowledge. For projects dealing with explicit knowledge, no significant difference could be observed. Taken together, these results suggest that (a) a high frequency of communication seems to be important for the success of cooperation projects, both for tacit and explicit knowledge, and (b) the closeness of partners seems to be especially relevant for projects involving predominantly tacit knowledge. These results could partly explain why Hansen (1999) and Reagans and McEvily (2003) came to different conclusions in their studies. While Hansen (1999) concluded that strong ties facilitate the transfer of tacit knowledge more than that of explicit knowledge, Reagans and McEvily (2003) stated that it is easier to share both tacit and explicit knowledge in a strong tie. While our study did not explicitly investigate the transfer of knowledge, we reason that the performance of a project is closely related to knowledge transfer. Accordingly, the different effects observed in both studies could be caused by differences in the levels of frequency of communication and closeness of partners. In light of our results, examining the underlying items of *tie strength* separately in future studies could help in further explaining their effects on knowledge sharing or project performance.

Overall, our study sheds new light on the role of different knowledge dimensions in R&D cooperative projects. Particularly, it contributes to existing research by (1) expanding the empirical basis of research towards the academic perspective, using a large scale survey, (2) showing that high levels of trust seem to be prevailing in cooperative R&D projects of academic scientists and that successful projects, especially those involving explicit knowledge, require *exceptionally* high levels of trust, and (3) demonstrating that the underlying dimensions of tie strength should be analyzed separately when the distinction between tacit and explicit knowledge is considered. Overall, the study further demonstrates the importance of analyzing cooperation projects with respect to knowledge, organizational and network characteristics, as proposed by van Wijk et al. (2008). While this study's emphasis lay primarily on network aspects, including knowledge characteristics (in this case the distinction between tacit and explicit knowledge) and the organizational context (in this case the academic environment) yielded a more sophisticated understanding of how the analyzed influence factors work in different settings.

Additionally, practical implications for the management of R&D collaborations emerge. First, trust is an indispensable ingredient for any cooperative effort. However, exceptionally high levels of trust seem to be required to achieve a project outcome above expectations. Second, a certain degree of interdependency between partners is needed to offer reciprocal incentives for cooperating. A high interdependency seems to be of special importance when mainly tacit knowledge is involved in the cooperation project. Thus, the interdependency between partners should be taken into account by researchers when planning a cooperative project. Third, scientists should be aware that the frequency of communication and the closeness of partners seem to have a different relevance for projects involving tacit or explicit knowledge. Communicating frequently seems to be important in cooperation projects, regardless of the type of knowledge involved. However, when tacit knowledge is involved, the closeness of partners seems to be of major relevance. Scientists should thus consider which dimension of knowledge dominates in their cooperation project when thinking about how the project success could be influenced. While our analysis focused on cooperation projects of academic scientists, the obtained results also offer implications for university–industry partnerships. In light of our findings, industry might consider new organizational forms of cooperative R&D projects to achieve higher levels of closeness with academic partners. For instance, in the chemical industry many firms recently established separate organizational units designed to enhance cooperative activities with external partners (e.g. Evonik's 'Science-to-Business Centers' or BASF's 'Joint Innovation Lab'). In these units, scientists from industrial firms, universities and research institutes come together in the same location to work on R&D projects. The units are usually laid out to operate in a timeframe of five years. In contrast to many 'conventional' cooperation projects, these new approaches differ in that they enable the partners to work in close physical proximity for longer periods of time. Furthermore, the organizational separation from the core company allows for creating an own organizational culture that might offer an opportunity for a shared cultural space with university scientists, an important factor for knowledge exchange (Bjerregaard, 2010). This, in turn, might lay the foundation for high-quality relationships, fostering tacit knowledge sharing.

We believe that our study offers some interesting empirical findings. Nevertheless, caution should be exerted when generalizing the results beyond the scope of our study. While we were able to obtain information about cooperation projects from a

Table A1

Questionnaire items	Loading
Degree of tacitness (3 items, Cronbach′s alpha=0.71; VE=0.46)	
• How well documented was the knowledge transferred in the project? [1=very well documented; 7=not well documented]	0.74
• To what extent was the knowledge in the project explained in writing (e.g. in reports, manuals, instructions, emails, etc.)? [1=everything available in writing; 7=nothing available in writing]	0.73
• In which form was the knowledge in the project available? [1=mainly in documents; 7=mainly personal practical know-how]	0.55
Dependency (2 items; Cronbach′s alpha=0.72; VE=0.57)	
• To accomplish our goals, we were strongly dependent on our cooperation partners. [1=strongly disagree; 7=strongly agree]	0.89
• Our cooperation partners were strongly dependent on us to accomplish their goals. [1=strongly disagree; 7=strongly agree]	0.89
Success (2 items, Cronbach′s alpha=0.69; VE=0.54)	
• Overall, how do you evaluate the achievement of project targets compared to the original plan? [1=far below expectations; 7=far above expectations]	0.87
• Overall, how do you evaluate the achievement of project targets compared to the (technological) problem? [1=far below expectations; 7=far above expectations]	0.87
Relational trust (4 items, Cronbach′s alpha=0.76; VE=0.47; GFI=0.997; AGFI=0.985; RMR=0.055)	
• We could freely share our concerns and knew our partners would listen. [1=strongly disagree; 7=strongly agree]	0.67
• Our cooperation partners understood our needs even if we did not describe them in detail. [1=strongly disagree; 7=strongly agree]	0.71
• We could freely share secrets and knew they would be treated confidentially. [1=strongly disagree; 7=strongly agree]	0.81
• We shared common values with our cooperation partners. [1=strongly disagree; 7=strongly agree]	0.85
Frequency of communication (1 item)	
• How frequently did you communicate with your cooperation partners? [1=once a day; 2=twice a week; 3=once a week; 4=twice a month; 5=once a month; 6=once every 2nd month; 7=less frequently]	
Closeness of partners (1 item)	
• How close was the working relationship between you and your cooperation partner? [1=very close – practically like being in the same working group; 7=distant, reduced to what was absolutely necessary]	

Notes: N=376; Confirmatory factor analysis was performed using AMOS 18.0. Goodness-of-fit measures for the overall measure model are: GFI=0.985; AGFI=0.975; RMR=0.094.

comparatively large sample of 376 university professors, these were only active in the fields of chemical and biological sciences. Thus, an investigation including other disciplines, such as physics or material sciences, could yield different results. Furthermore, by testing for group differences, we can only obtain results that indicate certain interrelations and allow us to point at areas of interest. However, regression analysis would be needed to allow for a clearer understanding of the causal interactions. As there are many factors influencing the outcome of a cooperation project, this analysis would have to encompass a wider selection of constructs. Another aspect that needs to be kept in mind is the potential threat of a retrospective bias, as all variables were measured subjectively, post-hoc and through a single-respondent questionnaire. As March and Sutton (1997, p. 701) noted, ''performance information itself colors subjective memories, perceptions, and weightings of possible causes of performance''. However, even in the less successful projects in our sample, we find comparatively high values of trust. While this finding does not completely rule out the possibility of retrospective bias, it at least indicates that it is not a substantial issue in the research design.

Despite these limitations and possibilities for future research, we still believe that our study helps in deepening our understanding of the role different dimensions of knowledge play in cooperative R&D projects.

Appendix A. Constructs, items, factor loadings, Cronbach′s alpha, VE

See Table A1.

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