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How companies learn to collaborate: Emergence of improved inter-organizational processes in R&D alliances

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Abstract

Previous research has maintained that the capacity to manage alliances is a distinct capability, defined as the ability to identify, negotiate, manage, monitor and terminate collaborations. This paper focuses on an important but hitherto neglected aspect of alliance capability by investigating how partnering firms may learn how to better manage their dyadic R&D collaborations. In particular, we seek to test the Nonaka and Takeuchi (1995) model of dynamic knowledge creation by establishing a link between the facilitation of four knowledge conversion processes – socialisation, externalisation, combination and internalisation – and an improved capability to manage inter-organisational R&D processes. We specify and extend the model by identifying and testing several critical interactions between these knowledge conversion processes. Relying on data from 105 R&D partnerships in the global telecommunications industry, we suggest that the failure to support one of these knowledge conversion processes has the potential to hamper the proper functioning of the other knowledge conversion processes and thus the emergence of capability to manage dyadic R&D collaborations.

Keywords: *R&D alliances, inter-organisational learning, alliance capability, dyadic collaboration processes*

Introduction

For companies operating in turbulent industries, sustainable competitive advantage stems largely from their innovative capability. To keep up with competition, companies need to bring new or improved product offerings to market with high speed, flexibility and reliability. The continuous upgrading of R&D processes has thus emerged as the primary target for many organisations as they start to extend the application of process management philosophy from manufacturing to new product development processes (Benner & Tushman, 2002; Harry & Schroeder, 2000; Repenning & Sterman, 2002).

Inter-firm collaboration may help companies face this challenge of continuous renewal. Various studies have suggested that inter-firm collaboration spurs the innovativeness and learning of the organisations involved (see, for instance, Cohen & Levinthal, 1990; Goes & Park, 1997; Hagedoom &

Duysters, 2002; Lee, Lee, & Pennings, 2001). However, despite their upside, R&D alliances are complex organisational forms, involving tacit, non-routine and highly uncertain knowledge conversion processes fraught with ambiguity (Anand & Khanna, 2000).

Previous research has maintained that the capacity to manage alliances is a distinct capability, defined as the ability to identify, negotiate, manage, monitor and terminate collaborations (see, for instance, Anand & Khanna, 2000; Draulans, DeMan, & Volberda, 2003; Kale, Dyer, & Singh, 2002; Kale & Singh 2009; Schreiner, Kale, & Corsten, 2009; Simonin, 1997; Zollo, Reuer, & Singh, 2002). This body of literature assumes that firms will be more successful in their alliances when they continuously develop mechanisms and routines to accumulate, store, integrate and diffuse relevant knowledge related to the management of alliances (Anand & Khanna, 2000; Dyer & Singh, 1998; Inkpen & Dinur, 1998; Kale et al., 2002). Previous research has identified several dimensions of alliance capability, such as the existence of a dedicated alliance function (Kale et al., 2002); partner-specific, technology-specific and general experience accumulation (Zollo et al., 2002) as well as relation-specific assets, complementary resources and effective governance (Dyer & Singh, 1998). Unlike most previous research focusing on the emergence of alliance capability that is generalisable across all firms' alliances (see, for instance, Schreiner et al., 2009), we are interested in how dyad-specific inter-organisational processes emerge and then serve as a foundation for a more general capability to manage R&D alliances.

This paper focuses on an important aspect of alliance capability, namely the management of the reciprocal interdependences between alliance partners through the coordination of their actions. This is cited to be one of the main drivers of alliance success (Kale & Singh, 2009; Schreiner et al., 2009). In particular, our study investigates how alliance partners may learn to better manage their inter-organisational R&D processes as a result of joint knowledge accumulation processes. We adopt the knowledge-based perspective to the study of alliance capability (e.g. Kale et al., 2002), according to which knowledge provides a basis for creating (inter)-firm-level capabilities and thus alliance success. Within this context, the theoretical foundation of our work relies on the Nonaka and Takeuchi (1995) model of organisational knowledge creation. In particular, we seek to establish a link between four knowledge conversion processes – socialisation, externalisation, combination and internalisation – the interactions between them and an improved capability to manage inter-organisational R&D processes.

The empirical data of this study are based on a survey of 105 R&D partnerships in the global telecommunications industry. In our study, R&D alliances are defined as formal (equity) or informal partnerships between two companies with the aim of developing a new product or technology to be used by one or both partners, or adopting a new technology for future use.

This paper contributes to the alliance capability literature by presenting evidence suggesting that the development of alliance management capability requires not only intra-organisational but also inter-organisational knowledge sharing and creation, i.e. joint learning. To be more specific, our study adds to the theoretical and conceptual understanding of inter-organisational learning in R&D alliances by being the first one to specify and test the Nonaka and Takeuchi (1995) model in collaborative R&D settings. This model has become widely accepted in a variety of management fields, such as organisational learning, joint ventures, new product development and information technology (see, for instance, Kidd, 1998; Nonaka, Toyama, & Nagata, 2000b). Although intuitively appealing, there is little empirical evidence confirming this model (Kidd, 1998; Nonaka, Byosiere, Boricki & Konno, 1994; Sabherwal & Becerra-Fernandez, 2003). We also specify the original model by identifying a number of interactions between the four knowledge conversion processes reinforcing inter-partner learning, thus resulting in an improved capability to manage R&D alliances. The results of this study offer important managerial implications for the application of knowledge management practices in R&D alliances and the emergence of an improved capability to manage inter-organisational R&D processes.

Our paper is structured as follows: first, we lay the foundation for this study by reviewing the Nonaka and Takeuchi (1995) model of dynamic knowledge creation. Thereafter, we formulate hypotheses describing the relationship between the four knowledge conversion processes, the interactions between them and the improved capability to manage R&D alliances. In the fourth and fifth subsections, we describe the method and report our results. Finally, this paper concludes with a discussion of the results as well as suggestions for future research.

Theoretical Context: The Nonaka and Takeuchi Model of Dynamic Knowledge Creation

In this study, collaborative R&D processes are understood as inter-organisational learning systems. We focus on process learning, i.e. improvements in the practices of collaborative R&D, as they are conceived in the R&D processes of collaborating organisations. Because of the multifaceted nature of the phenomenon of interest, we felt the need to draw on the several discussions and theoretical perspectives (for a review, see, for instance, Dodgson, 1993; Easterby-Smith, 1997; Shrivastava, 1983) existing within the field of organisational learning. By doing so, we acknowledge that learning is a collective accomplishment residing in the networks of relationships between organisations and the subjective experiences of individuals and groups (Araujo, 1998; Boland & Tenkasi, 1995; Venzin, Von Krogh, & Roos, 1998) or, put differently, situated within the communities of practice (Wenger, 1998). Besides viewing learning as a social phenomenon, we are interested in how new knowledge is created in inter-organisational practices through the cognitive processes of individual alliance participants (Anderson, 1983; Singley & Anderson, 1989), through the emergence of (inter)-organisational memory (Anand, Manz, & Glick, 1998; Croasdell, 2001; Walsh & Ungson, 1991) or through deliberate collaborative knowledge-creation efforts in trialogical learning (Paavola & Hakkarainen, 2005).[1] Nonaka and Takeuchi's (1995) model of knowledge conversion seems to integrate these aspects of learning and distributed knowledge creation and it has thus become a theoretical lens through which we analyse knowledge creation in R&D alliances.

The Nonaka and Takeuchi (1995) model is based on knowledge conversion processes relying on Polanyi's (1958) distinction between explicit and tacit knowledge. Explicit knowledge can be expressed in words or numbers and shared in the form of data, scientific formulae, specifications and manuals. According to Spender (1996), tacit knowledge can be best described as knowledge that has not yet been abstracted from practice. It is deeply rooted in an individual's actions and experience as well as in the individual's ideals, values and emotions. Tacit knowledge may also be held collectively in shared collaborative experiences and interpretations of events, firm routines and firm culture, and in collective mental models of teams (Nelson & Winter, 1982; Nonaka & Takeuchi, 1995; Nonaka, 1994; Polanyi, 1958; Rico, Sánchez-Manzanares, Gil, & Gibson, 2008). Thus, tacit knowledge, highly personal or community-specific, is hard to formalise, communicate and share with others.

According to the dynamic theory of organisational knowledge creation, knowledge is created in a spiralling process of interactions between tacit and explicit knowledge, where tacit knowledge is shared, explicated and combined into new knowledge through joint human experience and communication (Leonard & Sensiper, 1998; Nonaka, 1994; Nonaka & Takeuchi, 1995). This learning spiral relies on the four modes of knowledge conversion: socialisation, externalisation, combination and internalisation. *Socialisation* plays a crucial role in the knowledge creation spiral. It is a process through which tacit knowledge possessed by an individual or a community is converted into tacit knowledge held by a larger group of people. Socialisation occurs through human interaction, where individual experiences, mental models and skills are shared collectively to become 'sympathised' tacit knowledge. *Externalisation* refers to articulating this tacit knowledge into explicit knowledge, for example words, concepts or images. Externalisation is triggered through dialogue and collective reflection between individuals and groups. *Combination* is a process of merging diverse explicit knowledge items into more complex and systemic sets of explicit knowledge. According to Nonaka and Takeuchi (1995, p. 71) combination is triggered by 'networking' newly created explicit knowledge and existing knowledge from various units, thereby crystallising them into new managerial systems, products or services. *Internalisation* refers to converting explicit knowledge into tacit knowledge, typically through learning by doing. It may also be triggered by re-experiencing the experiences of others by reading documents or manuals written by them, or listening to the organisation's success stories (Nonaka and Takeuchi, 1995, p. 69). Internalisation bears some similarity to the traditional notion of learning (Nonaka, 1994).

An underlying idea of this spiral consists of the assumption that organisational knowledge creation starts at the individual level and moves up through communities that interact with each other, crossing sectional, departmental, divisional and organisational boundaries to produce new tacit and explicit knowledge (Nonaka, 1994; Nonaka & Takeuchi, 1995, pp. 59, 70–71; Nonaka et al., 2000b). Organisational knowledge creation is thus a complex process, where all four knowledge conversion processes need to form a continuous cycle reinforcing each other. In other words, although all four knowledge conversion processes contribute to organisational learning independently, the central theme of this model is the dynamic interaction between these processes for the creation of new knowledge (Nonaka, 1994).

Hypotheses

In an inter-organisational R&D project, the collaborating partners accumulate shared knowledge on the product they develop, on the specific R&D project and on the more generic R&D processes in the partnership. It is possible to distinguish between two inter-related processes of knowledge creation in collaborative R&D alliances. The primary knowledge creation process aims to develop new or improved products or production processes, whereas the secondary spiral involves learning about how to manage and implement R&D projects in inter-organisational settings. The primary spiral in collaborative R&D alliances is a deliberate knowledge creation spiral. It aims to jointly create the object of R&D. The second spiral, however, is less intentional. Seldom is there a conscious effort to develop the collaborative R&D process itself. Rather, new knowledge about how to manage R&D alliances emerges as a side effect of collaborative R&D projects, in a more 'tacit' and implicit mode.

It is important to note that if successful, the secondary spiral generates practical new knowledge and experience, thus giving rise to an improved capability to manage future R&D alliances, defined as improvements in the day-to-day collaborative R&D practices of the parties involved (Smeds, Olivari, & Corso, 2001). Thus, the primary knowledge creation processes rely heavily on the success of the secondary spiral; without adequate skills to manage inter-firm relationships, companies are likely to fail to meet the primary goals set for their alliances (Anand & Khanna, 2000; Dyer & Singh, 1998; Kale et al., 2002).

We focus on the secondary spiral of R&D process learning, because of its significance and our lack of knowledge thereof, by formulating a set of hypotheses on the role of socialisation, externalisation, combination and internalisation in the emergence of improved collaborative practices in the context of R&D alliances (Hypotheses 1–4). In addition, we elaborate on the Nonaka and Takeuchi (1995) model by identifying the various interactions between the knowledge conversion processes that are needed to reinforce learning. The first set of interactions focus on the interplay between individual (tacit) knowledge, the processes converting individual knowledge into inter-organisational knowledge and the improved capability to manage R&D alliances (Hypotheses 5a and 5b). The second set of interactions analyses the interplay between inter-organisational knowledge, the processes converting inter-organisational (explicit) knowledge into individual- or team-level (tacit) knowledge and the improved

capability to manage R&D alliances (Hypotheses 6a and 6b). Finally, we shed light on the interaction processes that may lead to the extension of alliance partners' body of explicit knowledge and thus an improved capability to manage R&D alliances (Hypothesis 7), see Figure 1.

Insert Figure 1 about here

Socialisation, Externalisation, Combination and Internalisation, and an Improved Capability to Manage R&D Alliances

R&D alliances pose several challenges for inter-partner learning in general and for the emergence of an improved capability to manage R&D alliances in particular. First, the physical distance between the partners may reduce personal face-to-face communication, which is deemed central for the maintenance and development of R&D work (De Meyer, 1991, p. 50). Second, social, organisational and individual barriers may hamper the emergence of shared understanding on the beneficial ways to collaborate and the transfer of best practices from one organisation to another (Leonard & Sensiper, 1998; Szulanski, 1996). Third, the very focus of our study, the improved capability to manage R&D alliances, involves the creation and sharing of knowledge that is partly tacit, sticky, complex and difficult to codify (Nelson & Winter, 1982; Szulanski, 1996). Finally, the nature of R&D project work often implies that project members are involved in several projects simultaneously and, therefore, cannot commit themselves full time to the interaction with one partner.

To overcome these organisational, cultural and physical barriers, it is crucial that the collaborating partners work hard to create 'inter-organisational learning communities' or 'virtual teams' conducive to the emergence of shared mental models and experience related to the practices of the specific collaborative R&D project (primary spiral) and to the management of the R&D collaboration process that spans many R&D projects (secondary spiral). These mental models often remain unwritten and unsaid, embodied more in the people than in the systems (Kim, 1993). Such shared tacit knowledge defines what the collaboration partners pay attention to, how they choose to act and what they choose to remember from their experience. This tacit knowledge, sometimes referred to as 'team situation models', concerns some key areas of the collaborating team's work, such as the objectives and roles of participating individuals, allowing them to anticipate one another's behaviour and to adjust their own behaviour accordingly without having to communicate (Rico et al., 2008, p. 164). Nonaka and Takeuchi (1995)

suggested that such shared tacit knowledge emerges through a process of socialisation, in which tacit knowledge is transferred from one individual to another without making it explicit. Socialisation is closely related to observational learning and the notion of apprenticeship frequently discussed in the (organisational) learning literature (Bandura, 2000, 2003; Catania, 2007, p. 227; Lave & Wenger, 1991; Ibarra, 1999; Zentall & Levine, 1972). In other words, by observing others, people learn actions and judgments, and extract principles and standards embodied in the thinking and actions of others. In a similar vein, cognitive psychology has discussed unconscious learning occurring as a way and in the course of daily work, in which the content of learning is never verbalised (see, for instance, Jordan, 1989; Overskeid, 1995).

As socialisation facilitates alliance partners' capacity to understand each other's ways of thinking and feeling (Nonaka & Konno, 1998), it helps alliance partners form accurate explanations and expectations of the joint project and the collaboration. This helps coordinate their actions and adapt their behaviours to the demands of the project and the alliance partner (Levesque, Wilson, & Wholey, 2001). Shared tacit knowledge also contributes to the emergence of trust and commitment in the inter-partner relationship, deemed of utmost importance to learning (Inpken & Currall, 2004; Kale, Singh, & Perlmutter, 2000). In line with this reasoning, the previous literature has cited the failure of individuals to become socialised into the common values and identities as a major barrier to learning across organisations and groups (see, for instance, Oldenqvist, 1991). One of the managers from our sample companies highlighted the importance of socialisation for successful collaborative relationships: *'We have done a considerable amount of team building in our alliance. The collaboration proceeds more smoothly when you have an opportunity to go out and throw darts with your alliance buddies…'* In a similar vein, as demonstrated by a participant in a software development project, the absence of mechanisms supporting socialisation might lead to sub-optimal learning results: '*I think the best way of learning is to work next to somebody with experience … At the beginning I was left too much alone from my point of view and I didn't like it. So as a result, I perhaps waste time on doing something that is not necessary or I don't spend enough time on something that is important. I waste time on looking for information that was supposed to be easy to reach, because I don't know how to do it'.*

Thus, in collaborative R&D settings, spending time together in close interaction with alliance partners may facilitate forming 'inter-organisational team mental models' and 'inter-organisational routines'

(Nelson & Winter, 1982), or, put differently, a 'common ground' or 'shared understanding' on the beneficial ways to collaborate (Mohrman, Finegold, & Mohrman, 2003; Lam, 2000). As this tacit knowledge held by an individual and his/her intra-organisational R&D team is disseminated further through inter-organisational socialisation, improvements in collaborative R&D processes are likely to follow. Therefore, we hypothesise that:

Hypothesis 1. Ceteris paribus, socialisation between the members of an R&D alliance is positively associated with an improved capability to manage R&D alliances.

In addition to the transfer of tacit knowledge through socialisation, it is extremely important that alliance partners are able to explicate some of their tacit knowledge and translate it into forms easily conveyed to others across organisational, physical and temporal barriers (Nonaka & Takeuchi, 1995; Nonaka & Konno, 1998; Nonaka, Toyama, & Konno, 2000a). The power of externalisation has been recognised from the social constructionist viewpoint, emphasising that learning is embedded in social interaction mediated by language (Catania, 2007, p. 230; Mezirow, 1991; Richter, 1998). This starts from the assumption that learning occurs and knowledge is created and negotiated mainly through conversations and interactions between people (Brown & Duguid, 1991; Easterby-Smith et al., 2000; Gherardi & Nicolini, 2000; Lave & Wenger, 1991). Thus, externalisation (through language) embedded in dialogue between alliance partners allows for the emergence of shared meaning and/or a better understanding of the partner's divergent position (Gherardi & Nicolini, 2001). Finally, externalisation not only helps alliance partners learn, it also preserves what already has been learned (Crossan, Lane, & White, 1999; Daft & Weick, 1984; Daft & Huber, 1987; Isaacs, 1993).

Hence, the articulation of one alliance partner's tacit knowledge increases the amount of information available for his or her alliance partner, allowing the partner to complete alliance-related tasks more efficiently (Mohr & Spekman, 1994). This also creates a platform for goal adjustment, coordination and joint decision-making in an alliance (Isaacs, 1993; Sivadas & Dwyer, 2000), facilitating the division of tasks and the definition of R&D procedures. As one of our project managers stated: *'It should be self-evident that project managers and key experts meet regularly and discuss matters related to the management of the joint R&D project. Regular meetings between alliance partners are really the key, otherwise partners will drift away from each other and never achieve the goal set for the alliance'*. Second, the articulation process can facilitate the ex post sensemaking

of actions and decisions as managers talk about and reflect on them. This helps alliance partners better understand the causal relationships that exist between those actions and their associated outcomes. Thus, externalisation can help managers identify both the effective and the suboptimal management practices related to alliance-related tasks (Kale & Singh, 2007; Zollo & Winter, 2002). Therefore, we hypothesise that:

Hypothesis 2: Ceteris paribus, externalisation between the members of an R&D alliance is positively associated with an improved capability to manage R&D alliances.

New knowledge is often created through combinations of existing knowledge (Kogut & Zander, 1992; Liebeskind, 1996; Zahra & George, 2002; Schumpeter, 1947; Teece, Rumelt, Dosi, & Winter. 1994). Partners in an R&D alliance may learn about the beneficial ways to collaborate by complementing their own knowledge bases with the knowledge possessed by their partners. This may occur partly through a process referred to as combination in the Nonaka and Takeuchi (1995) model of dynamic knowledge creation. In practice, the combination phase involves three processes: i) capturing and combining explicit knowledge from inside and outside the organisation; ii) disseminating the new explicit knowledge to others; and iii) editing or processing the combined explicit knowledge items into plans, reports, documents, market data or electronic databases (Nonaka & Takeuchi, 1995; Nonaka & Konno, 1998; Nonaka et al., 2000a; Roberts, 2000). Apart from the Nonaka and Takeuchi (1995) model of dynamic knowledge creation, similar processes have been discussed intensively by studies investigating the role of information technology in (inter)-organisational learning (Barua, Lee, & Whinston, 1995; Dewett & Jones, 2001; Quinn, Anderson, & Finkelstein, 1996; Scarbrough & Swan, 2001; Venkatraman, 1994). The main tenet of this literature is that advances in information technology have greatly facilitated organisational memory and the ability to capture and combine explicit knowledge. The automatic capturing and sophisticated retrieval of such information results in "completeness and precision that are superior to the human components of organisational memories" (Huber, 1990, p. 106). Thus, information technology-enhanced combination processes create a larger and richer pool of codified knowledge for any given employee to draw from, thus reducing the cost of information search (Dewett & Jones, 2001; Anand et al., 1998; Rockart & Short, 1989).

Hence, the principal benefit of combination arises from the reuse and extension of the collaborative R&D knowledge that exists within the firm itself, outside of the firm or with the partner (Kale & Singh, 2007; Zollo & Winter, 2002). In addition, combination leads to the codification of alliance-related knowledge (Kale & Singh, 2007), making it replicable and easier to transfer. Finally, by involving themselves in combining alliance-related best practices from various sources, managers engage in identifying what those best practices are, thus improving their own understanding of what works and does not work in the context of R&D alliances. Thus:

Hypothesis 3: Ceteris paribus, combination between the members of an R&D alliance is positively associated with an improved capability to manage R&D alliances.

For firms to enjoy repeated success with managing R&D alliances, it is important that individual managers possess the relevant know-how for managing them. Through internalisation, individual managers may absorb the knowledge explicated by others and convert it into their own mental models, operational frameworks and practices. For instance, by reading documents and manuals on their collaborative projects and by reflecting upon them, alliance partners can internalise the explicit knowledge written in such documents to enrich their tacit knowledge bases on how to manage alliances (Nonaka & Konno, 1998; Nonaka et al., 2000 a). The process of internalisation resonates with the traditional notion of learning and with the ACT model developed in cognitive psychology. The ACT model postulates that for cognitive skills to develop, explicit (declarative) knowledge has to be transformed into tacit (procedural) knowledge (Anderson, 1983; Nonaka & Takeuchi; 1995; Singley & Anderson, 1989). Along this process, what once required conscious, deliberate and explicit thought no longer does so, and it thus becomes the obvious thing to do (Crossan et al., 1999). The process of internalisation creates 'deep knowledge', namely knowledge that is thoroughly processed, structured and stored in a way that is useful for application and task performance (de Jong & Ferguson-Hessler, 1996; Glaser, 1991). Such learning results in the integration of previous and new knowledge, an "articulated, deep understanding of a domain, including the ability to reason and explain in causal terms, and to adopt multiple viewpoints about a problem or phenomenon" (Snow, 1989, p. 9), as well as the ability to apply these ideas in new situations (Le Heron & Sligo, 2005).

When explicit knowledge on the beneficial ways to collaborate is converted into individual tacit knowledge, it is more likely to become embodied in actions and routines (Nonaka et al., 2000 a,b) and applied in future collaborative projects. In addition, by virtue of internalising existing alliance management knowledge and best practices, managers acquire a knowledge base that helps them better absorb any new knowledge relevant to managing inter-firm relationships (Kale & Singh, 2007). Thus, we hypothesise:

Hypothesis 4. Ceteris paribus, internalisation by the members of an R&D alliance is positively associated with an improved capability to manage R&D alliances.

Interactions between Socialisation, Externalisation, Combination and Internalisation: From Single Knowledge Conversion Processes to a Knowledge Spiral

As stated above, each of the four modes of knowledge conversion may facilitate learning new collaborative R&D practices, as the members of the team exchange both tacit and explicit knowledge (Roberts, 2000). Socialisation and internalisation may produce new tacit knowledge held by groups and individuals, closely related to the notion of implicit learning in the psychology literature. Externalisation and combination, in turn, may result in the creation of new explicit knowledge through a process referred to as explicit learning by psychologists (Broadbent, Fitzgerald, & Broadbent, 1986; Reber, 1989).

However, the key tenet of the Nonaka and Takeuchi model is the dynamic interaction between the different modes of knowledge conversions (Nonaka, 1994; Nonaka & Takeuchi, 1995; Nonaka et al., 2000a, 2000b). In that sense, this model challenges the notion that all learning takes place inside individual human minds (Simon, 1991, p. 125), that all learning is embedded in complex social interaction (Brown et al., 1989) or that all learning is stored in organisational blueprints and organisational memory (Anand et al., 1998; Croasdell, 2001; Walsh & Ungson, 1991). Instead, the Nonaka and Takeuchi (1995) model of knowledge creation postulates that (inter)-organisational learning can be maximised when the cognitive, social, linguistic and information processing elements of knowledge creation co-exist and reinforce one another. Stated differently, weaknesses in one of the knowledge conversion processes discussed above may hamper the implementation of the other processes because of these interactions, thus potentially jeopardising learning about how to successfully manage R&D alliances. In the following, we extend and specify the Nonaka and Takeuchi model by formulating hypotheses on the interactions between

socialisation, externalisation, combination and internalisation, and their impact on the improved capability to manage R&D alliances.

We first focus on the interactions between individual (tacit) knowledge, the processes converting individual knowledge to inter-organisational knowledge and the emergence of an improved capability to manage R&D alliances. Some scholars have adopted a purist view, stating that knowledge is always created by individuals and that we should avoid attributing human characteristics such as learning to inanimate objects, such as organisations (March & Olsen, 1975; Simon, 1991; Easterby-Smith et al., 2000). However, others have argued that it would be a mistake to assume that (inter)-organisational learning is nothing more than the cumulative result of their members' learning (Fiol & Lyles, 1985; Hedberg, 1981), as the results of individual learning are stored in the systems, structures and procedures of the organisation. Individuals may come and go, but organisations preserve certain behaviours, mental maps, norms and values over time (Hedberg, 1981, p. 6). We take this discussion one step further by suggesting that in order to maximise knowledge creation, both individual-level and inter-organisational knowledge creation processes must co-exist and reinforce each other.

Thus, inter-organisational learning should be understood as a process that amplifies the knowledge created by individuals and teams and integrates it to the knowledge network of an organisation or an alliance (Nonaka & Takeuchi, 1995). This distribution of individual knowledge to other members of the R&D alliance leads to more broad-based learning, where more and more varied sources of information exist, and retrieval efforts are more likely to succeed (Huber, 1991). Stated differently, even though internalised tacit knowledge is crucial in adopting better ways to manage collaborative R&D processes, its impact is likely to remain limited or non-existing unless it is shared with other individuals and groups in the partner organisation (Hibbert, Huxham, Sydow, & Lerch, 2010). According to the social constructionist perspective, individual learning has to move up to cross-organisational boundaries (Pautzke, 1989; Wenger, 1998; Kim, 1993) through conversations and interactions between people (Brown & Duguid, 1991; Gherardi & Nicolini, 2000; Lave & Wenger, 1991). This requires both socialisation and externalisation. Socialisation mechanisms such as corridor talk, coaching and job rotation may help transfer tacit, R&D process-related knowledge from one individual or one group to another. Externalisation mechanisms, such as partner meetings, are instrumental for explicating individual or

group knowledge on the management of R&D alliances for the use of alliance partners through dialogue. Externalisation and socialisation also enable the storage of individual-level knowledge on the management of R&D alliances in the organisational memory in the form of routines and procedures (Huber, 1991), available for future use. Looking at the situation from a different angle, well-functioning internalisation processes resulting in deep, personal knowledge are a prerequisite for efficient social learning. Without well-developed individual cognitive structures, fruitful dialogue is not likely to thrive and shared mental models fail to emerge (Anderson, 1983; Singley & Anderson, 1989). Therefore, we hypothesise that the impact of internalisation on the improved capability to manage R&D alliances is reinforced in the presence of socialisation and externalisation practices. In a similar vein, the impact of externalisation and socialisation processes are maximised in the presence of well-functioning internalisation processes.

Hypothesis 5a. The effect of internalisation on an improved capability to manage R&D alliances is moderated by socialisation between the members of an R&D alliance.

Hypothesis 5b. The effect of internalisation on an improved capability to manage R&D alliances is moderated by externalisation between the members of an R&D alliance.

Second, we analyse the interactions between explicit (inter-organisational) knowledge, the processes converting explicit knowledge into tacit (team and individual) knowledge and the improved capability to manage R&D alliances. It has been suggested that carrying out complicated tasks, such as managing R&D alliances, requires a certain amount of implicit learning (Broadbent et al., 1986; Reber, 1989; Easterby-Smith et al., 2000), resulting in changes in individual skills and behavioural patterns. Nonaka (1994, p. 20) stressed the importance of implicit learning by stating that "ignoring the personal meaning of knowledge might lead to a superficial interpretation of existing knowledge, which has little to do with here - and - now reality. It may also fail to crystallize knowledge in a form that is concrete enough to facilitate further knowledge creation in a wider social context". Thus, organisations would be mistaken to believe that complex tasks, such as managing collaborative R&D processes, could be mapped on a set of simple canonical steps and followed without significant personal understanding and insight (Brown & Duguid, 1991; Bourdieu, 1977).

We thus expect that organisations failing to support internalisation may end up with huge amounts of explicated knowledge stored in reports, e-mails and databases that is never successfully translated into

individual skills, routines and team practices, thus failing to have a long-term impact on the management of collaborative R&D processes (Kim, 1993). In one of our less successful case alliances, alliance partners were not able to internalise and act on the information provided by their partners in the form of various documents for the reason that such codified information allowed for multiple interpretations. Thus, little of the explicated knowledge is likely to transform into an improved collaborative R&D capability unless internalised by individuals and teams and applied in practice (Nelson & Winter, 1982; Nonaka, 1994). Therefore, we hypothesise that the impact of externalisation and combination on the improved capability to manage R&D alliances is reinforced in the presence of internalisation processes converting explicit knowledge into individual and team-level tacit knowledge, such as behavioural routines and practices.

Hypothesis 6a. The effect of externalisation on an improved capability to manage R&D alliances is moderated by internalisation by the members of an R&D alliance.

Hypothesis 6b. The effect of combination on an improved capability to manage R&D alliances is moderated by internalisation by the members of an R&D alliance.

Third, we shed some light on the interactions between externalisation and combination processes, potentially leading to the extension of alliance partners' body of explicit knowledge and thus improved capability to manage R&D alliances. As learning is largely driven by a combination of expert knowledge from various sources, firms need to become efficient in combining and assimilating diverse items of externally sourced knowledge with their internal knowledge bases (Kogut & Zander, 1992; Cohen & Levinthal, 1990; Grant, 1996). Therefore, it is likely that that the value of explicated intra-organisational knowledge is enhanced if it is combined with diverse but complementary knowledge on the management of R&D alliances held by the partner. In the presence of efficient combination processes, explication not only converts tacit knowledge into organisational knowledge, but also allows for the expansion of the knowledge base possessed by a single organisation. In addition, the use of combination mechanisms, such as computer-mediated technologies, enhances the value of new combined knowledge by making it easily accessible, storable and transferable (Huber, 1991). Thus, we propose:

Hypothesis 7: The effect of externalisation on an improved capability to manage R&D alliances is moderated by combination between the members of an R&D alliance.

Methods

Data Collection

We started the data collection process with a multiple case study and continued with an international survey on R&D alliances in the global telecommunications industry. Given the unique setting of our project, a multiple case study was called for to gain a better understanding of knowledge conversion processes in R&D alliances and to develop the dependent variable for the survey part of the study, the improved capability to manage collaborative R&D processes. The case study was explorative in nature, analysing inter-partner learning in two collaborative R&D projects within the Finnish telecommunications industry. The data collection involved interviews, business process simulations, debriefing sessions and follow-up interviews with project managers to verify the findings (for a more detailed description of the case studies, please see Feller, Hirvensalo, & Smeds, 2004). Overall, we interviewed 49 project team members and R&D managers individually. In addition, 53 project team members (including project and R&D managers) participated in business process simulations.

We decided to complement interviews with business process simulations for the reason that this method makes it possible to gain a very thorough understanding of a collaborative R&D project, and its activities, roles, communication flows and decision making, as experienced and recalled by the project members and managers. Our business process simulation started with a kick-off meeting together with the research team and the collaborating companies' personnel. Thereafter, the researchers engaged in data collection through interviews and the analysis of secondary data. Based on the collected data, the research team organised a group modelling session with key people from the collaborating companies with the aim of producing a preliminary visual process model of the studied R&D alliance. During the actual simulation session, the facilitator guided the discussion along this process model, which helped explicate and share large amounts of tacit knowledge on the case. This business process simulation exercise allowed the research team to observe the interactions between project members during the simulation session and gain new insights into improved R&D alliance management practices.

The case study was followed by an international survey conducted during 2002–2003. Our questionnaire was developed based on previous literature on strategic alliances and the case study, and tested by the employees of the case companies and the Usability Laboratory of Helsinki University of Technology. The targeted population in our survey was network operators, network equipment

manufacturers and suppliers to network equipment manufacturers in the telecommunications industry in Europe, North America and Asia. Sample companies were identified from company directories, industry associations and trade fair exhibitor catalogues. Of all the network operators, network equipment manufacturers and suppliers to network equipment manufacturers listed in these information sources, we eliminated companies that did not belong to the telecommunications industry or had neither R&D activities nor R&D collaborations. This process of elimination was based on telephone conversations with the targeted sample companies and questionnaire items focusing on respondents' industry memberships, the extents of their R&D activities and the histories of their R&D alliances.

Data collection started with two rounds of mailings of questionnaires to 517 companies in 72 countries. This resulted in only 20 responses. There are many potential explanations for the distressingly low initial response rate. First, we expect that the increasing number of surveys has created a certain degree of 'survey fatigue' among our respondents, working against our data collection efforts. Second, we asked for two responses in each firm, complicating the process of filling out the questionnaire. Third, follow-up calls revealed that many of the questionnaires never reached the targeted respondent and ended up being thrown away by secretaries protecting senior executives from excessive demands on their time. To increase the response rate, the questionnaire was posted on the Internet. We also decided to focus on telecommunications companies in the US, the UK, Germany and Finland, the leading telecommunications countries in our targeted sample. By accessing new databases, we were also able to add 126 new companies from those countries to the sample. To maximise the response rate, we contacted each respondent by telephone, after which we sent them an e-mail message containing a link to the survey and some additional instructions. This second round produced the majority of the responses from 85 firms.

In order to increase the quality of the data, the questionnaire was divided into two parts, to be answered by two individuals. The first part focusing on company-level questions was filled in by the Vice President of R&D or the Chief Technology Officer of the respondent company. This individual provided us with some general background information of the respondent firm, such as sales, R&D expenditure, number of employees and number of collaborative R&D projects. After filling in the first part, the Vice President of R&D was asked to choose a collaborative case project and to forward the second project-

specific part of the questionnaire to the project manager of this case project. The case project had to fulfil the following criteria. First, it had to involve developing a new product or technology to be used by one or both of the partners, or adopting a new technology for future use. Second, the product or technology developed within the project had to be telecommunications-specific. Third, the project had to involve some interaction between the technical staff of the partnering firms as opposed to being a mere outsourcing project. Fourth, the project had to be completed by the time the questionnaire was filled in. The project manager was solely responsible for addressing the project-specific questionnaire items, except for our dependent variable, the improved capability to manage R&D alliances, for which we sought responses from both the Vice Presidents of R&D and project managers.

Sample

Of the total population of 643 companies, 28 reported that the survey did not apply to them (either had they no R&D activities or R&D collaboration, or they were not in the telecommunications industry). These companies were eliminated from the sample, leaving us with a targeted sample of 615 companies. Of the targeted sample, we received 105 responses, resulting in a response rate of 17.1 percent. Most sample companies were network operators (12.6 percent), network equipment manufacturers (42.7 percent) and suppliers to network equipment manufacturers (41.7 percent). In addition, a few companies were active in the area of mobile terminals. Most respondents were relatively small companies, with annual sales of less than US$50 million and fewer than 100 employees. Overall, we received replies from 19 countries in Western Europe (79 percent), Northern America (14 percent), and Eastern Europe (4 percent)[2]. Respondents were located mainly in Finland (33), the UK (21), the US (12) and Germany (10). The Kolmogorov–Smirnov test showed no differences between respondents and non-respondents in terms of number of employees, R&D intensity or net sales. Finally, we found no differences between early and late respondents, or responses delivered through paper or Internet questionnaires.

Constructs

Independent Variables. In this study, we adapted existing conceptualisations of four knowledge conversion processes (Nonaka & Takeuchi, 1995; Nonaka et al., 2000; Sabherwal & Becerra-Fernandez, 2003) to provide the context of inter-organisational R&D alliances. The previous literature suggests that it is possible to operationalise highly intangible *knowledge conversion processes* using various knowledge transfer

mechanisms as a proxy (Nonaka & Takeuchi, 1995; Nonaka et al., 2000a; Sabherwal & Becerra-Fernandez, 2003). We derived the knowledge transfer mechanisms from the study of Smeds et al. (2001), which focused on R&D collaboration in the information and communication technology industry and asked respondents the extent to which these knowledge transfer mechanisms were used in interaction with their alliance partners. In addition, respondents were asked to add any knowledge transfer mechanisms employed in their R&D alliances that were not included on our list.

Socialisation was measured as the extent to which collaborating partners were able to create a context where tacit knowledge could be successfully shared between partners. Activities supporting *socialisation* include joint activities, spending time together and walking around inside the company rather than giving or receiving written and verbal instructions (Nonaka & Takeuchi, 1995; Nonaka & Konno, 1998). Socialisation often occurs through informal apprenticeships including observation, imitation and practice, where individuals work side-by side (Nonaka, 1994). In the words of a manager from one of our case companies: '*Especially in the beginning of an R&D alliance, when you are exploring what you will be doing or when you are defining your test cases, there is no other way of doing it than spending time together with your partner*'. In R&D partnerships, companies sometimes co-locate some of their employees at their partner company (Sabherwal & Becerra-Fernandez, 2003). Among other purposes, co-location may facilitate transferring tacit knowledge from the more experienced company to the less experienced partner (Mohrman et al., 2003). Tacit knowledge transfer may also take place through coaching, job rotation or the use of process consultants (Smeds et al., 2001).

Externalisation, the conversion of tacit knowledge into explicit knowledge, takes place through dialogue and interaction (Nonaka & Konno, 1998). In R&D alliances with few opportunities for spontaneous and informal dialogue between alliance partners, meetings are likely to serve as major occasions that bring team members together and provide a possibility for the explication of tacit knowledge on the collaborative R&D project and its management practices. One of the R&D alliance managers stated: *'We had meetings weekly, even three times a week, depending on the situation. These meetings are very important. You can cover so many topics and issues'*. The importance of meetings is further accentuated by the fact that alliance participants often need to feel part of the group in order to be comfortable enough to convert his or her tacit knowledge into a form easily understandable to others (Nonaka & Konno, 1998;

Nonaka et al., 2000a). Meetings between alliance partners may thus serve as major occasions where this 'team spirit' and a common language can be explicitly created. Based on Smeds et al. (2001), the most widely used meetings in R&D alliances include design reviews, test results reviews and prototype review meetings. The previous literature also refers to metaphors and analogies as knowledge transfer mechanisms supporting externalisation (Nonaka & Takeuchi, 1995; Nonaka & Konno, 1998; Nonaka et al., 2000a). However, none of our case companies or sample companies reported using metaphors or analogies in their R&D alliances for knowledge transfer – if they were not used informally in the many meetings.

Combination, the gathering, combining, disseminating, editing and storing of explicit knowledge, often takes place in collaborative environments utilising information technology (Nonaka & Konno, 1998; Nonaka & Takeuchi, 1995; Mohrman et al., 2003; Nonaka et al., 2000a). This virtual interaction is likely to be of utmost importance for inter-organisational R&D projects with team members located physically apart. According to Smeds et al. (2001), the most frequently used means for sharing and combining explicit knowledge in new product development processes include the use of e-mail, e-mail distribution lists and telephone conferences, most likely because of their ease of use, speed and ability to reach alliance partners across physical and temporal barriers.

According to the previous literature on knowledge conversion processes within single organisations, *internalisation* involves the transformation of explicit knowledge into tacit knowledge through learning by doing, simulation, observation, training, reflection and self-reflection (Nonaka & Konno, 1998; Sabherwal & Becerra-Fernandez, 2003). R&D alliances provide fewer possibilities for learning by doing, simulation and training because of the tacit and abstract nature of R&D work and for the reason that partners are located physically apart. Therefore, we expect that alliance partners mainly resort to studying written reports and project descriptions, listening to lessons learnt presentations and reflecting on them when trying to assimilate explicit knowledge on collaborative R&D practices. As one of our interviewee's put it: '*We dedicated days to studying and going through the reports submitted by our partner to really understand what they meant*'. In R&D projects, the most critical presentations and reports include lessons learnt presentations and reports, written project descriptions and visual process maps (Smeds et al., 2001).

A potential weakness associated with our operationalisation and those presented in the previous literature (Nonaka & Takeuchi, 1995; Nonaka et al., 2000a; Sabherwal & Becerra-Fernandez, 2003) is that the measure is not directly focused on knowledge transfers per se, but instead is focused on the extent to which organisations created a context where such transfers could happen. Another assumption behind our operationalisation is that a particular knowledge transfer mechanism is mainly used to trigger one of the knowledge conversion processes even though it may play a supportive role in triggering other knowledge conversion processes in R&D alliances as well. For instance, inter-organisational face-to-face project meetings trigger the externalisation of tacit knowledge, but they are important vehicles for socialisation as well. However, externalisation is the primary objective of such meetings from the point of view of R&D management, and socialisation during meetings only supports this primary purpose. That is why meetings are regarded as a major vehicle for externalisation in this study.

A confirmatory factor analysis using AMOS software was conducted on the four knowledge conversion processes, see Table 1. For each questionnaire item representing different knowledge transfer mechanisms, the project manager was asked to indicate on a scale from one to seven how frequently that mechanism was used between the partners to a specific R&D alliance. The global fit indices of the measurement model (chi square 83.30; df = 71; p = 0.151; Tucker and Lewis index (TLI) 0.982; comparative fit index (CFI) 0.988; and RMSEA 0.048) indicate that the hypothesised factor structure fits the data well. The standardised factor loadings were strong and significant ($p<0.01$ or lower), thereby indicating a high convergent validity. In terms of variance extracted, each factor exceeded the value of 0.45. The factor solution resembles closely the mapping of knowledge transfer mechanisms on knowledge creation processes in the previous literature (Nonaka & Konno, 1998, Nonaka & Takeuchi, 1995; Sabherwal & Becerra-Fernandez, 2003). Any departures from previous studies can be explained by the context specificity of our study, and was discussed above.

Insert Table 1 about here

Dependent Variable. The measure for the *improved capability to manage collaborative R&D processes* was developed based on a multiple case study reported in Feller et al. (2004). This study identified several improvements in the collaborative R&D processes of alliance partners. These improvements may be interpreted as the improved capability to manage collaborative R&D processes. Of these collaborative

R&D process improvements, the definition of milestones and clear allocation of tasks and responsibilities are key characteristics of advanced R&D processes and the main determinants of time to market (e.g. Wheelwright & Clark, 1992, p. 136). In line with the previous literature, the participants of the business process simulation stressed the importance of communicating the allocation of tasks and responsibilities to all participants of the R&D alliance. All too often, the division of tasks is only known by the people at the top, which is likely to hamper the smooth functioning of the collaborative R&D process, as demonstrated by this quote from one of our alliance managers: '*It is very important to have direct contact with the experts at the partner organisation. If you communicate through intermediaries, your message might get distorted and this might cause problems*'. In a similar vein, by defining joint processes and milestones alliance partners might be able to prevent misunderstandings and delays in getting their products to market. By introducing a restructured sequence of activities and defining the phases of development and milestones that characterise the completion of each activity, alliance partners create a platform for the more efficient coordination of joint R&D processes (Wheelwright & Clark, 1992, p. 316). This view was strongly supported by the experiences of a manager of our case company: '*The conflicts between us and our partner largely resulted from us following our own process and them following theirs. In R&D alliances, you need to define a joint process that both partners follow from the very start'*. A novel item derived from our case study was improved release management, which was deemed of utmost importance in rapidly evolving high-tech industries, such as telecommunications. A joint release management plan is crucial in informing both partners on which functionalities to include in the product at each stage of the development project. In collaborative R&D projects, where partners jointly develop a product, but only one of the partners is responsible for the market launch, this coordination is highly important, but also very hard to achieve. These three items were rated by both the senior technology manager and the project manager on a seven-point Likert scale, see Table 2. For each item, the intra-class correlation coefficient (ICC) was calculated. As all the ICC scores were above 0.65 ($p<0.01$) (Boyer & Verma, 2000), we were able to form a combined measure using the data from both respondents. The factor analysis showed that all three items load on one factor. The Cronbach alpha of this construct was 0.78, while the factor analysis explained 71 percent of the total variance.

Insert Table 2 about here

Control Variables. Based on the previous literature, we decided to control for several factors known to affect the ability and motivation of partners to learn in their R&D alliances. First, the existence of competition between alliance partners is likely to influence their collaborative behaviour and thus inter-company learning (Larsson, Bengtsson, Henriksson, & Sparks, 1998; Tsai, 2002). Second, the degree to which partners will be able to learn from each other depends on their knowledge overlap (see, for instance, Cohen & Levinthal, 1990; Lane & Lubatkin, 1998). Third, the quality of current and past collaboration relationships is an important determinant of inter-organisational learning (Das & Teng, 2001; Kale et al., 2002; Lane & Lubatkin, 1998; Muthusamy & White, 2005). Fourth, the motivation behind the R&D alliance and whether or not alliance partners are motivated to learn new collaborative practices (Nonaka & Takeuchi, 1995; Dussauge, Garrette, & Mitchell, 2000; Hennart, 1988) are likely to affect process learning outcomes. Fifth, the administrative form of an alliance (equity or contract-based) is likely to affect the motivation to learn collaborative practices and thus learning outcomes (Garcia-Canal, 1996; Saxton, 1997; Mowery, Oxley, & Silverman, 1996; Muthusamy & White, 2005). Finally, we controlled for some basic characteristics of the participants, such as their R&D intensity and size, as proxies for the importance attributed to and the resources available for the R&D alliance.

The questionnaire items measuring the *perceived competitive situation* between the respondent organisation and its partner reflect the dimensions of current and future product competition between the alliance partners (Dussauge & Garrette, 1997-1998). Table 2 shows the questionnaire items and factor loadings for this construct. The Cronbach alpha for the three items was 0.79, whereas the factor analysis explained 71 percent of the total variance. The questionnaire items measuring *knowledge overlap* were developed based on the previous literature (Davis, Robinson, Pearce, & Park, 1992; Sorrentino & Williams, 1995). They were rated by the project manager on a seven-point Likert scale. The factor analysis produced two factors, labelled *knowledge similarity* and *knowledge complementarity,* see Table 2. The factor analysis explained 77 percent of the total variance. The Cronbach alphas for knowledge complementarity and knowledge similarity were 0.65 and 0.71, respectively.

Previous collaboration experience with the partner facilitates communication through the emergence of informal ties and trust between partners (Larson, 1992; Ring & Van de Ven, 1994). Companies with a long history of previous collaborations may have also developed a so-called relative absorptive capacity,

thus facilitating learning from each other (Lane & Lubatkin, 1998). As shown in Table 2, this construct was operationalised with three self-developed questionnaire items addressed to the project manager. The Cronbach alpha was 0.88 and the factor analysis explained 81 percent of the total variance. The focal firm's *general R&D alliance experience* was measured by the number of collaborative R&D projects during the past three years as a proxy. *Inter-organisational trust* relates to the expectations concerning the non-opportunistic behaviour of the alliance partner or, as Kale et al. (2002) put it, the "confidence the partners have in the reliability and integrity of each other". Table 2 presents the questionnaire items addressed to the project manager and the factor loadings for the inter-organisational trust construct. The factor analysis explains 75 percent of the total variance. The Cronbach alpha for items representing inter-organisational trust was 0.67. Alliance partners' *motivation to learn from collaborative R&D projects* was measured on a seven-point Likert scale with a single questionnaire item rated by the senior technology manager in charge of the overall alliance portfolio of the company. *R&D ratio* refers to the ratio of R&D spending to sales. *Equity stake* is a binary variable indicating whether the alliance was equity-based or not.

Results

We applied structural equation modelling techniques to test our hypotheses. Structural equation modelling is an extension of the general linear model that enables a researcher to test a set of regression equations simultaneously. Furthermore, structural equation modelling takes into account errors in measurement and variables with multiple indicators (Simonin, 1997).

To detect potential multicollinearity problems, we calculated the intercorrelations among all variables. As shown in Table 3, the correlations between the independent, dependent and control variables are well below 0.6, the threshold recommended by Grewal, Cote and Baumgartner (2004). However, in order to mitigate problems resulting from multicollinearity, the variables were standardised before statistical testing.

Insert Table 3 about here

In our case, the small variable-to-sample ratio necessitated the use of summated scores for the independent, dependent and control variables. The use of summated scores reduces the model's complexity, identification problems and the variable-to-sample ratio (Paulraj, Lado, & Chen, 2008). Thus,

it is worth noting that we were not able to test the measurement model in the structural equation modelling conducted in this study. Figure 2 depicts the results of our hypothesis testing.

Insert Figure 2 about here

The overall chi-square is non-significant ($\chi 2 = 89.94$, df = 62, p = 0.35), suggesting a satisfactory fit (Carmines & McIver, 1981). In a similar vein, in a small sample such as this, RMSEA (0.07) and CFI 0.89 are acceptable (Tabachnick & Fidell, 2007).

Figure 2 depicts the structural relationships among the constructs of interest. Our results lend support to the results reported by the previous literature by confirming a positive, statistically significant relationship between the improved capability to manage R&D alliances and inter-organisational trust, motivation to learn, previous collaboration experience, knowledge similarities and knowledge complementarities. In a similar vein, perceived competition between alliance partners has a negative impact on the emergence of an improved capability to manage R&D alliances. Equity stake fails to have a positive, statistically significant relationship with the dependent variable. This result may stem from the idiosyncratic nature of our data: only 9 percent of our R&D alliances were equity-based.

Relative to our hypotheses, Figure 2 shows that socialisation is positively associated with an improved capability to manage R&D alliances. This gives strong support to Hypothesis 1. We also observe positive, statistically significant relationships between externalisation and internalisation, and the emergence of an improved alliance capability, thus supporting Hypotheses 2 and 4. However, we find no support for Hypothesis 3, suggesting that combination is positively associated with an improved capability to manage R&D alliances.

To test the hypothesised moderating effects of knowledge conversion processes on the emergence of an improved capability to manage R&D alliances, we followed the procedure suggested by Baron and Kenny (1986). A moderating effect is present if the interaction term (predictor X moderator) is statistically significant. As shown in Figure 2, we found that internalisation and externalisation (Hypotheses 5b and 6a), internalisation and socialisation (Hypothesis 5a) and internalisation and combination (Hypothesis 6b) reinforce each other's impact. Our data give no support to the hypothesised interaction effect between combination and externalisation (Hypothesis 7).

Conclusions and Discussion

Discussion of the Results

Our study provides support for the Nonaka and Takeuchi (1995) model of dynamic knowledge creation. In particular, our study proposes that companies may learn to better manage their collaborative R&D processes by creating an environment conducive to inter-firm communication processes supporting socialisation, externalisation and internalisation. Owing to the numerous interactions between these knowledge conversion processes, it seems likely that a failure to support one of these knowledge conversion processes has the potential to hamper learning about better ways to manage R&D alliances. In particular, we found that newly internalised tacit knowledge cannot maximally contribute to an improved capability to manage R&D alliances unless this knowledge is made more widely available through socialisation and externalisation practices. In a similar vein, newly explicated inter-organisational knowledge can hardly lead to improved ways to collaborate unless supporting mechanisms are in place for its assimilation by individuals and teams through internalisation processes.

Surprisingly, our results cast some doubts on the role of combination processes in the emergence of the improved capability to manage R&D alliances. This is especially notable since these processes (e.g. e-mails and telephone conferences) are among the most widespread inter-organisational communication mechanisms used today. We discuss four possible reasons for our failure to detect a positive relationship between these combination practices as well as their interaction with externalisation practices and inter-organisational process learning. First, following Nonaka and Konno (1998), we operationalised combination as knowledge conversion triggered by various information and communication technologies. Even though information and communication technologies enhance information availability, they may result in the overload of decontextualised, often difficult to interpret information rarely used in organisations (McDermott, 1999; Tuomi, 1999). The recent challenge of an overload in e-mail communication is often mentioned by practitioners. Some react by moving to work in 'batch mode', where e-mails are read and answered only in fixed daily time slots (Morgenstern, 2005), others by proclaiming new 'E-mail Charters' of rules (Ferenstein, 2011). Recent innovations in communication systems (e.g. thread based- vs. timeline-based display of e-mails, the use of tags in company intranet blogs), by contrast, reflect the need to add contextuality to combination processes. In other words, it may not only be the mere combination of explicit knowledge items that matters, but also the way in which this

knowledge is structured and organised that makes a difference from a learning point of view (Maula, 2000; Lurie, 2004).

Second, the adoption of improved capabilities to manage inter-firm relationships poses a true learning challenge for the alliance partners involved. The adoption of such skills depends fundamentally on alliance partners' ability to articulate, transfer and adopt knowledge that is tacit in nature and closely related to organisational culture and the mental models possessed by individuals. Achieving this goal is demanding enough within a single organisation, let alone in an inter-organisational setting. Richer forms of communication (through socialisation, externalisation and internalisation mechanisms) may be more appropriate when learning complex, equivocal and tacit tasks (Daft & Lengel, 1984; Roberts, 2000), such as managing R&D alliances. Interestingly, this result suggests that the managers that are eager to learn better ways to manage their R&D alliances cannot replace these more costly and time-consuming communication practices with the use of more economical information and communication technologies. It is also possible that managers who dedicate scarce time to time-consuming socialisation mechanisms might do so because they have a higher motivation for learning R&D alliance skills beyond the immediate scope of the R&D project. However, it is important to note that our results do not completely rule out the role of combination practices in the emergence of improved capabilities to manage R&D alliances. It appears that combination through electronic communication may nevertheless work if mechanisms supportive of converting this combined explicit knowledge into individual tacit knowledge are present.

Third, some scholars have criticised the prevailing conceptualisation of combination as a synthesis of existing pieces of explicit knowledge. According to Tuomi (1999), this is simply impossible, as individuals – when combining existing pieces of explicit knowledge – always need to process this knowledge against their own knowledge structures that are tacit. In this sense, combination does not fundamentally differ from externalisation. Fourth, it might well be that the R&D knowledge transferred via ICT based mechanisms in our survey only captured knowledge on the development of new or improved products or production processes involving the *primary spiral of knowledge creation*. The *secondary spiral* that involves learning about how to manage and implement inter-organizational R&D projects is likely to require more tacit and implicit modes of communication.

Theoretical and Empirical Contributions

To our knowledge, this study is the first to extend, specify and empirically test the Nonaka and Takeuchi (1995) model of dynamic knowledge creation in inter-firm settings in general and in collaborative R&D projects in particular. The Nonaka and Takeuchi model highlights the importance of the 'knowledge spiral' resulting from the interactions between the four knowledge conversion processes. However, these crucial interactions have not been specified in the previous literature. Thus, our foremost theoretical contribution is to identify the hitherto unstated interactions between specific knowledge conversion processes in promoting improved R&D management capabilities. This conceptualisation calls for drawing theoretical insights from various seemingly separate fields, such as cognitive psychology, information processing theory, social learning theories and information management. Our major criticism of the prior theory development is that it conceptualises knowledge creation as either a cognitive (individual) or a social (collective) process. We believe that our more integrated and holistic view contributes to a better understanding of knowledge creation in (inter)-organisational settings, showing how this process constantly oscillates between tacit and explicit, as well as individual and shared. For instance, the social constructionist view of learning (Catania, 2007; Mezirow, 1991; Richter, 1998) emphasises the importance of dialogue and shared experience as crucial to knowledge creation. However, in order for a fruitful dialogue and shared mental models to emerge, individuals need to possess deep knowledge on the subject matter at hand, which results from the complex cognitive processes described in the 'traditional' literature on individual learning (Anderson, 1983; Singley & Anderson, 1989). Thus, the social aspect of learning cannot thrive without well-developed individual cognitive structures. In a similar vein, collective learning created through shared experience and dialogue needs to be stored in the organisational memory (Anand et al., 1998; Croasdell, 2001; Walsh & Ungson, 1991) to maximise its reach and impact. This is where theories on computer-mediated learning become helpful (Dewett & Jones, 2001; Barua et al., 1995; Quinn et al., 1996). We believe our work may serve as a preliminary step towards a more theoretically integrated view of knowledge creation.

Second, we contribute to the Nonaka and Takeuchi model by studying it in an inter-firm context where the process of learning creates new management practices for inter-organizational collaboration, i.e. we focus on the secondary learning spiral that has not been studied so far. This learning process is more related to the accumulation of tacit than explicit knowledge. Such a context creates enormous

learning challenges for the parties involved. The results of our study seem to indicate that companies wishing to overcome these challenges should resort to a wide variety of communication practices and should emphasise the social, even trialogical nature of learning in order to maximise the knowledge conversions between tacit and explicit knowledge, and individual, team-level and inter-firm knowledge. Third, this study contributes to the alliance capability literature in many important ways. Research on alliance capability has evolved along two streams, namely the study of the development of alliance capability and the study of the elements constituting a firm's alliance capability (Schreiner et al., 2009). Our findings provide a deeper understanding of how alliance partners learn to coordinate their actions, namely how they manage their collaboration processes better. The development of the capability to manage collaborative R&D processes requires inter-organisational knowledge sharing manifested in inter-organisational communication routines in addition to intra-organisational knowledge sharing processes. While the prior literature has stressed the importance of communication between the alliance partners (see for instance, Schreiner et al. 2009; Anand & Khanna, 2000; Dyer & Singh, 1998; Inkpen & Dinur, 1998; Kale et al., 2002), not enough attention was paid to the specific communication routines enhancing collaboration. We went to great lengths to conceptualize and operationalize the four knowledge conversion processes and the interactions between them through associated communication processes, thus serving as a theoretical and methodical contribution of this study and basis for future research.

There has been a considerable amount of research on the elements of alliance capability but empirical evidence is scarce. By focusing on one of its underlying elements, we have been able to develop a measure for alliance coordination capability, more specifically the inter-organisational R&D process management capability, and to identify factors contributing to its development. Interestingly, our study suggests that managerial routines learned in a dyadic R&D partnership may result in more generalisable skills applicable in subsequent partnerships. Such generalisable skills include improved release management, the better allocation of tasks and responsibilities and the improved use of milestones. They all improve coordination efficiency in the collaborative R&D process, and could become important drivers for deliberate trialogical learning in R&D alliance management.

Avenues for Future Research

It is possible to extend this study in several ways. First, our study allows us to examine the emergence of an improved capability to manage R&D alliances only through the eyes of one of the alliance partners. Thus, a fascinating route for future research would be to investigate whether the potentially different learning capacities and heritages possessed by both alliance partners would translate into differing learning outcomes that thus require different types of learning environments for managerial routines to emerge. In a similar vein, we only focused on the knowledge conversion processes that involve individuals and teams from both alliance partners. However, it is very likely that similar processes occurring within each partner organisation would contribute to the emergence of improved skills to manage R&D alliances. Indeed, it would be interesting to compare the effect of intra-organisational and inter-organisational knowledge sharing routines on improved alliance management capability. Second, it has been argued that knowledge creation processes are highly sensitive to the pervasive effect of culture (see, for instance, Glisby & Holden, 2003). Thus, a future study should explore the emergence of collaborative routines in alliances outside the geographical scope of our sample, for instance outside northern Europe and the United States. Third, the link between improvements in collaborative R&D practices and innovativeness was beyond the scope of our study. Thus, future studies could explore, for instance, how the standardisation of collaborative R&D processes affects the emergence of radical, as opposed to incremental, innovations (Benner & Tushman, 2002). Fourth, because the scope of the present study is limited to the telecommunications industry in general and to R&D collaboration in particular, this may weaken the applicability of our findings in other industrial sectors. Fifth, combination lies at the heart of learning, as new knowledge often results from bringing together diverse knowledge items. However, our results did not confirm this relationship. Therefore, in-depth case studies are called for to operationalise this construct in a way that deviates from the previous literature and current managerial practices to include items other than those related to electronic means of communication. Socio-cultural learning theories that stress the trialogical knowledge co-creation view (e.g. Hakkarainen, Palonen, Paavola, & Lehtinen, 2004, Paavola & Hakkarainen, 2005) can provide a basis for a richer operationalisation of knowledge conversion processes than that adopted in this study. In addition, the potential differences between knowledge conversion processes in the primary and secondary spirals of knowledge creation should be explored through in-depth case studies. We are particularly interested in the extent to which

improvements in the management practices of collaborative R&D projects are the intended learning and development outcomes for the parties involved. In a similar vein, we would like to learn more on what triggers the shift from the primary to the secondary spiral of learning. Sixth, the continuously increasing search for operational efficiencies and the streamlining of processes call for new socialisation mechanisms that are less time consuming. While some preliminary developments in this area can already be observed (e.g. the 'gamification' of internal communications, intra-company social networks), any research pointing to more time-efficient socialisation mechanisms should have a highly interested audience, especially among practitioners. Finally, and perhaps most importantly, we call for future studies that test and extend the Nonaka and Takeuchi model. The Nonaka and Takeuchi model provides a holistic view of (inter)-organisational knowledge creation that integrates the cognitive, social and information processing views of learning. We especially encourage future studies to test this model in a longitudinal setting. Our research design was cross-sectional and, therefore, we cannot inform the reader about the consecutive order in which the respective knowledge conversion processes should take place. Hence, future surveys relying on panel data or longitudinal qualitative research designs are called for to gain a better understanding of how individual knowledge conversion processes follow and feed from one another.

Notes

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[1] According to the trialogical learning metaphor, individuals collaboratively create knowledge when they develop shared artifacts with a deliberate effort to create something new (Paavola & Hakkarainen 2005: 539). Knowledge creation proceeds, when the collaborating individuals use mediating artifacts (models, prototypes, concepts, tools) and mediating processes in a conscious effort for transformation. (Paavola & Hakkarainen, 2005).

[2] This figure includes also responses from Russia and Israel.

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Figure 1: Research Framework

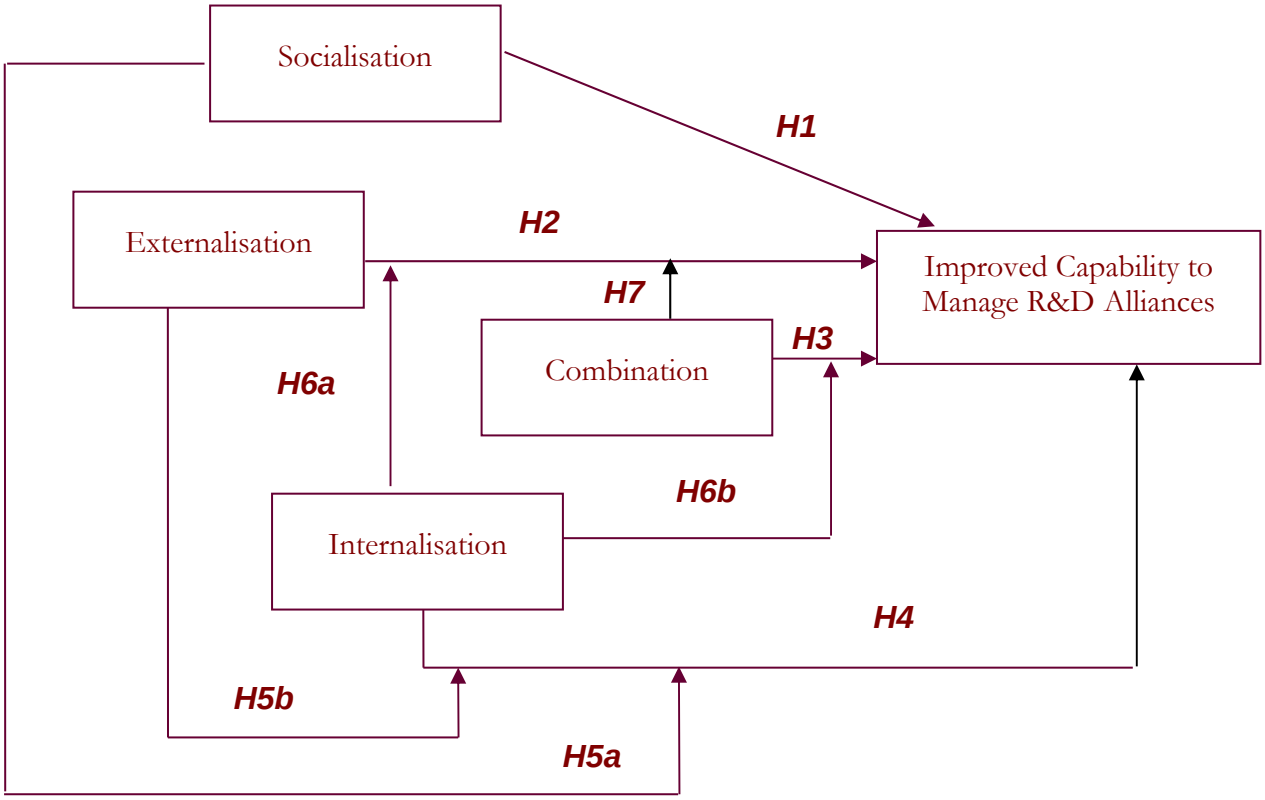

Figure 2: Path Diagram Model with Standardised Structural Coefficients

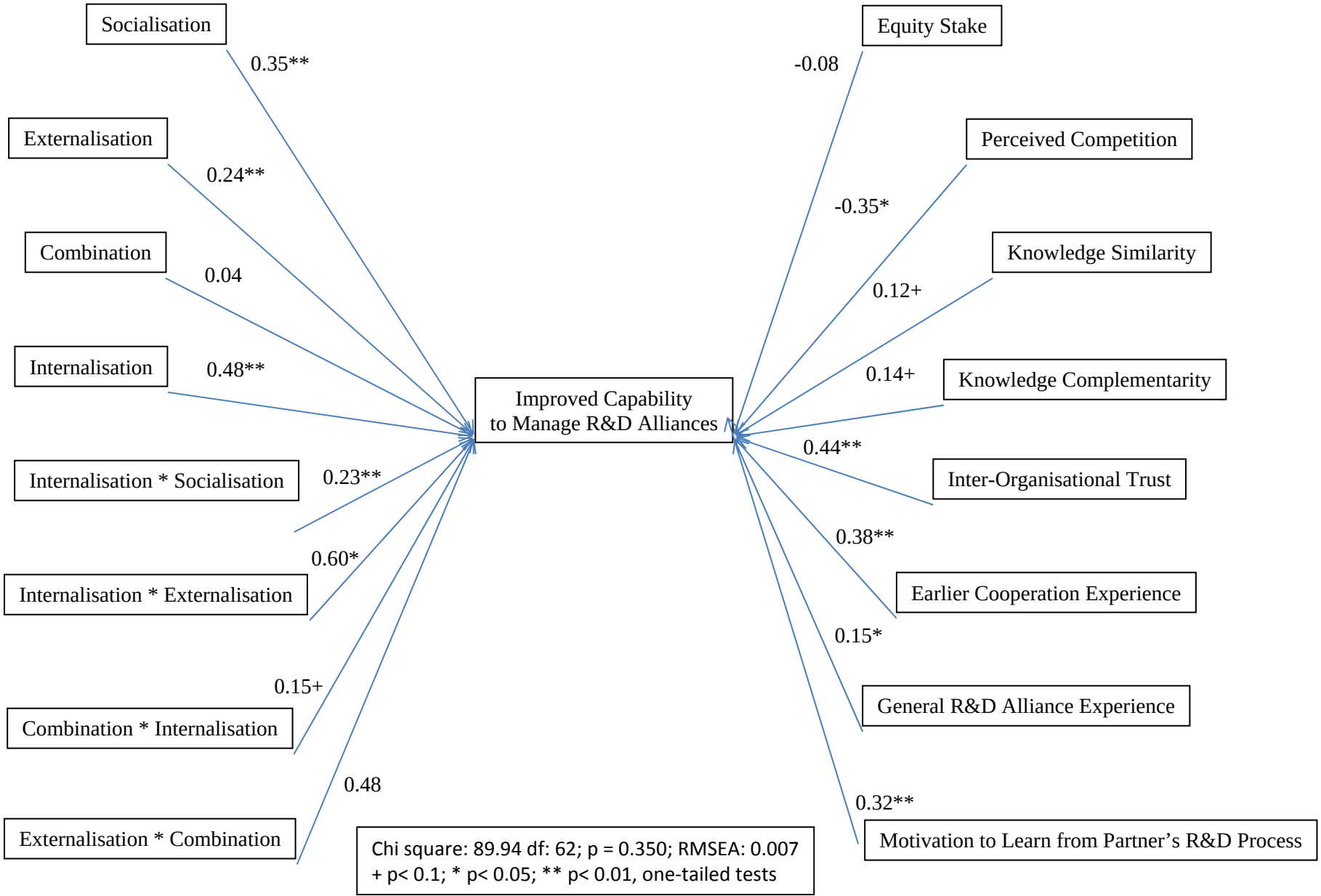

Table 1: Operationalisation of Knowledge Conversion Processes [a,b]

Variable	Measurement Item	Factor Loadings
Socialisation (α = 0.77)	Co-location	.47
	Coaching	.56
	Job rotation	.79
	Process consultants	.85
Externalisation (α = 0.87)	Design review meetings	.85
	Test results review meetings	.88
	Prototype review meetings	.74
Combination (α = 0.60)	E-mail	.62
	E-mail distribution lists	.85
	Telephone conferencing	.45
Internalisation (α =0.78)	Lessons learnt presentations	.72
	Visual process maps	.62
	Written project descriptions	.56
	Lessons learnt reports	.90

a Respondents answered the question 'How much were the following knowledge sharing means used in the collaborative research project with the partner?' on a Likert scale 1 (not at all) to 7 (intensively).

Table 2: Operationalisation of Independent and Control Variables [a, b]

Variable	**Items**	Factor Loadings
Improved Capability to Manage R&D Alliances	1. The project helped us improve our release management in collaborative R&D projects.	.86
	2. Through the project, we learned to better allocate tasks and responsibilities in collaborative R&D projects.	.74
	3. The project has improved our use of milestones in collaborative projects.	.92
Perceived Competitive Situation	1. In some markets, we are in direct competition with our partner.	.85
	2. We sell products that can replace some of our partner's products.	.88
	3. At some point in the future, our partner could become our competitor.	.82
Knowledge Similarity	1. The technical knowledge and skills of our partner were very similar to our company's knowledge and skills.	.88
	2. The R&D management capabilities of our partner were very similar to ours.	.83
Knowledge Complementarity	1. Our company and our partner complemented each other's technical knowledge.	.90
	2. Our company and our partner complemented each other's R&D management capabilities.	.85
Earlier Cooperation Experience	1. Our company's project members had extensive earlier cooperation experience with our partner.	.93
	2. Our partner's project members had extensive earlier cooperation experience with our company.	.85
	3. Project members from both sides have worked previously with each other.	.91
Inter-Organisational Trust	1. The project was characterised by mutual trust between us and the partner at multiple organisational levels.	.87
	2. Our partner has a reputation of being a reliable cooperation partner.	.87

[a] In factor analyses, the principal component analysis is applied; b For all of these items, respondents were asked 'How true are the following statements on a Likert scale from 1 (strongly disagree) to 7 (strongly agree)?'

Table 3: Means, Standard Deviations and Correlations [a]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Motivation to Learn from the Partner's R&D Process	1													
2. R&D Ratio	.201	1												
3. Perceived Competition	-.076	-.097	1											
4. Knowledge Complementarity	.054	.091	.299**	1										
5. Knowledge Similarity	.053	.064	.109	.270*	1									
6. Inter-Organisational Trust	.217	.146	.009	.221	.177	1								
7. Earlier Cooperation Experience with the Partner	.191	-.105	.027	.002	.178	.305**	1							
8. General R&D Alliance Experience	.155	.091	-.037	-.156	.037	.048	.208	1						
9. Equity Stake	-.028	-.152	.150	.062	.190	-.034	.033	-.030	1					
10. Socialisation	.287*	.278*	.043	.159	.150	.306*	.311**	.195	.025	1				
11. Externalisation	.168	.297*	.006	.292*	.260*	.356**	.111	.112	.061	.354**	1			
12. Combination	-.078	.151	.234*	.339**	.138	.113	-.291*	-.111	-.015	.195	.466**	1		
13. Internalisation	.278*	.116	.072	.162	.264*	.334**	.176	.208	.135	.498**	.580**	.487**	1	
14. Improved Capability to Manage R&D Alliances	.376**	.343**	.041	.062	.084	.269*	.197	.162	-.055	.504**	.380**	.163	.473**	1
Mean	4.88	0.31	2.58	5.25	4.03	5.28	3.83	22.83	0.09	3.01	4.71	5.16	2.67	4.55
Standard Deviation	1.58	0.33	1.67	1.28	1.61	1.28	2.05	102.38	0.29	1.36	1.58	1.33	1.34	1.18

[a] $p<0.05$, ** $p<0.01$, two-tailed tests