Transferring and Creating Technological Knowledge in Interfirm R&D Relationships:

The Initiation and Evolution of Interfirm Learning

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ABSTRACT

In this study, we examine the initiation and evolution of interfirm learning in interfirm R&D relationships. Based on in-depth case studies, we suggest that the process of learning in interfirm R&D relationships consists of different challenges: 1) initiating technological knowledge transfer, 2) continuing technological knowledge transfer, and 3) moving towards the joint creation of new technological knowledge. Our findings identify conditions needed to initiate knowledge transfer: the presence of legal knowledge transfer clauses, overlapping skills and equipment, fragile trust and organizational similarity. The continuance of knowledge exchange implies complementary modes of collaborating characterized by sharing technologies which are oriented towards different applications. Joint knowledge creation implies convergence on the level of applications which only becomes feasible when prior knowledge exchange processes have generated resilient levels of trust. These observations point to the relevance of conceiving and organizing interfirm R&D relationships in a time-phased, differentiated manner.

Keywords: Interfirm Learning, Knowledge Transfer, Knowledge Creation, Interfirm R&D Relationships

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INTRODUCTION

Interfirm R&D relationships are increasingly suggested as an important mechanism to acquire new technological capabilities (e.g. Hagedoorn 2002; Tidd et al. 2002). In this paper, we define interfirm R&D collaboration as a formalized link between two or more independent organizations characterized by interdependent R&D activities. Interfirm learning can take on the form of transferring existing knowledge from one organization to another, and of jointly creating new knowledge (Larsson et al. 1998; Lubatkin et al. 2001; Podolny and Page 1998).

Empirical research on learning in the specific context of interfirm R&D relationships has been dominated by cross-sectional studies, examining the impact of different factors on interfirm learning. These studies have provided evidence for the enabling role of conditions such as equity governance structures (Chen 2004; Mowery et al. 1996), overlapping technological skills (Lane and Lubatkin 1998; Mowery et al. 1996), trust (Cheng 2004), cultural similarity (Mowery et al. 1996), and organizational similarity (Lane and Lubatkin 1998) for interfirm learning to occur. However, the conceptualization of interfirm learning in these studies has been limited to the form of transferring existing knowledge, ignoring the form of joint creation of new knowledge (Lubatkin et al. 2001). In addition, because of the studies' cross sectional nature, insights on the dynamics of learning within interfirm R&D relationships are limited. Although scholars in this field (e.g. Ariño and de la Torre 1998; Doz 1996; Ring and Van de Ven 1994; Van de Ven and Walker 1984) have stressed that an interfirm relationship is a gradual dynamic process that is continually reshaped and recreated, longitudinal studies examining the evolution of learning in interfirm R&D relationships are rare. The study of Hamel (1991) is a notable exception in this respect. However, this study also only focused on interfirm learning as the transfer of existing knowledge between partners.

This study intends to contribute to a fine-grained understanding of learning in interfirm R&D relationships by examining both transfer of existing knowledge and joint creation of new knowledge and by studying both the initiation and the evolution of interfirm learning. In order to do so, we rely on a longitudinal study of three interfirm R&D relationships that occurred within one technological trajectory in which one industrial company collaborated with different partners. The analysis of this case study is structured along two research questions: 1) how does the presence of particular conditions facilitate the initiation of interfirm learning? and 2) how and under which conditions does interfirm learning evolves over time? This research allows us to identify conditions that have not yet been addressed in previous research as well as to examine the relevance of conditions as the interfirm relationship evolves. In this way we follow the suggestion of Mowery et al. (1996) to engage in research that looks at the complexity of learning dynamics in interfirm relationships.

The paper follows an inductive logic and is organized in five sections. First, we position our study within the existing alliance literature, further arguing the need to examine the complexity of interfirm learning. We then discuss the research design and the setting of our longitudinal study. In the respectively third and fourth section, we address our two research questions and formulate propositions about the conditions influencing the initiation and evolution of both transfer and creation of knowledge in interfirm R&D relationships. To conclude, we reflect on the contribution of this study.

THEORETICAL BACKGROUND

To position our study, we first extend on the phenomenon of interfirm learning. We then discuss more in-depth the conditions that are identified by previous research as facilitating interfirm learning in R&D relationships. We subsequently extend on why adopting a dynamic view on the process of interfirm learning seems appropriate.

Defining Interfirm Learning

In the alliance literature, several forms of interfirm learning have been identified. A first form of learning essentially involves the transfer of existing knowledge from one organization to another (e.g. Kale et al. 2000; Mowery et al. 1996; Muthusamy and White 2005). Such learning results in a private benefit for firms that participate in interfirm relationships (Khanna et al. 1998). Second, several researchers (e.g. Larsson et al. 1998; Lubatkin et al. 2001; Podolny and Page 1998) argued that interfirm learning can also generate common benefits. These researchers refer to interfirm learning as the process of jointly creating new knowledge. Where the transfer of existing knowledge requires partners to act as either 'novice' or 'expert', the joint creation of new knowledge asks for partners to act as 'co-researcher' or 'co-inventor' (Lubatkin et al. 2001). Third, researchers (e.g. Inkpen and Currall 2004; Doz 1996; Ariño and de la Torre 1998) also referred to learning when partners - in the context of their existing interfirm relationships – acquire experience and know-how on how to manage the collaboration process. Such learning is seen as critical to sustain interfirm relationships (Delmestri 1998; Dyer and Singh 1998; Uzzi 1997; Kale et al. 2000). Fourth, the notion of learning is used to denote how an individual firm learns how to manage its interfirm relationships, and build what has been referred to as alliance capability (Draulans et al. 2003; Kale et al. 2002; Parise and Casher 2003).

In this study, we focus on the first two forms of interfirm learning, namely the transfer of existing knowledge from one organization to another and the joint creation of new knowledge. Given the scope of the study, we do not examine the other two forms of interfirm learning.

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Conditions that Facilitate Interfirm Learning

To establish interfirm learning, two dimensions need to be present: transparency and receptivity (Larsson et al. 1998). Transparency refers to partners' motivation and ability to disclose knowledge while receptivity refers to partners' motivation and ability to absorb the disclosed knowledge by another partner. The literature on interfirm R&D relationships suggests that motivational as well as ability barriers might jeopardize the presence of transparency and receptivity within interfirm R&D relationships. First, the technological uncertainty that characterizes R&D partnerships creates exchange hazards (Oxley and Sampson 2004; Poppo and Zenger 2002). According to transaction cost theory (Williamson 1985), opportunistic behavior therefore is likely to occur in this kind of collaboration. Partners consequently may be hesitant to disclose knowledge to other partners, avoiding that these latter abuse the R&D relationship for their own private benefit (Hamel 1991; Gerwin 2004; Khanna et al. 1998). Second, technological knowledge is to some extent tacit and/or embedded within a specific context (Doz and Hamel 1997; Teece 2002). Several researchers (i.e. Hamel 1991; Larsson et al. 1998; Simonin 1999) have argued that the more tacit the disclosed knowledge, the more difficult it is to absorb and communicate in interfirm relationships. In sum, while the risk of opportunistic behavior threatens the willingness to disclose technological knowledge, the tacit nature of this knowledge hampers the ability to absorb and communicate it within interfirm R&D relationships.

Previous research has further identified five conditions of the interfirm R&D relationships that influence interfirm learning: equity governance structures, overlapping technological skills, trust, cultural similarity, and organizational similarity. We now briefly discuss these conditions but note again that interfirm learning in these studies refers to only one type of interfirm learning e.g. the transfer of existing knowledge from one organization to another. First, interfirm governance structures in terms of equity versus non-equity were found to strongly influence learning in interfirm R&D relationships (Chen 2004; Mowery et al. 1996). Equity governance structures include joint ventures, minority and majority participations; non-equity governance structures refer to all other cooperative arrangements not involving equity exchange (e.g. co-development agreement, technology sharing agreement) (Tsang 2000). This research indicated that equity governance structures support greater and more effective transfer of technological knowledge. Informed largely by transaction cost economics, the theoretical reasoning for this relationship is that equity governance structures create a mutual hostage situation through ex ante commitments to an alliance, reducing the incentives to behave opportunistically and promoting more active involvements of the partners (Dyer and Singh 1998; Kogut 1988; Pisano 1990; Williamson 1991).

Several researchers however have criticized the transaction cost economics perspective on interfirm collaboration for its singular focus on partner opportunism (Muthusamy and White 2005). Applying social exchange theory (Blau 1964), they argued that a sense of trust is essential for the transfer of knowledge (Gulati 1995; Larson 1992; Ring and Van de Ven 1992; Zaheer and Venkatraman 1995). Trust refers to 'a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another' (Rousseau et al. 1998: 395). The studies of Kale et al. (2000) and Muthusamy and White (2005) demonstrated the positive effect of trust on interfirm learning as trust tends to encourage and facilitate wide-ranging, continuous and intense contact between individual members of interfirm partners. Chen (2004) provided statistical evidence for this argument in the specific context of interfirm R&D relationships.

The presence of overlapping technological skills has been identified as a third condition that facilitates learning in interfirm R&D relationships. Mowery et al. (1996) showed that a firm's ability to absorb capabilities from its partner depends on the pre-alliance similarity between the two firms' patent portfolios. In a similar vein, Lane and Lubatkin (1998) found that partners, who share the same research communities, are more performant in terms of interfirm learning. These studies seem to confirm Cohen and Levinthal's (1990) argument on absorptive capacity: in order to absorb technological knowledge, a firm needs to have considerable in-house expertise that overlaps the technology activities of its external partners.

The fourth condition that is argued to stimulate learning in interfirm R&D relationships is cultural similarity. Mowery et al. (1996) found that U.S. firms' R&D partnerships with non-U.S. firms resulted in lower levels of interfirm learning than those involving only U.S. companies. This finding is consistent with the large amount of research on international strategic alliances (e.g. Lam 1997; Inkpen 1997; Parkhe 1991; Pucik 1988; Tiemessen et al. 1997) which has argued that differences in terms of language, customs, and traditions, have the potential to negatively affect the process of interfirm learning.

Differences between partners go beyond differences of nationalities; they also include differences in organizational culture. As the counterpart of cultural similarity, organizational similarity represents the degree of resemblance between the partners' business practices, institutional heritage, and organizational culture (Simonin, 1999). Lane and Lubatkin (1998) provided evidence for the importance of organizational similarity. In specific, they found that the presence of social context similarities (i.e. similarity of management formalization, management centralization, and compensation practices) had a positive influence on interfirm learning in R&D relationships.

Building on this previous research, a first purpose of this study is to examine to what extent the outlined conditions are still relevant when a broader definition of interfirm learning is taken. As indicated above, we consider two forms of interfirm learning – the transfer of existing knowledge as well as the joint creation of new knowledge – and examine which conditions facilitate both forms of interfirm learning.

The Evolution of Interfirm Learning

Although interfirm learning may be stimulated by the above identified conditions, interfirm relationships are likely to change over time. Collaboration among different partners is 'a gradual dynamic process that is continually reshaped and recreated by the actions and symbolic interpretations of individuals' (Van de Ven and Walker 1984: 604). Interfirm relationships are described as sequences of negotiation, commitment, and execution stages (Ring and Van de Ven 1994), as learning, re-evaluation, and adaptation cycles (Ariño and de la Torre 1998; Doz 1996), or as punctuated equilibrium processes, where terms of relationships are established during relatively short divergent periods followed by longer convergent periods to carry out the agreements made (Venkatraman et al. 1999).

Taking a dynamic perspective, scholars have argued the likelihood of change in transparency and receptivity over time. First, the motivation to disclose technological knowledge can evolve in both negative and positive direction. Some authors (Khanna et al. 1998; Larsson et al. 1998; Hamel 1991) argued that, as interfirm relationships evolve over time, the temptation of giving less and taking more becomes greater. Doz (1996), on the other hand, observed that, as companies passed through positive series of learning-action-reaction loops, trust between the partners increased, allowing for the widening up of the exchange to some underlying core technologies. This argument corresponds with the trust literature (e.g. Lewicki and Bunker 1996; Jones and George 1998; Newell and Swan 2000; Ring 1997), arguing that trust evolves in different phases, affecting the activities taking place. At the start of collaborative relationships, trust will be of a fragile nature. In these circumstances, parties are willing to transact with each other, as long as each behaves appropriately (Ring 1997). During later phases, when one party signals positive expectations of favorable attitudes to another and the other reciprocates those expectations, trust may spiral up towards more resilient modes. Within situations of resilient trust each party's trustworthiness is based on confidence in the other's values, backed up by empirical evidence derived from repeated behavioral interactions (Jones and George 1998). Such resilient trust provides individuals with the assurance that knowledge and information will be used for the greater good and that one need not to exercise power or enforce contractual arrangements to protect one's own interests (Ring 1997).

Not only the motivation to disclose knowledge, but also the motivation to absorb knowledge is likely to change. Several authors (i.e. Hamel 1991; Makhija and Ganesh 1997) indicated that, as one partner has successfully absorbed its desired knowledge from the other partner, its motivation to continue absorbing knowledge from the latter partner is likely to decrease, changing partner's bargaining power or even threatening the continuation of the interfirm relationship.

Partner's ability to absorb and communicate technological knowledge may also change over time in interfirm relationships. Several researchers (Delmestri 1998; Dyer and Singh 1998; Uzzi 1997) suggested that, as the interfirm relationship evolves, partners develop interfirm routines. Dyer and Singh (1998: 665), for instance, argued that over time "partners get to know each other well enough to know who knows what and where critical expertise resides within each firm." They referred to this process as the development of knowledge-sharing routines, suggesting that these routines enhance partner-specific absorptive capacity. Lane and Lubatkin (1998) provided evidence for the positive influence of the presence of knowledge-sharing routines on interfirm learning.

All above studies suggest that interfirm R&D relationships evolve over time but, except for Hamel's study (1991), studies examining the longitudinal evolution of interfirm learning are lacking. The second purpose of this study is therefore to understand how and under which conditions learning in interfirm R&D relationships evolves. As we – in contrast to Hamel's study (1991) – consider two forms of interfirm learning, we aim to examine how interfirm learning can evolve from transferring existing knowledge to jointly creating new knowledge.

METHOD AND RESEARCH SETTING

Research Design

In this study, we adopt a longitudinal approach (Pettigrew 1979), examining retrospectively the process of interfirm learning in one setting. The study focuses on one technological trajectory in one company that, over a ten years time period, transformed from a technological opportunity to a global business activity. This technological trajectory consisted of three interfirm R&D relationships that form the unit of our analysis. This research design allows us to perform a comparative analysis of three interfirm relationships, an analysis that facilitates 'analytic generalization' (Parkhe 1993; Yin 1984). Through selecting interfirm R&D collaborations that were part of the same technological trajectory, we minimize the influence of extraneous variation on our research findings (Eisenhardt 1989). In this study, all names of firms, products, and individuals are disguised to ensure confidentiality.

Research setting

The company under study was MAT, a Belgian company working on a global scale, with products and systems based on metal transformation and advanced coatings. In the early nineties, the company had identified diamond-like coatings as a new promising technology to expand its Advanced Coatings division. At the end of 2003, one of its divisions, MAT Diamond, had succeeded in becoming the leading supplier of diamond-like coatings for a wide array of applications such as DVD molding, chip manufacturing and automotive components. During the development of this technological trajectory, MAT initiated interfirm collaborations with three different partners (see Table 1).

Insert Table 1 about here

MAT-USCOAT relationship. In 1994, MAT contacted USCOAT, a small US-based firm with a coating division, because USCOAT had developed its own diamond-like coating (DLX). Their DLX coating seemed to possess more flexible technological characteristics than diamond-like carbon (DLC) coatings which were more known in the industry. In 1995, MAT and USCOAT signed a Technology Evaluation Agreement that allowed MAT to evaluate the technological and commercial potential of USCOAT's DLX technology. After exploring USCOAT's diamond-like coating technology for two years, MAT became convinced that this technology could entail new industrial applications. At the end of 1997, MAT bought a license from USCOAT to exploit the DLX technology in Europe and proposed USCOAT to start up together a business activity of diamond-like coatings in Europe. In April 1998, the joint venture 'MAT Diamond' officially took off in which MAT possessed 60% of the shares, while USCOAT and RES (see below) possessed 20% of the shares. In 2000, due to financial problems, USCOAT decided to sell not only its MAT Diamond shares, but also its entire coating division to MAT.

MAT-RES relationship. When MAT decided to start a diamond-like coating business activity in 1997, they asked not only USCOAT to become a joint venture partner, but also RES, a Flemish research institute. RES had developed its own diamond-like carbon (DLC) technology in the past. By bringing together USCOAT's DLX technology and RES's DLC technology in the joint venture, MAT hoped that it had collected the necessary complementary technologies, competences and know-how to turn the development of diamond-like coatings into a commercial success. In exchange for transferring the DLC technology, RES received 20% of the MAT Diamond shares. In 2000 and 2001, when USCOAT had already left the joint venture, MAT Diamond's activities were globally expanding. As this expansion required additional financial investments, MAT asked RES to jointly increase MAT Diamond's working capital. However, RES's board of directors was not willing to contribute financial resources to the JV. In 2002, MAT then preferred to buy out RES, making themselves the only decider on MAT Diamond's future. In this way, MAT Diamond, originally a JV between three partners became a fully owned subsidiary of MAT.

MAT-FRCOAT relationship. In 1999, when customers started to get interested in diamond like coatings, MAT realized that, to stay competitive in this emerging market, growth would be necessary. Next to internal expansion, collaboration with other partners was recognized as necessary in this respect. Scanning the industry to find interesting partners, MAT identified FRCOAT, a spin-off of a French university. This company was the main supplier of high quality DLC coatings for the Formula 1 industry. In November 2001, MAT took a minority participation in FRCOAT (48,7%). In July 2003, FRCOAT provided MAT the opportunity to increase its participation to 90% of all shares, making MAT the major shareholder of FRCOAT. At the same time, efforts were started to integrate FRCOAT's commercial, technological, and operational activities into the MAT Diamond Group, which at that time consisted of five, globally spread production plants.

USCOAT-RES relationship. Table 1 indicates that, between 1998 and 2000, USCOAT and RES had been partners in the same joint venture. However, no real interfirm relationship existed between these two firms as, apart from the managerial level, USCOAT and RES employees never met or had contact with each other. Because of the absence of collaborative activities between USCOAT and RES we do not consider this relationship in our study on interfirm learning.

Data Collection and Analysis

Data on the three interfirm relationships were collected in a retrospective way which allows for a much more focused data gathering process (Leonard-Barton 1990; Poole et al. 2002). At the same, unconsciously accepting respondent bias might occur in retrospective studies, leading to confusion about cause and effect relationships (Leonard-Barton 1990). We therefore triangulated our data, applying multiple data collection techniques, including interviews and document analysis.

Following Pettigrew (1990) and Pentland (1999), we made an explicit distinction between different stages in our theory building process, representing an evolution from surface levels to deeper levels of data collection and analysis (see Table 2). In line with the observations made by Glaser and Strauss (1967); Pettigrew (1990) and Poole et al. (2000) this process involved iterative cycles of data collection and data analysis.

Insert Table 2 about here

Construction of chronology of interfirm R&D relationships. In the first stage, we conducted unstructured interviews with two MAT managers who had been closely involved in the different interfirm R&D relationships. For each interfirm R&D relationship, we also studied relevant documents (i.e. contracts, reports of managerial and operational meetings, and publicly available data). Based on this information we applied a visual mapping strategy (Langley 1999; Miles and Huberman 1984) to construct a graphical representation of the chronology of the major events that had taken place within that each interfirm R&D relationship.

Writing of case study report. In the second stage, we conducted semi-structured interviews (Kvale 1996) with informants of the different involved organizations. We interviewed in total 19 persons (see Table 3). The structure of the interviews was derived from the chronology of the major events that we had identified in the previous stage. In the interviews, we asked respondents to describe these events and the kind of interaction these events triggered between the partners. The average length of the interviews was between one and two hours. All the interviews were taped and transcribed. The transcribed interviews were sent back to the interviewees to give them the opportunity to hand over additional comments.

Insert Table 3 about here

After semi-structured interviews were completed, a case study report was written. In this case study report, we discussed in detail the initiation, the formal design, and the evolution of each interfirm R&D relationship. In these reports, we made extensive use of citations from interviews and documents. In this way, we wanted to stay very close to the original data, achieving a high level of accuracy (Weick 1979). According to Langley (1999), this analysis step can be seen as a narrative strategy for sensemaking in process research.

Formulation of theoretical propositions. The purpose of the third stage was to interpret the narrative, developed in the previous stage, in order to come to theoretical propositions about the initiation and evolution of interfirm learning. A pattern-matching logic (Miles and Huberman 1984; Pauwels and Matthyssens 2004; Yin 1984) was applied in this respect.

In order to identify patterns, data from different sources were coded. For each interfirm relationship, a coding matrix was constructed. The rows of the coding matrix represented categories that referred to 1) the conditions that act as learning facilitators in interfirm R&D relationships (i.e. governance structure, overlapping technological skills, trust, cultural and organizational similarity, and other not yet identified conditions), 2) the interfirm learning dimensions (i.e. motivation and ability to disclose technological knowledge; motivation and ability to absorb technological knowledge), and 3) the two forms of interfirm learning (i.e. transfer of existing technological knowledge and joint creation of new technological knowledge). The columns of this matrix represented the separate events that were identified in the previous stages. The data from the interviews and documents subsequently were coded into this matrix. In this way, we were able to construct for each interfirm relationship a chronological overview of the presence of the specific conditions, the evolution of the interfirm learning dimensions, and the accompanying interfirm learning forms (i.e. transfer and creation). Subsequently, we searched for causal patterns within each technological interfirm relationship. In specific, we looked for causal relationships between the identified conditions, interfirm learning dimensions, and different forms of interfirm learning. Next, we compared the causal patterns that had surfaced in the different technological interfirm relationships. Finally, the dominant causal patterns that emerged from this analysis were translated into several theoretical propositions. Together, the propositions abstract the initiation and evolution of interfirm learning as observed in the different technological interfirm relationships.

In sum, to come to theoretical sound propositions we applied a pattern matching logic that built upon recurring comparison of data, analytical findings, and theory, and explicitly allowed for feedback loops between coding, within-case and across-case analysis.

INITIATING LEARNING IN INTERFIRM R&D RELATIONSHIPS

In this section, we address our first research question on which particular conditions influence the initiation of interfirm learning. Examining the first year of the different interfirm R&D relationships, we identify the main events that triggered the disclosure and/or absorption of technological knowledge and interpret which conditions act as facilitators or inhibitors. In Table 4, 5 and 6 the following two aspects are presented for each interfirm relationship: a description of the main events and illustrations of the presence or absence of transparency and receptivity within these events.

Insert Table 4, 5 and 6 about here

Conditions that increase the motivation to disclose technological knowledge

Previous cross-sectional research in the alliance literature (Chen 2004; Mowery et al. 1996) has argued that the presence of equity governance structures stimulates learning in interfirm R&D relationships. However, when explicitly considering the influence of equity structures on the motivation to disclose knowledge, our data seem to question the necessity of equity structures for initiating interfirm learning activities.

In the MAT-RES relationship, RES employees immediately started to disclose knowledge about RES' DLC technology with MAT people who were responsible for the MAT Diamond activities (Event 1, Table 5). Although this relationship had an equity governance structure, RES interviewees did not mention this condition to explain their immediate willingness to disclose technological knowledge. Instead, the RES interviewees referred to the presence of specific contractual safeguards as explanation:

> "In the RES Technology Agreement, a number of annexes were present that described in detail which technology would be transferred to the joint venture. At that moment, we just had started working on another technology that had some linkages with the DLC technology. Through these annexes we could avoid that this new technology also would disappear." (RES project manager)

Besides the Joint Venture Agreement, both parties had signed a Technology Agreement that stipulated in detail which knowledge of RES would be transferred to the joint venture. According to the RES interviewees, this contract substantially reduced the risk that, apart form the DLC-related knowledge, other valuable knowledge would be transferred to the joint venture. This finding points out the importance of specific contractual safeguards, providing a framework for the exchange of knowledge, on the motivation to disclose knowledge.

Our analysis of the MAT-USCOAT relationship seems to affirm the importance of such 'legal knowledge transfer clauses'. Although this interfirm relationship was governed by a non-equity structure, technological knowledge was disclosed from the beginning. During the first technological meeting, knowledge about USCOAT's DLX technology was openly exchanged from USCOAT to MAT (Event 1, Table 4). As reason for their willingness, USCOAT interviewees referred to the presence of specific contractual safeguards. At the start of their collaboration, both firms had signed a Technological Evaluation Agreement with specific clauses that prevented MAT to abuse the acquired technological knowledge. USCOAT consequently felt they could disclose knowledge about their DLX technology without having to fear that MAT would abuse this information for its own personal benefits. One month later, a MAT engineer, visited USCOAT's coating division for one month. During this month, USCOAT continued to disclose knowledge about their DLX technology by handing over samples of DLX coatings (Event 2, Table 3). From that moment, also MAT started showing transparency towards USCOAT. Results of characterizations conducted by MAT on the samples of DLX coatings were fed back to USCOAT. (Event 2, Table 4). To explain their willingness to disclose technological knowledge, MAT interviewees also referred to the presence of specific contractual safeguards. In the Technology Evaluation Contract, it was mentioned that both partners were obliged to disclose results concerning DLX-related technological activities. These findings consequently suggest that the presence of legal knowledge transfer clauses have a positive influence on the motivation to disclose knowledge even when an equity governance structure is absent.

Our data on the MAT-RES relationship further question the necessary facilitating impact of an equity structure. Although this interfirm collaboration was characterized by an equity governance structure, disclosure of technological knowledge was only unilateral. MAT engineers and managers were very hesitant to disclose knowledge about their technology with RES engineers (Event 2, Table 5). Even when the joint venture became operational and RES engineers conducted characterizations of MAT Diamond coatings and assisted MAT's sales persons in answering customers' questions regarding technological specifications, MAT remained very unwilling to disclose technological knowledge. Asked for their reasons, MAT interviewees referred to their fear that RES engineers, being members of a research institute, would be tempted to talk about these new technological developments at conferences or workshops. This finding suggests that, the absence of organizational similarity between partners, even in the presence of equity governance structure, might prevent the disclosure of technological knowledge. We have to remark here that the organizational distance was much smaller in the other observed interfirm R&D relationships. Although MAT was an established firm, MAT's diamond-like coating activities were situated within a specific venture, characterized by a culture that was very similar to the entrepreneurial culture at USCOAT and FRCOAT.

Finally, the MAT-FRCOAT relationship illustrates the positive influence of trust on the willingness to disclose knowledge. As the events in Table 6 indicate, this interfirm relationship was characterized by a willingness of both parties to openly disclose knowledge about each others coating technology (Event 1, Table 6) and technological fundamentals (Event 2, Table 6). Although an equity governance structure was present in this relationship, both MAT and FRCOAT people rather referred to the importance of trust to explain their willingness to disclose knowledge. In the interviews, MAT people especially mentioned their trust in the CEO of FRCOAT:

> "I thought of him as a very reliable person. I did not see him as a person who would cheat on me. I consequently had no problem in sharing knowledge with him." (MAT manager)

Also FRCOAT's transparency was explained in terms of trust. When MAT first contacted the CEO of FRCOAT to initiate a partnership, his reaction was rather hesitant. A previous experience with one of MAT's competitors had made him very suspicious about interfirm collaborations. To address this distrust, MAT showed him the corporate research center and its extensive R&D resources and organized meetings with the Director and General Manager of MAT Diamond to ensure him their dedication to the development of diamond-like coatings. During the interview, the CEO of FRCOAT stressed that these initiatives made him confident in the good intentions of MAT and their commitment to a development project within this technological domain, stimulating his willingness to disclose technological knowledge.

To conclude, our analysis of these interfirm relationships tends to question the necessary relevance of equity governance structure and to affirm the importance of legal knowledge transfer clauses, organizational similarity and trust as conditions affecting the motivation to disclose knowledge at the beginning of interfirm R&D relationships. Legal knowledge transfer clauses seem to provide guarantees and a feeling of protection, even when an equity structure is absent (i.e. MAT-USCOAT relationship) and even when the disclosure of technological knowledge occurs unilateral (i.e. MAT-RES relationship). Besides legal knowledge transfer clauses, organizational similarity and trust are identified as important conditions. The absence of organizational similarity inhibits disclosure of knowledge, even if the interfirm collaboration is governed by an equity structure. The presence of trust tends to stimulate a bilateral disclosure of technological knowledge. We need to remark here that the feelings of trust were based on first perceptions of the values, attitudes, and emotions of the other partner. For instance, both MAT and FRCOAT people described the beginning of the interfirm R&D relationships as a 'marriage d'essai' (i.e. an attempt to marry), indicating that the trust between the partners was of a fragile nature. We therefore propose:

> Proposition 1a: Equity governance structures are neither a necessary nor a sufficient condition for partners to disclose knowledge.
> Proposition 1b: The presence of legal knowledge transfer clauses positively influences a partner's motivation to disclose knowledge.
> Proposition 1c: The presence of fragile trust positively influences a partner's motivation to disclose knowledge.
> Proposition 1d: The absence of organizational similarity negatively influences a partner's motivation to disclose knowledge.

Conditions that increase the ability to communicate and absorb technological knowledge

Besides the willingness to disclose knowledge, it is argued that partners need to be able to communicate as well as absorb the disclosed knowledge to achieve interfirm learning (Larsson et al. 1998). While our data affirm this reasoning, they also suggest that the presence of overlapping technological skills - as argued by previous research (Lane and Lubatkin 1998;

Mowery et al. 1996) – is not the only guarantee for the presence of communicative and absorptive ability in interfirm R&D relationships.

Analyzing the MAT-FRCOAT relationship, the interviewees explicitly stated that, although exchange of fundamental principles had taken place during the first six months, transfer of technology remained absent (Event 2, Table 6). Despite the presence of overlap in skills and experience in the field of diamond-like coatings between the MAT and FRCOAT engineers and their open disclosure of knowledge, the interviewees indicated that they were not able to arrive at a fine-grained understanding of the partner's technology (Event 2, Table 6), indicating the inability to absorb technological knowledge. After six months, the firms therefore decided to install each other's coating systems: a FRCOAT coating system was installed at MAT, while a MAT coating system was installed at FRCOAT. According to both MAT and FRCOAT engineers, from then onwards, they became able to learn the partner's technology (Event 3, Table 6). As one FRCOAT engineer expressed, it was the installation of each other's technological equipment that was experienced as a fundamental step in generating the ability to communicate and absorb technological knowledge:

> 'You start to live with the technology. You try to do the same things. It is a very interesting step because in advance you think that everything works very well but, by using the machines, you start experiencing problems. When the coating system broke down, we telephoned people at MAT. This created new exchanges of information and new explanations. In this way, a detailed transfer of technology became possible (FRCOAT engineer)

Similar dynamics were observed in the two other interfirm relationships where the ability to communicate and absorb knowledge was said to be present after the same equipment was installed at both firms. In the MAT-USCOAT collaboration, partners had signed a Unit Manufacturing Agreement that stipulated that MAT would 'design and manufacture two identical units of a vacuum coating system suitable for the deposition of DLX coatings' (Unit Manufacturing Agreement, p.1). In November 1995, these coating systems were installed at MAT and USCOAT and, according to the interviewees, allowed engineers of both firms to "speak the same language" (Event 3, Table 4). In the case of the MAT-RES relationship, the Technology Agreement stipulated that a coating system, similar to the existing one at RES, would be installed at MAT during the first year of the collaboration. Again, the MAT interviewees stressed they were only able to become familiar with RES's technology after the installation of this equipment at MAT (Event 3, Table 5).

To conclude, we found evidence that the presence of overlapping technological skills is not always a sufficient condition for the ability to communicate and absorb technological knowledge. We observed that engineers were only able to understand the partner's technology when they could apply their knowledge of diamond-like coating technology on coating systems that were equal or similar to the equipment of the partner. We therefore propose:

> Proposition 2: The positive influence of overlapping technological skills on a partner's ability to communicate and absorb knowledge is magnified with the presence of similar technical equipment.

Before moving to the next section, three additional comments need to be made. First, we notice that, during this initiation phase, interfirm learning remained limited to the transfer of technological knowledge. Jointly creating new technological knowledge was not observed at this stage. Second, the absence of cultural similarity, discussed in previous research as an important condition (Mowery et al. 1996), was not experienced by the interviewees as a factor influencing interfirm learning. Although the interfirm R&D relationships under study here were collaborations between Belgian and American, and between Belgian and French culture, cultural differences were not mentioned as reasons to explain difficulties in initiating interfirm learning. Third, several scholars (e.g. Hamel 1991; Larsson et al. 1998) have stressed that partners also need to be motivated to absorb the disclosed knowledge. In all the studied interfirm relationships, this learning dimension was present as interviewees of all partners mentioned that, at the start of the interfirm relationship, they were very eager to learn more about the partner's technology. However, as will be illustrated below, the motivation to absorb knowledge drastically changed in some cases later on.

THE EVOLUTION OF LEARNING IN INTERFIRM R&D RELATIONSHIPS

In addressing our second research question on how interfirm learning evolves over time, we first describe this evolution for each interfirm relationship separately. Next, through comparing the three cases, we discuss which conditions seem to influence the evolution of interfirm learning.

Evolution of Interfirm Learning in the MAT-USCOAT Relationship

Our data suggest that the further evolution of the MAT-USCOAT relationship consists of two additional phases. While in a first phase, interfirm learning in terms of transferring existing knowledge between the partners remained present; it decreased in the second phase. Table 7 provides a characterization of these two phases, also in terms of events that influenced the evolution of interfirm learning.

Insert Table 7 about here

Between 1995 and 1998, the collaboration between MAT and USCOAT remained effective in terms of transferring technological knowledge. The data suggest that transfer of existing knowledge continued between MAT and USCOAT. In this interfirm relationship, both partners started to experiment with the DLX technology, using the same technological equipment. However, while USCOAT searched for high-end DLX applications within the American micro-electronics market, MAT evaluated the feasibility of the DLX technology for industrial wear applications within the European market. The results of these distinct experiments were discussed on regularly held technological meetings. As the interviews suggest, these meetings were characterized by a high motivation to disclose knowledge (Phase 1, Table 7). During the meetings, the presentation of results triggered detailed technological discussions among the engineers about how the technological potential of DLX coatings could be improved. In the interviews, these meetings also were described as very informative (Phase 1, Table 7) indicating that partners were also able to communicate and absorb relevant technological knowledge during these meetings.

The MAT-USCOAT relationship began to change when MAT engineers started to realize the limitations of the DLX technology for industrial production. They started to experiment with combinations of the DLX and an alternative DLC technology. This combination of both technologies soon proved to have the best potential for industrialization. In 1998 MAT decided to focus on the development of combinations of the DLX and DLC technology. USCOAT was not involved in these developments. USCOAT engineers, although they were informed about MAT's successful experiments in combining DLX and DLC, continued to focus on the development of pure DLX applications. USCOAT interviewees stressed that USCOAT's management was not willing to invest in the development of DLC-oriented coatings. After all, USCOAT had recently launched an intensive marketing campaign in the US to promote its DLX technology as an alternative for DLC coatings. If USCOAT would have started to look at DLC, they would have jeopardized their former marketing efforts. The decision of USCOAT's management not to get involved in the development of this new DLX/DLC coating negatively influenced the amount of knowledge transfer between the partners. Both MAT and USCOAT interviewees mentioned that MAT engineers became less willing to engage in disclosing technological knowledge to USCOAT engineers (Phase 2, Table 7). Given the absence of a 'common ground', engineers were no longer interested in the specific challenges faced by the other partner (Phase 2, Table 7), indicating that the motivation to absorb technological knowledge also decreased.

Evolution of interfirm learning in the MAT-RES relationship

In the MAT-RES relationship, we identified two phases, both representing a decline in knowledge transfer. Table 8 provides an overview of this evolution.

Insert Table 8 about here

After the first year, the transfer of RES' DLC technology to MAT was completed. MAT, as stipulated in an R&D agreement, subsequently started to fund R&D projects at RES in order for them to continue research on DLC. MAT told RES engineers to exclusively focus on optimizing their original DLC technology in these R&D projects. However, through experimenting with RES' DLC technology, MAT engineers already had learned that this technology was limited in terms of industrial products. Still, instead of involving RES engineers in the optimization of the combined DLX/DLC technology, MAT preferred to fund research projects at RES that focused on optimizing RES's original DLC technology. At the same time, the MAT engineers, who also were very busy commercializing and expanding the MAT Diamond activities, showed little to no interest in these R&D projects (Phase 1, Table 8). In other words, MAT's motivation to absorb RES' knowledge substantially decreased, reducing the transfer of knowledge from RES to MAT. In addition, in 2001 the appointment of a new CEO at RES implied a radical change in the strategic vision of RES on joint ventures. For instance, RES management refused to participate in additional financial investments to expand the activities of MAT Diamond. Also the subsequent negotiations to transfer RES' shares to MAT were described in the interviews as very difficult. These managerial tensions had its influence on the operational level. Although the R&D agreement stipulated that MAT would fund R&D projects for five years, RES initiated no more R&D projects on DLC. RES engineers also mentioned that the managerial tensions made them more cautious in disclosing technological knowledge to the MAT people (Phase 2, Table 8), indicating a decrease of the willingness to disclose knowledge from RES to MAT. In this way, knowledge transfers between the partners became completely absent.

Evolution of Interfirm Learning in the MAT-FRCOAT Relationship

Similar to the MAT-USCOAT relationship, knowledge transfer continued between MAT and FRCOAT in a first phase. However, while negative evolutions were observed in the MAT-USCOAT relationship, this interfirm relationship evolved towards the joint creation of new knowledge (see Table 9).

Insert Table 9 about here

Between March 2002 and December 2002, MAT and FRCOAT continued to transfer knowledge. Making use of the exchanged technical equipment, engineers of both firms started to experiment with the partner's technology. MAT engineers, on the one hand, investigated how the FRCOAT technology could improve the quality of MAT's existing coating applications in the wear market. FRCOAT engineers, on the other hand, examined how they could apply MAT's technology to improve their existing applications in the speed racing market. When one of the partners experienced new difficulties, ad hoc discussions occurred. As one MAT engineer describes, these discussions were open and fruitful (Phase 1, Table 9), suggesting the presence of valuable knowledge transfer.

At the end of 2002, due to a failure to develop an application for an important customer in the automotive industry, both firms realized that a new coating technology should be developed. This led to the initiation of the Adhere project, in which MAT and FRCOAT engineers jointly tried to develop a new technology that combined the positive characteristics of the MAT and FRCOAT technology. In this project, engineers of both partners not only had ad hoc discussions, but also worked shoulder to shoulder to develop a new coating. One FRCOAT interviewee mentioned that the joint R&D efforts triggered excessive information exchange (Phase 2, Table 9), allowing for the creation of new technological knowledge. At the end of 2003, the Adhere project was successfully completed. A new coating was jointly developed that combined the positive characteristics of the MAT and FRCOAT technology.

Discussion: The Evolution of Interfirm Learning

Our data suggest that interfirm R&D relationships can evolve in different ways. Besides, discontinuation, preserving the continuance of technological knowledge transfer and evolving towards the creation of new technological knowledge were observed.

Conditions that facilitate the continuance of technological knowledge transfer. We observed that, in some cases at particular moments, partners were able to continue transferring technological knowledge, while, in another case and at other moments, technological knowledge transfer decreased. We argue that the complementary versus distinct nature of the scope of the partners' R&D activities determines the degree to which continuance of technological knowledge transfers will occur.

Our findings on the MAT-USCOAT and MAT-FRCOAT relationship suggest that a complementary scope of R&D activities tends to facilitate the continuance of technological knowledge transfer in interfirm R&D relationships. The main characteristic of this complementary scope seems to relate to the firms' independent search for *different* market applications while using and developing a *shared* technological platform. A MAT manager expressed this as follows:

> "If the R&D teams of USCOAT and MAT would do the same thing, they would all target the same markets, contact the same customers, and try to find solutions for the same applications. This is not efficient. Instead, it is good to make the R&D teams of the different partners accountable for specific markets and products. Long discussions about who has the best solution for particular problems are avoided. This, however, does not mean that they can not contact each other to exchange technical information. If one team has a problem, they can contact the other team to discuss these problems. But, in the end, individual teams are solely responsible for reaching their own objectives. Consequently, discussions in which both teams accuse each other of not doing what had to be done are avoided." (MAT manager)

Such a complementary scope of R&D activities in terms of market applications seems to increase accountability of individual R&D teams, overall efficiency and reduces the risk of competition. These factors, in turn, positively influence the willingness to exchange technological knowledge while the presence of a shared technological platform provides the optimal environment to continue communicating and absorbing technological knowledge. Because both partners focus on the same technologies, they are likely to have a fine-grained understanding of the partner's technological activities and capabilities.

In contrast, when R&D activities do not share technology platforms one is likely to observe a decline in knowledge transfer between the partners. In the MAT-RES relationship, both partners explicitly focused on different technologies. As one RES engineer suggested, such separation reduced the likelihood that technological activities of one partner could have value for the other partner.

> "They [MAT] actually told us: 'this is your process, try to improve it and try to scale it up.' It would have been better if they had told us: 'our process looks like this; you can start from this and try to improve it.' When we would have defined R&D projects in that way, it would have been more efficient and more ideas would have emerged out of it." (RES engineer)

When the scope of the partners' R&D activities is of a distinct nature, the motivation to absorb knowledge decreases and consequently jeopardizes the continuation of technological knowledge transfer. Similar dynamics were observed in the MAT-USCOAT relationship. Although these partners had been able to continue to exchange technological knowledge for a substantive period, such knowledge transfers quickly disappeared after partners had decided to focus on different technologies. We therefore propose:

> Proposition 3a: If the scope of the partners' activities is complementary -each organization works with the same technology on different market applications-, technological knowledge transfer is likely to continue.
> Proposition 3b: If the scope of the partners' R&D activities is distinctive -each organization works with a different technology-, technological knowledge transfer is likely to decrease and even come to an end.

Conditions that facilitate the joint creation of new technological knowledge. Within our case study, the cooperation between MAT and FRCOAT evolved towards joint knowledge creation. This evolution was related to a more convergent scope of not only the partner's R&D activities but also their market applications:

> "In 2002 we worked on a large application for an important customer in the automotive industry. First we had tried to develop this application with limited resources in Belgium. This project was a failure because the customer told us that we were not able to deliver a coating that satisfied their needs. That was the moment that we understood that we needed to build one large R&D team. We needed to converge the MAT and FRCOAT technology to develop one technology that would combine the best characteristics of the two technologies." (MAT project manager)

The failure to develop an application for a specific customer made MAT and FRCOAT realize that they jointly needed to develop a new coating that combined the positive characteristics of both partners. Therefore, the Adhere project was initiated, oriented towards developing jointly a new application for one specific - shared - customer.

These findings lead to – at first sight – contradictory observations. While pursuing distinctive market applications turned out to be beneficial for the continuance of technological knowledge transfer (proposition 3a), the movement towards joint knowledge creation seems to ask for convergence on the level of market applications. As argued within the previous section, distinctive market approaches reduce the risk of competition between collaborative partners, allowing for the continuation of technological knowledge transfer. However, as knowledge transfer continued in the MAT-FRCOAT relationship, the need to protect against the threat of competition was reduced because of a sufficient amount of positive experiences, as suggested by a MAT engineer:

> "Before, this [Adhere] project could not have been initiated. However, now we found ourselves in an advanced phase of the collaboration… Because we successfully had disclosed technological knowledge for more than one year, we felt that a more structural collaboration on the technological level was possible." (MAT manager)

The MAT-FRCOAT relationship provides indications that partners need first-hand evidence of the other partners' trustworthiness to evolve towards convergence on the level of market applications. This finding seems to correspond with Jones and George's (1998: 539) argument that, only when partners have received empirical evidence of the other partner's trustworthy behavior, the quality of the exchange relationship can fundamentally change and engaging in joint knowledge creation activities becomes feasible. In other words, once trust has spiraled up to more resilient levels, joint knowledge creation is possible. However, initiating a joint development project that enables joint creation implies – at least – one shared application, hence to some extent, convergence on the level of market applications.

We therefore propose:

> Proposition 4a: Only to the extent that the scope of the partners' activities is converging -each organization works with the same technology towards a similar application - interfirm R&D relationships are able to evolve towards joint knowledge creation.
> Proposition 4b: The evolution from a complementary to a convergent scope requires previous positive knowledge exchange experiences between partners in order to establish resilient trust.

CONCLUSION

The purpose of this study was to contribute to the development of a more complex and dynamic view on learning in interfirm R&D collaboration through identifying conditions that, over time, affect transfer of existing knowledge and joint creation of new knowledge. In this concluding section, we first summarize the main findings of our study. Next, we focus on the contributions of our study and discuss limitations as well as promising avenues for future research.

Summary of Findings

Based on an in-depth case study of three interfirm R&D relationships within one technological trajectory, we suggest that the process of learning in an interfirm R&D collaboration tends to consist of different phases: initiating technological knowledge transfer, continuing technological knowledge transfer, and moving towards the joint creation of new technological knowledge. For each of these three phases, different conditions seem to play a role.

Regarding the initiation of technological knowledge transfer, the conditions of legal knowledge transfer clauses and conditional trust, rather than equity governance structure, positively influence the motivation to disclose knowledge of partners. Our data strongly indicate that, even when equity based governance structures are not present, organizations are willing to disclose technological knowledge as long as specific contractual safeguards that provide a framework for the exchange of knowledge are present. This finding is important, given Hagendoorn's (2002) observation that, because of the flexibility of non-equity based governance structures, organizations tend to increasingly prefer this type of legal structure above an equity structure to govern R&D partnerships. Consistent with other research (Larsson et al., 1998), we found that organizations only get a fine-grained understanding of a partner's technology when partners are able to communicate and absorb the tacit components of the technology involved. While previous research (i.e. Lane and Lubatkin 1998; Mowery et al. 1996) has emphasized the importance of overlapping technical skills, this study stresses the importance of sharing technical equipment in order to transfer sticky or tacit knowledge.

Finally, it became apparent that organizational similarity is more influential than cultural similarity regarding the initiation of knowledge transfer.

After the initiation of technological knowledge transfer, interfirm R&D collaborations face the challenge to continue technological knowledge transfers. In this phase, the scope of the partners' R&D activities strongly influences the organizations' willingness to continue transferring knowledge. A complementary scope of R&D activities, whereby each organization works with the same technological platform on different market applications, was found to facilitate the continuance of knowledge transfer activities. If the scope of R&D activities is distinctive – each organization works on different technologies – interfirm knowledge transfer tends to dissolve.

The following challenge is to move to a third phase in which new technological knowledge is jointly created. Our findings suggest that such joint knowledge creation requires convergence also on the level of market applications. Our data further indicate that past positive experiences – on the level of knowledge transfer activities – is required in order for convergence on the level of market applications to be effective. As such, these observations accentuate the relevance of stage based views on trust (e.g. Lewicki and Bunker 1996; Jones and George 1998; Newell and Swan 2000; Ring 1997) for understanding the dynamics of interfirm R&D relationships.

Future Research and Limitations

Through engaging in research that examines the complexity of learning dynamics in interfirm relationships, the insights of this study points to four directions for future research. While in the past several scholars (e.g. Chen 2004; Mowery et al. 1997) have focused on the influence of ownership structure (i.e. equity versus non-equity structure) on interfirm learning, our findings suggest that not the ownership structure per se, but rather the presence of specific contractual safeguards influences the willingness to disclose knowledge. Following Gulati and Singh (1998) and Klein Woolthuis (1999), we therefore suggest a more fine-grained research of the impact of legal governance structures on interfirm collaboration. In specific, we encourage studies to examine the impact of specific contractual safeguards on the potential for interfirm learning.

Second, we observed that the presence of legal knowledge transfer clauses as well as the presence of fragile trust positively influences a partner's motivation to disclose technological knowledge. However, given the limited number of observed cases, we were not able to examine whether legal knowledge transfer clauses and trust should be regarded as complements or substitutes. Our study therefore supports the call of several scholars (e.g. Madhok 1995; Young-Ybarra and Wiersema 1999) to combine contractual-based approaches (i.e. transaction cost economics) with relational-based approaches (i.e. social exchange theory) to better understand the dynamics of interfirm collaboration. Recently, a number of studies (e.g. Garcia-Canal, Valdés-Llaneza and Arino 2003; Lui and Ngo 2004; Luo 2002; Poppo and Zenger 2002), have examined the combined effects of contractual and relational conditions on the performance of interfirm relationships. Future work that looks at the emergence of such effects in terms of learning would be very productive.

Third, existing research (Lane and Lubatkin 1998; Mowery et al. 1996) has argued that the amount of overlapping skills largely determines the ability to absorb knowledge in interfirm R&D relationships. Our study, however, indicates the relevance of not only overlapping skills but also the availability of similar equipment and the execution of complementary R&D activities by the partners as conditions facilitating the absorption and communication of technological knowledge. Except for the study of Carson et al. (2003), these factors have been neglected in explaining the success or failure of interfirm relationships, indicating a promising direction for further research.

Finally, past research on the dynamics of interfirm learning has focused on the transfer of knowledge between organizations (Lubatkin et al., 2001). In this study, we also examined the process of moving towards jointly creating new technological knowledge through which we were able to identify specific conditions that facilitate the continuation of knowledge transfer and those that facilitate the joint creation of new knowledge. Future research may benefit from including multiple forms of interfirm learning, examining how each form is related to a different phase in the interfirm relationship, and identifying its crucial challenges.

As a final reflection, we point to the main limitation of this study. Our findings are based on an in-depth examination of a limited number of interfirm relationships in one technological trajectory. Although this research design allowed us to compare the three relationships with a minimum influence of extraneous variation, its findings are contextualized. Particular characteristics of the technological trajectory or the companies themselves influence the way in which the interfirm R&D relationships under study evolved. The development of a more general dynamic theory on interfirm R&D collaboration requires additional case studies in other contexts to fully understand how and to what extent different conditions affect different forms of interfirm learning and their evolvement over time. We hope our study inspires scholars to conceptualize interfirm relationships and interfirm learning as phased processes and to examine the critical points of attention for each phase.

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Table 1: Chronology of the interfirm R&D relationships

	´95	´96	´97	´98	´99	´00	´01	´02	´03
MAT-USCOAT relationship									
MAT-RES relationship									
MAT-FRCOAT relationship									

Table 2: Overview of different stages of data collection and analysis

Stage	Data Collection Technique	Data Analysis Technique	Output
1	- Unstructured interviews - Analysis of documents	Visual mapping strategy	Graphical representation of chronology of different interfirm R&D relationships
2	Semi-structured interviews	Narrative strategy	Case study report that in detail describes the events that shaped the interfirm R&D relationships
3	Feedback interviews with managers of involved companies	Pattern-matching logic	Theoretical propositions about the initiation and evolution of interfirm learning

Table 3: Overview of the interviews

Company	Function of Interviewee	Number of Interviewees
MAT	Corporate Manager	2
	Project Manager	2
	Engineer/Technician	2
	Sales Manager	1
	Lawyer	1
RES	Corporate Manager	2
	Project Manager	2
	Engineer/Technician	1
USCOAT	Project Manager	1
	Engineer/Technician	3
FRCOAT	Corporate/Project Manager	1
	Engineer/Technician	1
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Table 4: Initiation of transparency and receptivity in the MAT-USCOAT relationship

	Event 1: April 1995	**Event 2: May 1995**	**Event 3: November 1995**
Event	First technological meeting between MAT and USCOAT	MAT's project manager visits USCOAT plant and MAT conducts first characterizations of USCOAT's coatings	Installation of joint DLX coating systems at MAT and USCOAT
Interfirm learning dimensions	*Presence of willingness to disclose knowledge at USCOAT* "Initially there was a lot of information exchange: papers, journal articles, unpublished communications." (USCOAT project manager) "Despite the risk of withholding information during this initial phase, they played it openly." (MAT manager)	*Presence of willingness to disclose knowledge at MAT and USCOAT* "He [MAT project manager] received lots of information about the coatings, about what they could be used for. We provided even samples from coatings from Russia." (USCOAT project manager) "We got these samples analyzed…The exchange of these findings was open. (MAT engineer) "	*Presence of ability to communicate and absorb knowledge at MAT and USCOAT* "Through the presence of these joint coating systems, everybody spoke the same language. This facilitated the discussion of specific problems." (MAT manager)

Table 5: Initiation of transparency and receptivity in the MAT-RES relationship

	Event 1: Jan 1998	**Event 2: April 1998**	**Event 3: July 1998**
Event	First technological meetings between RES and MAT	RES provides operational assistance to initiate operational activities in the joint venture	Installation of a RES coating system at MAT
Interfirm learning dimensions	*Presence of willingness to disclose knowledge at RES* "We passed on the set-up of the RES process as well as the process parameters." (MAT engineer)	*Presence of willingness to disclose knowledge at RES and absence of willingness to disclose knowledge at MAT* "Regarding the exchange of technology, it definitely was one-way communication." (RES project manager) "We were not open about our technology towards RES to avoid an outflow of knowledge." (MAT manager)	*Presence of ability to absorb knowledge at MAT* "In this way, we were able to get familiar with the technology. It allowed us to observe the possibilities of it. We wanted to be able to imitate the DLC-characteristics of RES." (MAT engineer)

Table 6: Initiation of transparency and receptivity in the MAT-FRCOAT relationship

	Event 1: Nov 2001	**Event 2: Dec 2001**	**Event 3: March 2002**
Event	First technological meetings between FRCOAT and MAT	Visits from engineers to partner's production plant	Installation of a FRCOAT coating system at MAT and a MAT coating system at FRCOAT
Interfirm learning dimensions	*Presence of willingness to disclose knowledge at MAT and FRCOAT* "I did not hide anything about FRCOAT's process. Also the MAT people did not hide anything. During this first meeting, for instance, it became clear that there was an essential difference between the MAT and FRCOAT process."(FRCOAT engineer)	*Presence of willingness to disclose knowledge at MAT and FRCOAT* This was not really a transfer of technology but rather a transfer of the principal fundamentals." (FRCOAT engineer) *Absence of receptivity at MAT and FRCOAT* "We received information about their coating systems and technology. However, we quickly realized that seeing the process on a blackboard or looking at how their engineers were turning the buttons of the machines would not be sufficient to learn about the technology." (MAT project manager)'	*Presence of ability to absorb and communicate knowledge at MAT and FRCOAT* "This allowed both parties to get familiar with the technology and to experiment with it through applications."(MAT engineer) "For me this was the fundamental step in the collaboration: both parties started working with each others technology." (FRCOAT engineer)'

Table 7: Evolution of interfirm learning in the MAT-USCOAT relationship

	Phase 1: 1995-1998	Phase 2: 1998-2000
Events	USCOAT and MAT both experiment with DLX technology for different applications in different markets. The results of these parallel experiments are regularly exchanged during technology steering committees.	MAT decides to develop a new coating that combines DLX and DLC technology. Because of financial problems and sunk-cost investments, USCOAT's CEO decides not to get involved in the development of this new coating.
Evolution of interfirm learning	*Continuation of knowledge transfer* "The exchange of findings was open. I did not have the feeling that information was withheld or that people did not want to tell certain things." (MAT engineer) "There was a lot of sharing of information. The technical meetings were very informative." (USCOAT project manager)	*Decrease of knowledge transfer* "When we felt that the technology of USCOAT had its limitations, we became more reserved concerning new developments of other coatings." (MAT manager) "A part of the frustration was also that we did not know what actually happened at MAT. We did not have all the information." (USCOAT project manager) "I think gradually it became less and less clear what was happening." (USCOAT project manager) "They worked on applications for the electronics industry where you had to put Fluor in the coatings. That was none of our business. There almost was no common ground left." (MAT engineer)

Table 8: Evolution of interfirm learning in the MAT-RES relationship

	Phase 1: 1999-2001	**Phase 2: 2001-2002**
Events	MAT funds R&D projects at RES. Although MAT focuses on the optimization of its DLC/DLX coating, RES engineers are told to focus on the optimization of the original DLC technology.	Appointment of new CEO at RES, causing tensions between RES and MAT on the managerial level.
Evolution of interfirm learning	*Decrease of knowledge transfer* "I remember that we really had to insist on sitting together to discuss the research. Those people [MAT engineers] were busy with other things." (RES project manager)	*Decrease of knowledge transfer* "In these circumstances, you no longer sit together and discuss the main strategies. You are a bit more careful." (RES project manager)

Table 9: Evolution of interfirm learning in the MAT-FRCOAT relationship

	Phase 1: March 2002 – Dec 2002	**Phase 2: Dec 2002 – Dec 2003**
Events	MAT and FRCOAT experiment with each others technology for different applications in different markets. These parallel experiments trigger ad hoc discussions between engineers.	Because of the failure of a project for a specific customer in the automotive industry, the Adhere project is initiated. In this project, MAT and FRCOAT jointly try to develop a new coating that combines the positive characteristics of the original MAT and FRCOAT technologies.
Evolution of interfirm learning	*Continuation of knowledge transfer* "It was a very open discussion with them. There was no confrontation. The experience of everybody was put on the table. In this way, you can start to find solutions." (MAT engineer)	*Emergence of joint knowledge creation* "In this project engineers of the different teams work closely together. I think that the fact that we shared a specific project, which was important for each partner, stimulated extensive information exchange… As a result, the newest coating actually is the synthesis of the positive aspects of both the MAT and the FRCOAT technology, which, at the beginning, were actually competitive technologies. The two technologies have met each other." (FRCOAT CEO)