INTER-FIRM INTERACTION

FOR TECHNOLOGY-BASED RADICAL INNOVATION

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GUIDE FOR THE READER

This dissertation is the result of a research journey that encompasses about 5 years. During this time a significant evolution took place in the way I viewed the central research problem and in the philosophies of science and methods I applied in an attempt to generate 'good research'. The PhD process has been a tremendous learning experience and it has been a challenge to incorporate that learning process in the dissertation in a way that improves its readability.

The first chapter is an important introduction to the PhD research as a whole. It presents the central research question and explains how three studies are designed to address different aspects of the central research problem. Each of these three studies results in a full paper that can be understood autonomously. However, because of the learning process involved in completing a PhD there is a significant evolution in the theoretical and methodological approach of the studies. The first chapter outlines this evolution explicitly and, thus, enables the reader to correctly interpret the aggregated research. Chapters II, III and IV report on Studies 1, 2 and 3 respectively. The final chapter presents an integrated discussion of the results of the three studies and links them back to the central research question of the PhD.

In sum, I want to advise readers to read Chapter I first. After that, the different chapters can be consulted in any random order.

Good luck!

Anne.

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CHAPTER I

INTER-FIRM INTERACTION FOR TECHNOLOGY-BASED RADICAL INNOVATION: A RESEARCH STRATEGY

I.1. Introduction to the research focus

Growth, competitive advantage and profitability are just some of the potential consequences of innovation. They drive a firm to devote a considerable share of its resources to infuse novelty in its processes and products or services (Christensen and Raynor, 2003; Porter, 1985; Tidd et al., 2005). Innovation can be realised by changes in the social, economic and/or technological aspects of the firm. Examples of changes in the social or economic aspects of a firm are adaptations in organisational routines or in the business model (Kanter, 1997; Slywotzky et al., 1998). A firm can also innovate by commercialising a new technology (Jolly, 1997). There are a variety of ways to appropriate such new technology. It can be acquired externally (Chesbrough, 2003), invented and developed internally or in some form of partnership between firms (Cantner and Graf, 2004; Rocha, 1999). Technological invention can be the result of any kind of combination of a purposeful research strategy and a fortunate synchronicity of events. Once a new technology is acquired, the firm then needs to develop commercial applications based on this new technology in order to reap its gains. The level of innovativeness of commercial technology-based applications can be situated anywhere on the continuum between incremental and radical.

Preferably, the firm tries to combine both types of innovation in order to secure short term gains and long term growth (Chandy and Tellis, 1998; March, 1991; Vercauteren, 2005). Technological innovations that offer relatively minor improvements are traditionally called incremental innovations (Ettlie et al., 1984). Radical innovations present a more significant leap forward and provide substantially greater customer benefits compared to existing solutions (O'Connor 1998; Chandy and Tellis 1998). Radical innovation requires considerable risk taking and the costs and failure rates involved are the subject of dazzling estimates (Clugston, 1995; Millier, 1997; Di Masi et al., 2003; Choffray and Lilien, 1980; Cooper, 1990). Incremental and radical innovations pose very different management challenges (Ettlie et al., 1984). Incremental innovation relies on monitoring customer needs and adapting current offers to better serve those needs. Radical innovation originates from a radically innovative idea or technology that has the potential to redefine existing markets or create new markets (Christensen, 1997). Genuine radical innovations occur rather infrequently though, especially viewed from the perspective of one firm. Hence, it is extremely difficult to gain experience in this area. In this dissertation we aim to generate a better understanding of the process of technology-based radical innovation and the context in which it occurs. This context is important since every firm is embedded in a larger market of firms that are interrelated through inter-firm interactions and exchanges (Håkansson and Snehota, 1989). In industrial markets, a firm is part of a constellation of firms that connect it with its suppliers, its customers, suppliers of complementary products and services, and competitors. In the midst of all these interrelated and constantly changing environments a firm tries to concentrate on developing a technology-based radical innovation. Managers may experience considerable tension between an internal versus an external focus. On the one hand, there may be a tendency to protect the valuable technological knowledge involved by keeping it in-house. Innovating firms are eager to secure competitive technological knowledge and this may prevent them from engaging in inter-firm interactions. Firms do attempt to establish exclusive ownership of this knowledge in the form of patents and other intellectual property rights (Helper et al., 2000), but these kind of tools may not be able to capture all the specific know-how involved. They are also expensive to establish and enforce. On the other hand, innovation implies exchange and an outward focus. It is hard to imagine that a firm can fine-tune a technological invention to market needs without actually consulting potential customer firms in any way. Though technology-driven firms may have the most to gain by incorporating a customer perspective into their innovation process (Zhou et al., 2005; Dutta et al., 1999), customer interaction for radical innovation seems to be fraught with uncertainty. Current customers are observed to lobby with their suppliers to persuade them to concentrate on incremental improvements instead of radical innovations (Christensen, 1997). Doubt exists about the ability of customers to reveal their own latent needs and to understand radical innovations at all (Day, 2002; Leonard and Rayport, 1997; Veryzer, 1998). Hence in spite of the fact that there is a real need to involve customers in radical innovation (Lukas and Ferell, 2000; Atuahene-Gima et al, 2005), little is known about how such interaction can take place and how the involvement of customer firms can facilitate radical innovation. Another complicating factor is that every dyadic interaction between an innovating firm and a potential customer firm may be part of a whole set of dyadic interactions between the innovating firm and other potential customers (Anderson et al., 1994). These customer firms may be in direct competition with one another.

Therefore they may be reluctant to cooperate. Nevertheless, it is important that the innovation be designed to serve a larger market of customers and that it is not just customised to the needs and usage context of one or a few particular customer firm(s). Furthermore, in industrial markets a technological product needs to fit into a firm's productive system in which technological and organisational resources are combined in an intricate way (Rosenberg, 1982). Any radical change in such a technological system is likely to affect more firms than only the customer firms that want to adopt the innovation. It is likely that their own customers and suppliers might also need to adapt to the effects or requirements of the innovation in order to enable its adoption. However, all these firms' current activities are the result of large investments and long technological trajectories that constrain their potential future actions (Dosi, 1982; Dosi et al., 1990). It may be crucial to identify these firms and try to address any limitations that they may experience in trying to adapt to the technology-based radical innovation. The above considerations stress the potential relevance of a research into inter-firm interactions during the technology-based radical innovation process. We are particularly interested whether and how interactions with customer firms are incorporated into the innovation process. Because of the radicalness of the studied innovations we also expect a role for inter-firm interactions with firms other than direct customer firms. Hence, we formulate our central research question as follows:

Central research question: "How does inter-firm interaction facilitate technology-based radical innovation?"

The exploratory nature of this research question is tailored to the relatively young domain of research into radical innovation in which very little attention has concentrated on the role of inter-firm interaction during the radical innovation process. The relatively scarce extant literature on this topic justifies an explorative approach to studying the central problem. For this purpose we combine 3 scientific studies. These studies evolve around the theme that is captured in the central research question. Every single study offered learning opportunities in terms of the investigated problem and the applied methodology. The learning experiences in Study 1 contributed to the design of Study 2. What we learned in the Study 2 was taken into account when conducting Study 3. In general, such learning is an important aspect of doing research (Dubois and Gadde, 2002). In the academic community current research builds on the lessons learned from previous studies. This learning aspect was also a distinctive feature of the present dissertation. The central research question guided us towards some crucial choices with respect to the research paradigm of the aggregated research. This research paradigm served as a basis for the three studies. The learning process, that we went through while conducting this PhD research, caused an evolution in some of the central aspects of the three studies. The theoretical and methodological approaches to the two basic components of the central research question – inter-firm interaction and the innovation process – evolved considerably over the three studies. In this chapter we show how the studies build on one another by indicating the evolution of the basic problem, the theoretical approach to key concepts and the specific methodology. We introduce and report on the studies in chronological order, to respect this evolution. In the dissertation, every study is reported on in a chapter that can be read and interpreted as an autonomous paper. Study 1 is reported on in Chapter II. Study 2 is the subject of Chapter III and Chapter IV reports on Study 3.

Section I.2. introduces the research paradigm that we strived to adhere to in the aggregated research. It provides the basic guidelines for conducting the three studies in this dissertation. Sections I.3., I.4. and I.5. discuss those aspects of the research designs of Studies 1, 2 and 3, respectively, which are specific to each study. In section I.6., we conclude this chapter with an overview of each study's methodological design and we summarise how the studies build on one another.

I.2. Research paradigm

A research paradigm combines the researcher's beliefs about ontology, epistemology and methodology (Guba, 1990). As human beings we are all guided in our day-to-day activities and experiences by our personal, highly abstract beliefs about reality and our place in it. This section makes this implicit background explicit for this dissertation. The following sub sections evolve from the metaphysical topic of ontology, over epistemology to the more operational topic of research methodology. Together, they describe the research paradigm that we strived to adhere to while conducting the three studies that make up this dissertation.

I.2.1. Ontological background: critical realism

Ontology concerns our beliefs about the nature of reality. We adopt a critical realist position when saying that there is a single reality and that this reality is independent of our fallible knowledge of it (Easton, 2002; Denzin and Lincoln, 2000). Critical realism captures our belief that reality can only to a limited extent be explained by laws and patterns, e.g. natural, legal laws or social habits. Critical realism does not rely on causality as an absolute relationship between two discrete events, one labelled 'cause' and the other 'effect'. Rather, in critical realism "a causal explanation is one that identifies the objects and their mechanisms and the way they combine to cause events" (Easton, 2002, p. 105).

I.2.2. Epistemological background: interpretivism

Epistemology bears on the relationship between the human being, as a researcher in our case, and reality. In an epistemological stance the nature and limits of human knowledge are explained.

The 'one reality' as acknowledged in the previous sub section can not be observed objectively. Only from a God's point of view could reality be observed from the outside (Putnam, 1985). We can not observe reality from nowhere, without being who we are (Nagel, 1986). Thereby, we confirm an interpretivist epistemological stance. Extracting knowledge from reality always occurs in a theoretical context (Guba, 1990). To the inability to observe reality objectively we add that it is also impossible to fully comprehend reality in all of its harmonious complexity. Nevertheless, the ontological acknowledgement that there is a reality acts as a constraint, even if it is only in principle, on any claim of knowledge. From an interpretivist perspective we can aim at understanding well delineated parts of reality (Smith and Deemer, 2000). The relation between the phenomenon and its context is crucial here, to make sure that the generated understanding is not merely reduced to a description but that it can serve as a tool to understand phenomena in similar contexts. Trustworthiness is the key criterion for the value of such interpretations. In the critical realist tradition, the four components of trustworthiness are credibility, transferability, dependability and confirmability. They are the respective equivalents of the more positivist internal and external validity, reliability and objectivity (Denzin, 1998; Miles and Huberman, 1994). The next sub section elaborates on the methods applied to guarantee trustworthiness.

I.2.3. General methodology: case-based research

A methodology describes the plan of action for extracting knowledge from reality. The central research question of this dissertation asks about the influence of one business process, inter-firm interaction, on another business process, technology-based radical innovation. Case-based research is most suitable for an investigation into processes and the links between them. Analysing secondary data sets would only result in very indirect indications of the processes at work. Also because radical innovations are relatively rare phenomena, it would be extremely difficult to design a large scale survey research that could investigate radical innovation in a valid way. Our epistemological perspective also guides us towards case-based research: we aim for in-depth understanding of the phenomenon at study rather than the formulation of statistically generalisable normative statements (Yin, 2003). Also, cooperative strategies are regarded in business as a highly confidential topic. Therefore we expect a research method that relies on personal interviewing to prove more fruitful in generating valid information than the use of standardised questionnaires.

I.2.3.1. Data collection

The underlying logic of our data collection strategy is one of 'crystallisation' (Richardson, 2000). In case-based research, triangulation is seen as an essential technique for safeguarding the validity and reliability of inquiry (Yin, 2003). The notion of triangulation stems from a positivist tradition in which the technique aims to check the accuracy of a particular dataset (Greene, 1990). In a critical realist research paradigm triangulation techniques not only aim to confirm (or reject) information gathered from other sources or by other methods. We also apply triangulation as a strategy for discovering new information. Hence we confirm the use of the triangulation technique and even apply it for a broader set of purposes than it was originally intended for. To stress this broader use for triangulation we follow Richardson's (2000) terminology and refer to triangulation in a critical realist paradigm as crystallisation. Richardson (2000) compares reality to a crystal "which combines symmetry and substance with an infinite variety of shapes, substances, transmutations, multidimensionalities, and angles of approach. Crystals grow, change, alter, but are not amorphous. Crystals are prisms that reflect externalities *and* refract within themselves, creating different colors, patterns and arrays casting off in different directions. What we see depends upon our angle of repose. … crystallisation provides us with a deepened, complex, thoroughly partial understanding of the" phenomenon (p. 934, with original italics). The author uses the term crystallisation to denote a broader class of data collection techniques. Crystallisation is not only the accuracy check triangulation is. Crystallisation is also a means of revealing new aspects, phenomena and relations (Dubois and Gadde, 2002).

For collecting case data we rely mainly on interviewing, observation and analysis of business documents. In what follows we discuss each of these strategies with specific attention for the underlying crystallisation logic.

- Interviewing

We conduct semi-structured interviews with managers from the firms involved in the innovation project in which customer and/or inter-firm interaction played an important role. In interviews with corporate managers we typically aim at understanding the strategic context of an innovation project. Managers directly involved in the project provide accurate information on the studied processes, e.g. interaction process and innovation process. When desirable and possible, relevant managers at the partner firm(s) are also approached to integrate their perspective of the interaction and the innovation process in our study.

A topic list is composed to assure comparability across interviewees and, when this is the purpose, across cases. The topic list aims to take into account the dynamics over time of the studied processes to enable complete understanding of how inter-firm interaction did or did not contribute to the technology-based radical innovation process. Also, before interviewing, the base technology involved is explored by means of desk research.

When conducting interviews, special attention is paid to formulating questions in a non-threatening and unbiased way. Empathic listening and active interviewing are important components of a successful interview strategy (Kvale, 1996). Empathic listening involves not only hearing what is said but also how it is said and noticing what is not said. Active interviewing means that during the interview we interpret the given information in terms of the larger context of the phenomenon and the aim of the research. This enables us to respond adequately by correctly rephrasing the given information as an accuracy check or by formulating additional questions to reveal relevant information. Interviews are taped and transcribed following Miles and Huberman's (1994) guidelines. Interviewing also includes completion of a short survey (see Appendix) to assess radicalness of the technology involved.

- Observation

When interviewing managers on site, looking at samples of and demonstrations with the discussed base and/or application technology, leads to a better understanding of the studied innovation (Yin, 2003). Body language also provides signs of the confidence with which managers are able to make certain statements. Further probing into more objective criteria for the trustworthiness of the respondent's response provides an opportunity to correctly assess the dependability of the response.

- Business documents

During and after company visits for interviewing, access to documents is negotiated. These documents contribute to a deeper and richer understanding of the case situations. Documents can serve as interpretation as well as accuracy checks or can provide information complementary to the information received directly in face-to-face interviews. These documents were assembled for other purposes than our research and, hence, provide us with additional angles on the project involved. The documents are always interpreted in the light of the aim for which they were composed (Yin, 2003). Relevant documents include intermediate business plans, business presentations of the innovation project studied and information on websites of the firms involved.

I.2.3.2. Data analysis

The general aim of our research is to generate a deep, rich and contextualised understanding of the potential role of inter-firm interaction in technology-based radical innovation projects. In qualitative research against a critical realist background, data analysis involves looking at the phenomenon from numerous angles, with attention for the dynamics involved and with tolerance for both predictable patterns and one-off events. With special attention for the criteria for trustworthiness, as described in section I.2.2., the data form the basis for an interpretive analysis. We find it especially important that our research results are "empirically grounded and scientifically credible" (Denzin and Lincoln, 1998, p. 276). During data interpretation we are "internally reflexive"(p.277), which means that we strive to take into account the effects of ourselves as researchers and of the research strategy applied on our research results. This awareness should improve both dependability and confirmability of the conducted studies. In the next paragraph we elaborate on the applied technique of analysis as a combination of deduction and induction in which iteration plays an important role.

- A combination of deduction and induction

For conducting our research we demonstrate a deductive logic to the extent that we rely on extant theory for formulating our research questions and for establishing the theoretical framework of the research (Pettigrew, 1997). However, there is a distinctive inductive character to case-based qualitative research in the sense that we, rather than imposing theory on the data, let interpretations and theory emerge from the data (Strauss and Corbin, 1999).

Iteration is an important facet of such inductive analysis. We apply at least two forms of iteration: iteration between data and theory and iteration between data analysis and data collection. In multiple-case research we also iterate between within-case analysis and across-case analysis. But first, iteration between data and theory forces us to go beyond initial impressions. By systematically comparing the emergent theory to different pieces of data the theory becomes stronger and better grounded when evidence from one piece of data is corroborated by another piece of data. We apply this type of iteration to develop theory that closely fits the data, to sharpen the definition of concepts and/or to verify relationships. Simultaneously, the emergent theory, concept or relationship is compared to relevant findings in extant literature to incite us to double-check seemingly contradictory findings or to improve credibility and transferability when our emerging theory is confirmed in the work of other researchers (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Second, iteration between data analysis and data collection occurs, when during case analysis, we experience a blind spot in the collected data or when we want to check our own interpretation with that of experts within the empirical case. This enables us to expand our understanding of both the emergent theory and the empirical case (Dubois and Gadde, 2002).

In this section we have discussed the basic research paradigm for the aggregated research in this dissertation. The following sections, sections I.3., I.4. and I.5., introduce the specific research designs of Study 1, Study 2 and Study 3 respectively.

I.3. Study 1: Customer involvement for technology-based radical innovation

Incremental innovations are improvements to existing products, services and processes. These improvements are aimed at better serving current customers' needs. Hence users are frequently consulted about and involved in incremental innovation. Customer involvement in radical innovation is a much more contested issue. Two theoretical streams seem at first sight to be arguing against customer involvement in radical innovation. We outline the basic idea of both of them below and we show that our research focus is not contradictory to them.

First, it has been observed how in large firms the demands of powerful customers drive resources away from radical innovation projects (Christensen, 1997). Current customers often prefer a better version of 'the same technology' over a 'completely new but better technology'. Since higher management's support tends to follow only after a first customer has shown his commitment to a technology-based radical innovation project, many promising innovation projects within large firms wither for lack of internal support. Quite often, frustrated members of such innovation teams form or join a new, usually relatively small, company to see the commercialisation of the technology through (Christensen and Bower, 1996). We agree that listening too carefully to current customers can have exactly this effect. Our research attempts to look beyond this mechanism by saying that not only current customers deserve a firm's attention. When innovation teams within large firms reach beyond the current customer base, as radical innovations tend to force them to, they can benefit from interacting with prospective, new industrial customers in the target market(s) (Chandy and Tellis, 1998).

Second, radical innovations often address needs that are initially present only latently. Hence one could wonder how involving a potential customer can be beneficial to an innovation process when the respective customer might still be unaware of his relevant, but latent need(s). Furthermore, a potential customer might even decide not to mention his desires because (s)he assumes they can never be fulfilled (Leonard and Rayport, 1997). Again, we agree that straightforward asking potential customers about the kind of technology-based radical innovations they would need, is a pointless exercise. Luckily, knowledge about approaching this problem differently is emerging. The lead user method is one such example (von Hippel, 1986; Herstatt and von Hippel, 1992; Lilien et al., 2002), the empathic design technique is another (Leonard and Rayport, 1997). Visiting industrial customers on-site is also regarded as a powerful tool for identifying relevant customer problems and needs (Kanter, 1997; McQuarrie, 1993; Souder et al., 1997). In this study we investigate how firms during the technology-based radical innovation process go about involving prospective industrial customers for the innovation under development.

I.3.1. Research questions

In the first place, we are eager to verify empirically whether firms involve industrial customers at all during radical innovation projects. Next, we want to learn for which activities customers are involved and how they contribute to the technology-based radical innovation process. The following research questions define the focus of Study 1:

Research question 1: “At what point in the innovation process do customer firms contribute to technology-based radical innovation?”

Research question 2: “In what ways do customer firms contribute to technology-based radical innovation?”

I.3.2. Key concepts

One important indication of the underlying learning process in this research is the gradual change in the approach to the basic problem. The innovation process and inter-firm interaction are two of the basic phenomena studied on which the theoretical perspective evolves considerably over the three studies. Here, we explicitly clarify the meaning of these key concepts for Study 1.

- Innovation process

Throughout the innovation literature there is a general focus on the supplier’s role in making innovation happen. Even in lead user research considerable attention is awarded to how a supplier can incorporate user innovations into its products and reap economic gains from offering the innovation to the larger market (von Hippel, 1988). The first study also adopts this supplier focused approach to innovation. In this study we view technology-based radical innovation as a process that is the result of a technology push from within an innovating supplier firm. Implicitly, this view sees the inventing firm as the initiator and manager of the technology-based radical innovation process.

- Customer involvement

In Study 1 we concentrate on the involvement of industrial customers in the innovation process. Hence the involvement of customer firms in a supplier's innovation process is an initial approach to inter-firm interaction. In a supplier focused approach to innovation the customer is considered an external source of information that might be relevant for the supplier's innovation process. From a supplier perspective customer involvement is an activity that is managed by the supplier. The research aim of Study 1 is to investigate at which point in the technology-based radical innovation process the supplier allows a prospective customer to participate in the innovation process and in what way the involvement of that prospective customer contributes to the supplier's innovation process.

I.3.3. Specific research methodology

For Study 1 we combined an extensive literature review with an empirical investigation of the role of customer involvement for technology- based radical innovation. The literature review served as a basis for the design of a multiple case research. The study aimed at integrating the findings from extant literature with the first-hand findings of the multiple case research.

- Multiple case research

The exploratory undertone of this study's research questions can most suitably be addressed with a multiple case design. Multiple case research is generally believed to lead to compelling and robust results. Following a replication logic (Yin, 2003), multiple cases were selected and studied to verify if the emergent theory also held under the slightly different conditions of yet another case. Only by virtue of such replication is an original finding considered worthy of continued investigation and/or theorising (Yin, 2003).

- Case selection

For the identification of cases for Study 1 we searched for technology push projects within large firms that involved interaction with industrial customers during the innovation process. Hence the firm, within which a technological invention formed the onset for an innovation project, is the focal firm.

The selection criteria applied are the following:

For the *focal firm*, we looked for large, established firms. Although initial research of the relation between firm size and innovation did not distinguish between incremental and radical innovation (Ettlie and Rubenstein, 1987; Cohen and Klepper, 1996), later work confirms that radical innovation within large firms specifically deserves researchers' attention (Chandy and Tellis, 2000; Leifer et al., 2000; Sorescu et al., 2003). Large firms provide a context that differs distinctively from that of medium sized enterprises or smaller start-up firms. This justifies a research focus on large, established firms for the study of radical innovation.

For the *radical innovation project*, we searched for technology-based projects with radically innovative potential. The technology's potential to radically innovate was assessed by the managers involved in the innovation project by means of a set of survey questions (see Appendix). In the business landscape innovation is a desirable outcome. Managers may thus, consciously or unconsciously, portray the discussed innovation as more radical than it 'really' is. We attempted to limit the influence of such potential self-report bias (Price and Mueller, 1986) by eliciting more than one opinion per case. To enable valid assessment of an impalpable characteristic as ‘radical’ it is important to describe it in objective, unambiguous and measurable terms. Hence we defined a radically innovative project as a project that is “…viewed within its firm to have the potential to offer unprecedented performance features or embody familiar features that offer the potential for five- to tenfold improvements in performance or at least a 30% reduction in cost” (O’Connor and Veryzer, 2001, p. 233). This definition combines information on the underlying technology - unprecedented or familiar technological features - with information on the market value of the technology - a five- to tenfold improvement in performance or at least a 30% reduction in cost. Additionally, we asked whether the radical innovation creates a new line of business for the inventing firm and/or for the market. Hereby we considered a technological and a market perspective as well as a micro and a macro level perspective to assess the potential to radically innovate (Garcia and Calantone, 2002).

For the *customers* involved, we only selected cases that involved interaction with industrial customers.

Because of the strategic character of the studied topic, cases were selected within companies that were not directly competing with each other. It is important that the managers involved could speak as openly as possible about the studied phenomena, without having to worry about the researcher’s potential contacts with competitors.

The above selection criteria had to be met for every case involved in Study 1. Because of the exploratory character of this Study, the cases for the multiple case study research were also selected on the basis of diversity in relevant characteristics for customer involvement in the context of technology-based radical innovation. This way the transferability of the resulting findings was improved. Hence we selected cases from various industries. We also allowed the cases to vary in terms of the stage of the innovation process they were in at the time of the research. Also, considerable effort was made to include a case of an unsuccessful technology-based radical innovation project. 'Unsuccessful' could both be seen in terms of a project that did not result in a commercial product as in terms of instances of customer involvement that were experienced as unproductive. However, we found that managers were highly reluctant to speak about negative experiences. At one time, we did get access to an unsuccessful technology-based radical innovation project that also had involved potential industrial customers. We could not convince the manager involved to cooperate in our research. He felt he had lost already too much time and energy in the project and he did not want to waste any more time talking about it.

- Data collection

For data collection we negotiated access to three large firms. Across these firms, we contacted four corporate managers to identify relevant cases and gain background information, e.g. with respect to corporate innovation strategy. We provide an overview of the number and duration of the interviews in Table I-1.

Corporate manager	Number of interviews	Total interview duration in hours	Other
mgr_1	1	3	
mgr_2	1		e-mail
mgr_3	1	1	
mgr_4	1	2	
Total	4	6	

Table I-1: Interviews for identification of cases

Table I-1 shows that three managers were personally interviewed. A fourth corporate manager was able to direct us to the appropriate cases via e-mail. In total, we were able to identify eight cases within three large firms. To guard confidentiality we can not specify how these cases are distributed across the firms. Whenever we investigated more than one case in any firm, we assured that the cases differed substantially in relevant parameters such as current innovation phase, number and type of (customer) firms involved and the purpose and form of inter-firm interaction.

Table 2 provides an overview of the interviews taken to collect data for each of the eight cases. The cases are displayed by a fictive name. Instead of listing each interviewee's specific management title we list the functional area in which his/her activities are situated in the second column of Table I-2.

Case	Interviewee's functional area	Number of interviews	Total interview duration in hours
Display Case	Business development	1	2
	Research and development	1	3.5
Laser Case	Business development	3	3.5
	Research and development	1	2
Food Test Case	Business development	2	2
Bumper Case	Business development	2	2.5
Hose Case	Business development	2	1.5
	Business development	1	1
Elevator Case	Business development	2	2
	Business development	1	0.5
Rubber Case	Business development	1	1.5
Strong Fibre Case	Marketing	1	2
Total		18	24

Table I-2: Overview of interviews per case for Study 1

- Data analysis in multiple case research

For analysis of the multiple case research in the first study we followed the logic of a ladder of analytical abstraction (Miles and Huberman, 1994, p.92) by progressing from the descriptive accounts of the interviewees, to a, by the researcher, constructed overview of interactions with customer firms and finally to a theory or model of when and how customer firms contribute to technology-based radical innovation. The method of analysis can best be described as consisting of consecutive, embedded rounds of coding. Each single case in the multiple case research constituted a case study, in which customer interaction was researched with attention for the context in which it occurred. In Study 1 every instance of customer interaction can be regarded as a critical incident. Analogue to the creation of a critical incident chart (Miles and Huberman, 1994, p. 115), we listed the instances of customer interaction chronologically per case. In a second round of coding in the within-case analyses, these incidents of customer interaction were grouped or coded along a five-phased process model (Jolly, 1997) of technology-based radical innovation. Correct interpretation of the aim of each interaction with a customer firm was of capital importance to determine the innovation phase that it reflected. This interpretation was, as much as possible, done together with the respective interviewees. The result of these two rounds of coding was a matrix that displayed customer interaction activities per innovation phase and per case. The conformity in coding across cases enabled a third round of coding in a cross-case analysis. The third round of coding followed a replication strategy (Yin, 2003). Now every interaction was analysed in terms of whether it conveyed solution or problem information to the supplier (von Hippel, 1978). These contributions were analysed per innovation phase across cases to achieve confirmation of an emergent theoretical model by replication or enrichment of the emergent theoretical model by attaining new, yet non contradictory, insights (Yin, 2003).

- Strengths and weaknesses of the specific methodology of Study 1.

We end the discussion of the specific methodology of each of the three conducted studies with a self-reflective section. We reflect on the strengths and weaknesses of each conducted study to clarify our learning experiences.

One of the weaknesses of Study 1 is that the approach to the second and third round of coding in the analysis of the multiple case research relied heavily on deduction. Each time a theoretical frame, Jolly's (1997) five-phased process model of innovation for the second round of coding and von Hippel's (1978) distinction between solution and problem information for the third round of coding, served as a point of departure for the analysis. This deductive logic resembles the positivistic influence in the research. In positivistic research traditions there is a heavy reliance on theory testing through deduction. A more inductive approach is better able to make use of the richness in qualitative case data. Second, in many multiple case research designs it is unclear how the exact number of cases was decided on. We were unable to find guidelines on this matter in extant literature. Though some authors do provide very rough estimates of the number of cases that is generally accepted for a multiple case research (Remenyi et al., 1998, p.182), they most often fail to provide a solid argumentation for the choice of a specific number of cases. Though we were also unable to provide such solid motivation for the choice of combining eight cases in the multiple case research of Study 1, we do wonder if this quantitative aspect of multiple case research could be anything more than a trace from a positivist research tradition. Our choice for multiple cases was motivated by the desire to allow for certain variation in case-specific aspects, such as innovation phase and industry, to improve the transferability of the emerging theory across different circumstances. The comparison between multiple cases and multiple experiments is often made to strengthen the logic of this argument (Yin, 2003). However, the fact remains that the limited number of cases in Study 1 can not allow for any kind of statistical generalisability. Hence what is the scientific value of the replication of a finding in yet another case? Dubois and Gadde (2002) argue that the general opinion that multiple cases and replication results in better theory than single cases is a relic of a time when situation specificity was considered a weakness. In multiple case research many of the case-specific contingencies are levelled out in favour of a general theoretical result. Researchers such as Ragin (1987) try to remedy this effect by developing techniques for qualitative, holistic comparison, e.g. with the aid of Boolean algebra.

The method applied in Study 1 has the strength of representing the results of an extensive literature review and the multiple case research in an innovation process model. This allows for proper integration of both extant and new findings concerning customer involvement for technology-based radical innovation.

I.4. Study 2: Uncertainty in customer / supplier cooperation for technology-based radical innovation

Technology-based radical innovations present such a radical change that many aspects of their development, production, adoption and use differ dramatically from 'common practice'. Hence the innovation process is subject to a high level of uncertainty. Close customer interaction has the potential to facilitate the innovation process (Vercauteren and Vanhaverbeke, 2007; Athaide et al., 1996). However the uncertainty reducing influence of such close cooperation between customer and supplier follows only indirectly from extant literature. The second study aims for a more explicit and in-depth study of uncertainty in technology-based radical innovation and the potential uncertainty reducing effect in a customer/supplier cooperative effort to realise technology-based radical innovation.

I.4.1. Research question

In Study 2 we aim to explain how customer/supplier cooperation can facilitate technology-based radical innovation. We focus on the uncertainty in technology-based radical innovation and investigate how the cooperation can reduce this uncertainty. This research focus translates into the following research question:

Research question 3: "How does customer/supplier cooperation reduce uncertainty in technology-based radical innovation?"

I.4.2. Key concepts

- Customer/supplier cooperation for innovation

Study 1 revealed that customer involvement for technology-based radical innovation can also result in a joint development effort of a customer and a supplier. Study 2 focuses on this close form of inter-firm interaction. Whereas Study 1 displayed a supplier centred approach to inter-firm interaction between a customer firm and a supplying firm, Study 2 departs from a more balanced interaction between customer and supplier in the course of the innovation process. This means that the two firms in the cooperation contribute more equally to the joint innovation process in terms of initiative, contribution and commitment than was assumed in Study 1.

- Innovation process

In Study 2 the innovation process is regarded to be a cooperative effort between two firms. The realisation of the innovation is the joint goal that motivates the firms to engage in the cooperation. The firms work hard to create a joint understanding of the challenge at hand as they learn how to learn jointly (Helper et al., 2000).

- Uncertainty

We aim to create a comprehensive understanding of uncertainty by studying three different, though complementary, conceptual aspects of uncertainty. These different conceptual approaches stem from multiple scientific disciplines. This provides a multidisciplinary character to the study. Then we investigate, in terms of each aspect of uncertainty, how customer/supplier cooperation offers opportunities to lower the uncertainty in technology-based radical innovation.

A first conceptual approach uses the firm's ability to influence the level of uncertainty as an indicator to distinguish between two types of uncertainty. Endogenous uncertainty is uncertainty that "can be decreased by actions of the firm" (Folta, 1998, p. 1010). Exogenous uncertainty "is largely unaffected by firm actions" (Folta, 1998, p 1011). This last type of uncertainty is resolved over time. In terms of this aspect of uncertainty we investigate to which extent uncertainty is within a firm's range of control and whether engaging in a customer/supplier cooperation influences the distinction between endogenous and exogenous uncertainty.

Second, we concentrate on the different areas uncertainty can relate to. In high-tech environments market and technological uncertainties are relatively well understood (Moriarty and Kosnik, 1989). In the context of technology-based radical innovation these are but two of the areas in which high uncertainty levels occur. Especially in large firms, radical innovation projects also struggle with organisational and resource uncertainties (Leifer et al., 2000). We develop the findings in extant literature further into a conceptual model of four uncertainty categories that can be relevantly interpreted both from the perspective of the customer firm and the supplier firm in a cooperation for technology-based radical innovation. We explain how inter-firm cooperation can lower uncertainty by studying the different areas uncertainty can relate to.

A third conceptual approach to uncertainty stems from cognitive science. Implicit in the above two theories is a definition of uncertainty as a lack of information. Nyström (1974) expands this notion by pointing out that it is not only the amount of information, or lack there of, that determines the state of uncertainty. Also the causal links between these pieces of information influence the level of experienced uncertainty. The author combines these two aspects in the concept of a cognitive structure. A cognitive structure is defined by its degree of differentiation in the information it contains and the causal linkages between these pieces of information.

I.4.3. Specific research methodology

- Single case research

Two components are critical in answering the research question of Study 2 adequately. One component is the conceptualisation of the meaning of uncertainty in the specific context of customer/supplier cooperation for technology-based radical innovation. This context-specific conceptualisation is important to derive a practical, as opposed to an indeterminate, meaning of uncertainty (Gubrium and Holstein, 2000, p. 491). Appropriate conceptualisation of uncertainty will enable the second component of our research, namely the theorising about the relationship between the customer/supplier cooperation process and uncertainty reduction.

To gain such in-depth insight in an abstract phenomenon as uncertainty, and, the relationship between a customer/supplier cooperation process and uncertainty reduction, a single or intrinsic case design is most appropriate (Stake, 2000). This case design allows us to study the complexity of the phenomenon, uncertainty, and of its context, customer/supplier cooperation for technology-based radical innovation, to gain a better understanding of both. In comparison to the multiple case research design of Study 1, we find that focusing research efforts on one case allows for a more refined analysis and a closer study of phenomena and relations. Furthermore, we are convinced that studying the particular implies studying the general (Denzin and Lincoln, 2000). Similarly, when studying the person Gustave Flaubert, Sartre (1971) stated "qu'un homme n'est jamais un individu; il vaudrait mieux l'appeler un universel singulier: totalisé et, par là même, universalisé par son époque, il la retotalise en se reproduisant en elle comme singularité. Universel par l'universalité singulière de l'histoire humaine, singulier par la singularité universalisante de ses projets, il réclame d'être étudié simultanément par les deux bouts[1]" (p 7). From Sartres' statement Denzin and Lincoln (2000) conclude that "no individual or case is ever just an individual or a case. He or she must be studied as a single instance of more universal social experiences and social processes. Any case will necessarily bear the traces of the universal" (p 370).

- Case selection

For the selection of a case that can serve as an empirical basis for Study 2 we took further advantage of the extensive case identification we had gone through for Study 1. For an investigation into the effect of customer/supplier cooperation on uncertainty we looked for an especially revelatory case (Yin, 2003). This would be a case in which customer/supplier cooperation offered remarkable opportunities for uncertainty reduction so we could study the phenomenon in a context where it prevails distinctively.

The study of customer/supplier cooperation in a context of radical innovation poses some additional challenges. Precisely because of the high uncertainty inherent in radical innovation it is often difficult for managers to assess the potential of any customer/supplier cooperation. Consequently, cooperative relationships may fail to live up to expectations or even be dissolved in the course of the innovation process. To avoid focusing research efforts on a customer/supplier cooperation that turns out not to contribute to radical

[1] Own translation: "that a man is never just an individual; we would better call him a singular universe: totalised and, by that, universalised by its era, he retotalises that era by reproducing it and himself in it as a singularity. Universal by the singular universality of human kind, individual by the universalising singularity of his plans, he demands to be studied from these two perspectives simultaneously"

innovation or that is dissolved during the research we selected a retrospective case.

The Strong Fibre Case meets the above requirements. The case was selected for further investigation into how customer/supplier cooperation can reduce uncertainty in technology-based radical innovation. In the Strong Fibre Case a new fibre technology is the onset for a close cooperation between the inventing firm, a raw material supplier, and a fishing net manufacturer, the customer. In the case, the radical innovation for which customer and supplier team up is the fishing net based on the new, radically innovative fibre technology. Note, that the fact that fishing net as a product existed also before this customer/supplier cooperation, does not mean that it can not be subject to radical innovation. We refer to the survey in appendix which we applied to assure that only genuine radical technology-based innovations were included in this dissertation. When discussing the case selection criteria in section I.3.3. we explained how this list of questions is based on findings in recent literature. In terms of the survey questions in appendix, we point out that though the innovation offers familiar features, i.e. fibre strength per unit of diameter applied to fishing nets, it does so at unprecedented performance levels. The best example thereof is that the largest fishing trawl in the world, that has a mouth opening of 35 800 m^2, uses the super strong fibre. No other kind of net can deliver such remarkable performance levels. Also, the technological knowledge on which this radical innovation is based was so radically different from ‘common practice’ in the industry that close cooperation with firms in the rope and net industry was necessary to integrate this radically different approach to manufacturing and using fishing nets into the market. This is why it took seven years to realise the first commercially available fishing net made out of the super strong fibre.

Furthermore, the innovation creates a new line of business for the supplier for whom the fishing industry was an unfamiliar industry before. This was also one of the criteria in the survey in Appendix.

- Data collection

For Study 2 we relied on the data collected on the Strong Fibre Case in the context of Study 1 and we undertook additional interviews as displayed in Table I-3. We strived to interview both firms in the focal dyad. In line with the crystallisation logic for triangulation in this dissertation, triangulation of sources not only served to confirm the information gained from the other source. We also aimed to reveal new aspects of the customer/supplier cooperation and its effects on uncertainty with every additionally consulted source of information.

Firm	Respondent's functional area	Number of interviews	Total interview duration in hours	Other
Supplier	Marketing	1	3	
Customer	General manager	1		e-mail
		2	0.25	telephone
Total		4	3.25	

Table I-3: Additional interviews Strong Fibre Case

Since the customer firm is located in Iceland we had to rely on means of communication other than personal interviewing for data collection. Main tool for requesting and receiving information was e-mail, preceded and followed up by telephone contact. In the course of the research we were able to negotiate permission to reveal firm and product names of the two focal firms in the research. This further increased the trustworthiness of our data.

- Data analysis

A first step in the case analysis entailed developing a context-specific conceptualisation of uncertainty. For this purpose, the three conceptual aspects of uncertainty that were identified from different fields of study were applied deductively to the case. In multiple rounds of deductive and inductive reasoning (Dubois and Gadde, 2002) these different aspects of uncertainty were applied to and interpreted in the context of the case. This resulted in a theoretically relevant and empirically valid conceptualisation of uncertainty in terms of each of the different, but complementary, aspects of uncertainty.

In a second step in the case analysis, we investigated how the process of customer/supplier cooperation affected each of these aspects of uncertainty. Interpretation checks with the interviewees were an important part of this step in the analysis. During these iterations between case interpretation and data collection important, detailed aspects of the customer/supplier cooperation and its circumstances were revealed by the interviewees. This additional round of data collection improved the empirical grounding of our analysis considerably.

- Paper structure

Chapter III contains the paper that reports on Study 2. The paper structure displays aspects of both deductive and inductive approaches to the case analysis. The three conceptual aspects of uncertainty were applied deductively to the case context. We first explored the different aspects of uncertainty before going into the case. This deductive method of analysis is also reflected in the paper structure. The three conceptual aspects of uncertainty are introduced before the case. After the case is included in the paper, we return to the various aspects of uncertainty. Then we discuss the development of a conceptualisation of uncertainty that is relevant in the context of customer-supplier cooperation for technology-based radical innovation. This context-specific conceptualisation then serves as a basis for theorising about the uncertainty reducing effect in customer/supplier cooperation for technology-based radical innovation.

From the case analysis follows inductively that governance issues in the customer/supplier cooperation are a remarkable aspect of the case. Because this topic is closely linked to the uncertainty in customer/supplier cooperation for technology-based radical innovation, it is appropriate to discuss this matter in the same paper. We devote a separate section to the discussion of governance in customer/supplier cooperation for technology-based innovation. In the paper, we add this section after the case to emphasise the inductive nature of the presented insights.

- Strengths and weaknesses of the method

When reflecting on the strengths and weaknesses of the methodology applied in Study 2 we identify the fully retrospective nature of the empirical case as one of its weaknesses. Due to the retrospective nature of the case the interviewees experienced limited recall of some of the phenomena and circumstances that we aimed to study. At the same time, the fully retrospective nature of the case also had a positive effect. Thanks to the fully retrospective nature of the empirical case the interviewees did not object to disclosure of their firm and product names. Since the innovation process was completed and the innovative product, i.e. fishing net made of the super strong fibre, was commercially available in the market the interviewees saw no reason for anonymity. This openness increased the credibility of the case which is a strength of the study. Concentrating our efforts on the full development of a single case study resulted in considerable more depth in this empirical case compared to each of the eight cases in Study 1. This depth is another strength of Study 2. However, the method of analysis with its strongly deductive starting point is considered a weakness in single case research. This weakness was compensated for by developing a context-specific conceptualisation of uncertainty in multiple rounds of deduction and induction.

I.5. Study 3: Business networks in technology-based radical innovation

In Study 2 the supplier interacted also with firms other than the customer firm that he was closely cooperating with. These other firms contributed as well to the innovation process in the dyadic customer/supplier cooperation. Therefore we broaden the scope of our study of inter-firm interaction for technology-based radical innovation in Study 3 to investigate the role of networks of firms in the innovation process.

Radical innovations entail a radical change compared to a current situation. In technology-based industrial markets realising this radical change has far-reaching consequences. The technology-based radically new product is likely to not only affect the products and infrastructures that it directly interacts with. It also becomes part of a larger system of customers and suppliers of complementary products, processes and technologies that may have to adapt to the indirect consequences of the technology-based radical innovation (Rosenberg, 1982). Every firm's current economic activity is the result of a long technological trajectory (Dosi, 1982) and is manifested in the firm's productive system. These productive systems are the cumulative result of large investments in infrastructure, equipment and organisational routines. Hence every firm is constrained in its potential options for the future by investments made in the past (Dosi et al., 1990). For any radical innovation to have value in an industrial market it has to become embedded into these current intricate productive systems in an economically valuable way. Hence the development process of a technology-based radical innovation is closely linked to the use process of the innovation in the productive systems of the target customers for the innovation under development (Håkansson and Waluszewski, 2007). Realising a technology-based radical innovation entails not only matching a new technology-based product to already existing products and infrastructures that it needs to fit into. These existing products and infrastructures are also controlled in organisational systems that are strongly interrelated according to a dominant business logic. In Study 3 we aim to investigate the resource interfaces between such technological and organisational resources to determine how networks of firms are involved in technology-based radical innovation.

I.5.1. Research question

For Study 3 research activities concentrate on finding an answer to the following research question:

Research question 4: "How are networks of firms involved in technology-based radical innovation?"

I.5.2. Key concepts

- Network

For Study 3 inter-firm interactions are studied in the broader context of the network in which they take place. In analogy with Håkansson (1987) we define a network as a set of two or more connected relationships. Such networks are the result of inter-firm cooperative and exchange behaviour that can take on many forms. The network that originates is a complex constellation of firms that are directly and indirectly linked to each other. When we take business networks into account we acknowledge that no firm acts as an autonomous, independent unit (Håkansson and Snehota, 1989). Similarly, the innovating firm is also part of a network of interrelated firms.

- Innovation process

Though we still define a technology-based radical innovation project from the perspective of the inventing firm, we aim to present a more complete view of the innovation process by linking it to the business network in which it is situated. For an innovation to have commercial value it has to be embedded in the technological productive systems of its target customers. In a network perspective on innovation, the innovation process consists of investigating and adapting the resource interfaces that enable the embedding of the innovation in industrial target markets in an economically valuable way.

I.5.3. Specific research methodology

- Longitudinal single case research

For addressing the research question of Study 3 we opted again for a single case research design. This allows us to concentrate our efforts on gaining in-depth understanding of the complex issue of business networks in the context of technology-based radical innovation. A longitudinal follow-up of a technology-based radical innovation project would offer most valuable opportunities to capture the specific link between the innovation process and a network of firms.

- Case selection

The empirical case for Study 3 is selected from the set of cases studied in Study 1. We identified the Laser Case only 6 months after the initial technological discovery was made. Hence this case provided an opportunity to collect data on processes while they were practically ongoing. The technology on which the case is based is a new laser additive technology with radically innovative potential. In the Laser Case a team of technical staff and a business development manager interact with a large variety of firms in multiple application industries. Hence the case provides ample opportunities to study how these networks of firms were involved in the innovation process.

- Data collection

For Study 3 we continued data collection on the Laser Case. For investigation of the role of the business network in technology-based innovation we completed the interview data listed in Table I-1 with additional interviews as displayed in Table I-4. The firm in which the base technology was invented was considered the focal firm. Because we aimed to study the business network we complemented interviews with managers of the focal firm with interviews with managers from firms in the focal firm’s network, firms X, Y and Z. Because of their interrelatedness all the firms that cooperated in the research requested strict anonymity. Nevertheless we can add that firm X is a laser supplier, firm Y a raw material supplier and firm Z an end user of laser additives. Managers in some of these firms had to be interviewed by other means than personal visits because of the geographical distance involved. The interviews for the Laser Case listed in Tables I-1 and I-4 took place in the period from December 2003 until September 2007.

Firm	Respondent's functional area	Number of interviews	Total interview duration in hours	Other
focal	Business development	2	3.5	
	Research and development	1	0.5	
X	Marketing and sales	1	2	
Y	Business development	1		e-mail
		1	0.66	telephone
Z	General manager	1	0.33	telephone
Total		7	7	

Table I-4: Additional interviews Laser Case

- Data analysis

The purpose of our data analysis was to track the resource interfaces that were most relevant for the innovation process in order to reveal how networks of firms were involved in the innovation process. We made use of a research tool named the 4R model (Håkansson and Waluszweski, 2007, p. 17). 4R refers to the four basic kinds of resources that the model is based on. Two of these are of a technological nature. The other two are organisational resources. The technological resources are products and facilities. Organisational units and organisational relationships are the organisational resources.

For enabling a sound analysis of the involvement of networks of firms in the process of building a business from a new laser additive technology we applied an embedded case design to the Laser Case (Yin, 2003). This means that within the single case, embedded sub units of analysis were identified with the aim of improving the depth and quality of the overall single case analysis. Since the main unit of analysis in the Laser Case is the process of developing a business from the innovative laser additive technology, sub units of analysis should be sub processes of this main process. In the main process the four basic kinds of resources played on important role. The technology-based radical innovation is a new ***product***, i.e. a laser additive, which needs to be embedded into existing production systems that mark polymers with the aid of laser ***equipment***. Before the polymers can be marked, the raw material is processed in several ***organisational units*** that are linked in inter-firm ***relationships***. The four basic kinds of resources directed our identification of four sub units of analysis. For the inductive identification of the four sub processes we coded and recoded the different activities in the case until four logical sub processes emerged. During the coding it was crucial that the context of the activity was taken into account to determine to which sub process it belonged. Customer trials with the innovative product, for example, could be conducted for at least two aims. One aim could be to generate customer feedback that served as input for the product development process. Another aim of a customer trial could be to test compatibility between the product and the customer's productive system as a first step in the sales process. Hence context-specific interpretation of activities and events was crucial during this coding process. For the coding itself we highlighted activities with one particular colour per sub process in the interview transcripts. Once the sub processes were defined, we established a chronological account of the inter-firm interactions per sub process in an Excel sheet[2]. This document served as a basis for the analysis. The sub processes that we identified are product development, equipment development, sales generation and growth in terms of geographical areas covered and the number of technological applications realised. The first two processes are closely linked to

[2] This document can not be disclosed for reasons of confidentiality.

the technological resources in the 4R model: product and equipment. In the next two processes organisations and organisational relationships are important resources for generating sales and for enabling growth in market scope.

In an embedded case design, the analysis started with analysing the resource interfaces per sub process. The chronological account of inter-firm interactions in the Excel sheet was an important tool for identifying the critical resource interfaces in each sub process. Per sub process we identified the managers directly involved in the interactions listed on the sheet. They were important sources to find out from 'why was this specific interaction set up?'. This is how we identified the aim of an interface. We systematically compared this direct information to the possible resource interfaces in terms of the 4R model to identify the critical resource interface that matched the aim of each interaction. The identification of technological resource interfaces was relatively clear because of the physical nature of these resources. Organisational interfaces had a more abstract nature, though interviewees often mentioned explicitly when they were approaching an organisation for gaining access to its relationships. The information gained in the interviews was often corroborated by the information in internal intermediate reports and business presentations. In three inter-firm interactions we were also able to directly investigate the purpose of the resource interfaces from the perspective of the firm in the network – see firms X, Y and Z in Table I.4.. Every time a relevant resource interface was identified, further probing into the further progress of the sub process in the inter-firm interaction was continued to find out about any additional critical resource interfaces in the interaction and their aim. It is important to note that it was the logic in the sub processes themselves that guided the identification of critical resource interfaces and the number of critical resource interfaces identified. This enabled us to study the involvement of networks of firms in each sub process in a meaningful way. This is the kind of true induction that makes use of the richness available in a longitudinal single case research.

After analysing the resource interfaces in each of the sub processes we integrated the results of these four analyses to return to our main unit of analysis: the process of building a business from a technology with radically innovative potential. The networks revealed in this analysis were not 'just' relationships between firms, they were the ensemble of inter-organisational links that made the resource interfaces possible that enabled the technology-based radical innovation process.

- Paper structure

The paper structure resembles the inductive nature of the case design in Study 3. This is already clear in the introduction of the problem in the first section. In Study 1 an elaborate literature review was an important means to justify the research focus, which is a deductive approach to problem definition. In contrast, in Study 3 the most important justification for the research focus lied in the complexity of the problem itself. This is an inductive approach to problem justification. We also refrained from writing elaborate theoretical discussions before introducing the case to signal that we did not apply a deductive approach to the case analysis. In such a deductive approach to case research the case is predominantly used as an illustration of theory. We added theoretical discussions after the case to stress that the case served as an inspiration for, rather than an illustration of, a theory of the involvement of networks of firms in technology-based radical innovation (Siggelkow, 2007).

- Strengths and weaknesses of the method

In this final paragraph of the discussion of the specific methodology of Study 3 we reflect on its strengths and weaknesses. Because the innovation process was actually in progress while studied, the managers involved requested strict anonymity to avoid leakage of information that could harm the innovation process. For similar reasons we experienced relatively limited openness in interviews with firms in the network of the focal firm. This limited openness was also due to the interrelatedness of the interviewed firms. Nevertheless, the longitudinal character of the case study provided the genuine richness that Weick (2007) refers to. Richness entails "preservation of disorder and confusion" (p. 17). Applied to the Laser Case, richness lies in also taking into account those actions that did not prove as fruitful as they initially were believed to be, in order to observe how the interviewees eventually did find a way to achieve their aims. This not only resulted in a more realistic case description, but also in a more truthful analysis. These are important strengths of Study 3 because they improve the transferability of the research results. Though statistical generalisability is an important aim in quantitative research, it is not the aim of qualitative case-based research. Case-based research aims for richness in the empirical material to enable case-to-case transfer of the developed concepts, theories and/or described relations (Firestone, 1993). We, the researcher/sender, provide rich descriptions so the reader/receiver can compare with his/her own context to assess whether transfer of the research results is appropriate (Hammersley et al., 2000). This type of generalisation is also termed *naturalistic generalisation*. Single-case research is a powerful means for generalisation based on personal direct and vicarious experience (Lincoln and Guba, 2000). If "you want people to understand better than they otherwise might, provide them information in the form in which they usually experience it. They will be able, both tacitly and propositionally, to derive naturalistic generalisations that will prove to be useful extensions to their understandings" (p. 36).

I.6. Conclusion

In this chapter we have introduced the research strategy of this dissertation. The dissertation is composed of three studies that investigate the role of inter-firm interaction in technology-based radical innovation. This is the central problem that connects the three studies. During the research we learned about both the research problem and research methods. This learning process had a significant influence on the variation in the three studies in terms of research topic, theory and method. Though chapter V is devoted to the results of this dissertation, it is important to clarify up front how the research results of Study 1 contributed to the problem definition in Study 2 and, similarly, how the results of Study 2 affected the approach to the central problem studied in Study 3. The key concepts in each of the three studies, namely 'inter-firm interaction' and 'the innovation process' reflect a learning process. In **Study 1** we followed a more traditional supplier centred approach to innovation. The investigation of inter-firm interaction was limited to identifying and analysing instances of interactions with customer firms during the supplier's innovation process. Study 1 revealed that such interaction with a customer firm can also take the form of a close cooperation with a joint aim. Therefore the theoretical approach to inter-firm interaction and innovation evolved in Study 2. In **Study 2** the innovation process is seen as a joint effort of a customer firm and a supplier firm. The inter-firm interaction between the two firms in the cooperation process is a more balanced interaction in terms of initiative, contribution and commitment. In the empirical case in Study 2 we noticed that inter-firm interactions outside the focal dyad also contributed to the innovation process in the customer/supplier cooperation. This motivated us to investigate in Study 3 the role of business networks in innovation. In **Study 3** the innovation process is a process of embedding a new technological product in the existing technological and social systems in target markets. The innovation process is a process of identifying, investigating and adapting resource interfaces in networks of firms to enable the fit of a technology-based innovative product in industrial markets in an economically valuable way. Inter-firm interactions are now seen as interrelated dyadic links that mutually influence one another in a network of firms.

The learning process across the three studies is also reflected in the evolution of the applied research methods. The central research aim guided us towards a qualitative case-based research methodology against a critical realist ontological background and an interpretivist epistemology. Nevertheless, comparison of the specific methodologies of the three studies reveals that we also underwent a learning process before we were able to actually apply this research paradigm in all the aspects of research. **Study 1** showed definite traces of a positivist influence. **Study 2** can be regarded as a mixed form between the deductive tradition and an inductive approach to case research. **Study 3** resembles the research paradigm that combines a critical realist ontology with an interpretivist epistemology best in a more truly qualitative way of doing research. The evolution in research methodology can be summarised in terms of the approaches to problem justification, case analysis, research results and paper structure.

Study 1 relied strongly on extant literature for the justification of a research focus on customer interaction for technology-based radical innovation. This reflects the emphasis on deduction in the positivist research tradition. **Study 2** relied on a mix of deductive and inductive reasoning to justify its research focus. References to extant literature were added to the extent that they illustrated the relevance of the research focus, which is a deductive approach to problem definition. The research focus was also justified by discussing the complexity of the problem itself, which is an inductive approach. In **Study 3** the research focus was justified in a discussion of the complexity of an innovation process that involves a network of firms. Here the nature of the research problem itself was the main reason for justifying its investigation. This reflects the importance of induction in the research paradigm of this dissertation.

This shift of emphasis from deduction to induction can also be observed in the analyses in the three studies. Closely related to this shift, is the change in the kind of research results across the studies. The analysis in **Study 1** applies theoretical frames deductively to a multiple case research of eight cases to generate a theoretical model of how and when customers contribute to technology-based radical innovation. Though the deductive approach in the analysis does improve the comparability of the eight cases in the cross-case analysis it also largely ignores the specific contingencies in the cases. The result of the analysis is a relatively general theoretical model in the sense that it has limited depth. However, this is partially compensated by the fact that the model reflects the role of customer interaction across the complete innovation process in a meaningful way. Nevertheless, it is important to be aware of the fact that the relatively large number of cases used in Study 1 is not to be interpreted as any kind of approximation of statistical generalisability. In **Study 2** the analysis combines a deductive with an inductive logic. Uncertainty is an important concept in Study 2. For the conceptualisation of uncertainty we build on different conceptual aspects of uncertainty that are applied deductively to a single case. In consecutive rounds of induction and deduction these general conceptual aspects of uncertainty are interpreted in a way that is relevant for the context of customer/supplier cooperation for technology-based innovation. The theoretical part of the analysis uses this context-specific conceptualisation of uncertainty as a starting point for an analysis of the uncertainty reducing effect in the customer/supplier cooperation. In terms of research results some of the, deductively derived, aspects of uncertainty turn out to have weaker explanatory value than others. The link between uncertainty and governance issues in customer/supplier cooperation for technology- based radical innovation is a more truly inductive finding of the research. The longitudinal case in **Study 3** allows for a rich account of the involvement of networks of firms in the innovation process. The analysis is driven by an inductive logic that creates depth in the research results by taking into account the complexity in the specific context of the studied phenomena.

The paper structure of **Study 1** mirrors the emphasis on deduction by discussing the theoretical framework before the analysis. In **Study 2**, theoretical discussions and problem-related references to extant literature are included in the paper before the case when they are applied deductively to the case, and after the case when they were the result of inductive reasoning. In **Study 3** the inductive nature of the analysis is reflected in the paper structure by adding theoretical discussions after the case.

The dissertation now proceeds with three chapters that can be read and interpreted independently. Chapters II, III and IV report on Studies 1, 2 and 3 respectively. The closing chapter, chapter V, focuses on the contributions of the studies with respect to answering the central research question. Chapter V also discusses directions for further research and managerial implications.

CHAPTER II

WHERE'S THE CUSTOMER IN TECHNOLOGY-BASED RADICAL INNOVATION?

Abstract

There is a growing understanding of the importance of customer involvement in bringing radical innovations successfully to the market. In this chapter, we analyse 'when' and 'how' industrial customers can facilitate technology-based radical innovation. For this purpose, we combine a literature review with a comparative case study research comprising eight empirical cases. For management theorists, the presentation of extant findings in a process model allows integration and coherent interpretation of current literature. In addition, the empirical research provides an improved understanding of the way customers contribute throughout the innovation process. For managers, the overview of existing findings in the literature gives an indication of the benefits and difficulties of involving customers in the development and commercialisation of technology-based radical innovations. The empirically observed range of activities involving customers shows that managers are aware that customer involvement can facilitate technology-based radical innovation.

II.1. Introduction

In an increasingly competitive environment, innovation is perceived as a promising way to realise competitive advantage. Several authors argue that radical innovations are critical to long-term success, although incremental innovations allow firms to stay competitive in their current business (e.g. Utterback, 1994; Leifer et al, 2000). Many firms understand that message and dedicate a significant share of their resources to research and development in pursuit of technological discoveries with radically innovative potential. However, the mere fact of having innovative technologies in-house is no guarantee for creating and sustaining a competitive advantage in the market. Matching technological features with real customer needs is the key challenge in technology-based innovation.

Research shows that technology-driven firms have the most to gain from combining their technological skills with a market orientation (Zhou et al., 2005; Dutta et al., 1999). Technological know-how needs to be complemented with a deep understanding of customers' needs and usage situations, their habits and problems (Leonard and Rayport, 1997). Research shows successful examples of incorporating such customer knowledge into technological innovations by actively organising for customer involvement (e.g. Kanter, 1997; McQuarrie, 1993; Souder et al., 1997). For incremental innovation, the importance of customer input is well understood. A growing body of research confirms that also radical innovation can benefit from customer involvement (e.g. Lukas and Ferell, 2000; Atuahene-Gima et al., 2005). Though there is a clear understanding that management of radical innovation differs from incremental innovation, many questions remain. In a radical innovation context, the supplier can experience difficulty in conveying the benefits of a new technology to customers. Unfortunately, this phenomenon holds in two ways: since radical innovations often address latent needs, it may be equally difficult for a customer to recognise a technology's value for his usage situation. Because of the important technological component, we rule out any possible role for private consumers in technology-based radical innovation. We assume consumers possess neither the technological nor the market knowledge to contribute to radical innovation. However, even when focusing on industrial customers, numerous issues render the cooperation for radical innovation an exceptionally demanding task. The radical innovation process is long and investment-intensive, technologically complex and highly uncertain.

This chapter aims to clarify when and how industrial customers can facilitate technology-based radical innovation. The research aim holds the implicit assumption that we expect the potential for customers to contribute to radical innovation to vary across the innovation process. This is why we start the research with the identification of a suitable process model to represent the technology-based radical innovation process. We use this process model as a tool to demarcate when industrial customers can contribute to radical innovation and how this contribution changes throughout the innovation process. To analyse at which moments and how customers can contribute we combine a literature review with insights from multiple case study research. This combination of methods has several advantages. First, the literature review, providing an overview of current findings, serves as a preparation for designing the multiple case study research. Second, by combining results from a literature review with empirical research we achieve a more complete understanding of how customer involvement contributes to radical innovation.

The chapter is organised as follows. In the second section we describe a process model and motivate the choice for it. Next, we present the results of a literature review focusing on existing insights relating to customer involvement in technology-based radical innovation. In the fourth section, we elaborate on the empirical research. We start by outlining the research strategy and then proceed to discuss the analysis and results. The fifth and final section consists of a concluding analysis in which the results of the literature review and the case-based research are integrated. Here, we summarise the main contributions and outline directions for further research.

II.2. A process model for technology-based radical innovation

In this section, we describe a model for the technology-based radical innovation process. This process model allows us to represent the results of the literature review and empirical research in a meaningful way. Moreover, it facilitates the integration of the results in the final section of the chapter.

Jolly (1997) developed an instructive model for technology-based innovation. Figure II-1 shows how he uses five overlapping circles to depict five sub processes in the innovation process. Where the circles overlap, he indicates how to build the bridges for transition to the next sub process.

This model has several advantages over other types of models. One advantage over the sequential stage-gate models (e.g. Cooper, 1990; Cooper 2006) is that it allows for iteration, as indicated by the arrows on each circle in Figure II-1. In the context of radical innovation, high uncertainty levels necessitate a management approach with flexibility and iteration (MacCormack and Verganti, 2003; Lynn et al., 1996). Stage-gate models are also known for applying traditional market research techniques to incorporate a marketing focus. When technologies with radically innovative potential are involved, such techniques do not provide the needed information (O'Connor, 1998; Deszca et al., 1999).

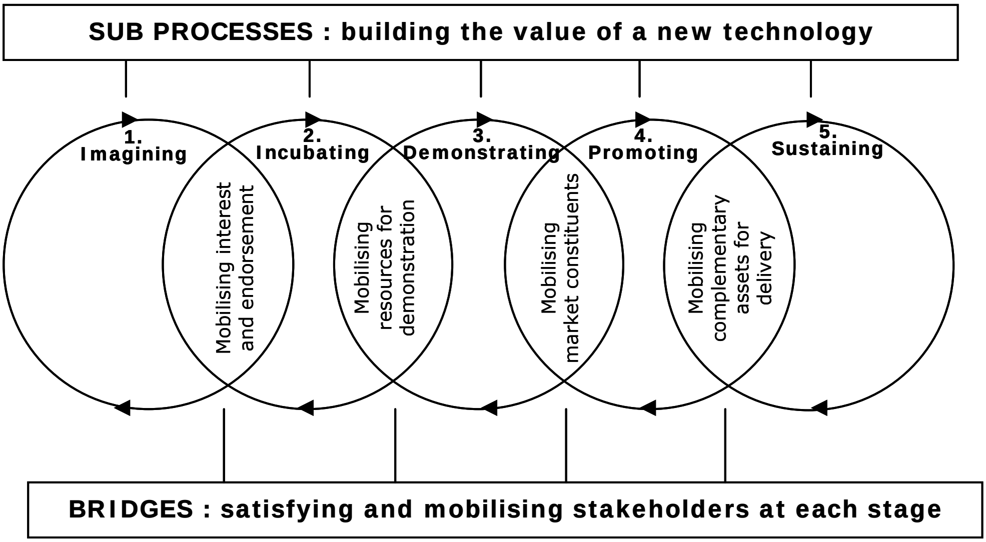

Figure II-1: Process model for technology-based innovation (Jolly, 1997, p.4)

Another advantage of the work of Jolly is that he refers to more appropriate ways to integrate a market orientation such as intensifying contacts between researchers and the market. Because of the important technological component, we could also consider adopting a process model based on the concept of a technology life cycle curve (e.g. Anderson & Tushman, 1990; Millier, 1997; Moore, 1995; Tushman and Rosenkopf, 1992; Utterback, 1994). These models show a rather weak link to the underlying management activities. Another strength of the Jolly model is that it is embedded in a management context. This facilitates the transfer of knowledge from practice to theory and vice versa.

For our purpose, we apply a simplified version of the model in Figure II-1. We concentrate on the five sub processes[3]:

1. *Imagining* a technological application linked to a market opportunity,
2. *Incubating* the technology by defining its added value
   in customer relevant terms,
3. *Demonstrating* the technology contextually in products and processes,
4. *Promoting* adoption of the new technology inside the firm and in the market,
5. *Sustaining* commercialisation to realise long-term value.

II.3. Literature review

In this section, we present the results of the literature review. We focus on the marketing and management literature since these research streams have been discussing the customer's role in technology-based radical innovation. We used three criteria to assess the relevance of each article. In the first place, we are interested in contributions that explicitly discuss the interaction with industrial customers. Second, findings have to be applicable to a situation of radical innovation. Third, we focus on technology-based innovations within large firm.

[3] Findings concerning the bridging activities are included in the preceding sub process.

Findings	Authors	Research topic	Conceptual (C) Emprical (E)
1. Imagining the techno-market insight			
Customers play little if any role in visioning radical innovations.	Mascitelli (2000)	Tacit knowledge and breakthrough innovation	C
	O'Connor and Veryzer (2001)	Market visioning for radical innovation	E (11 cases)
Opportunities are most often recognised by low to mid-level research managers.	O'Connor and Rice (2001)	Opportunity recognition and breakthrough innovation	E (12 cases)
Carefully selected lead users can come up with radical innovations.	Lilien et al. (2002)	Lead user idea-generation	E (47 cases)
2. Incubating to define commercialisability			
Relying on current customers for defining radical innovations can be misleading.	O'Connor (1998)	Market learning and radical innovation	E (8 cases)
For breakthroughs: do not ask customers what they want,	Day (2002)	Market learning	C
but uncover their latent needs (e.g. by observation).	Leonard and Rayport (1997)	Innovation through empathic design	C
Alliances with key customers provide feedback and internal justification.	McDermott (1999)	Managing radical product development in large firms	E (7 cases)
	Moriarty and Kosnik (1989)	Market and technological uncertainty in high-tech	C
3. Demonstrating contextually in products and processes			
There is a need to work closely with customers in the product development process of radical innovations, even though customers might attempt to negotiate exclusivity and joint patent ownership.	O'Connor (1998)	Market learning and radical innovation	E (8 cases)
	Stump et al. (2002)	Seller-buyer NPD for customised products	E (survey n=296)
Iterative prototyping creates a visible focus for customer involvement and exchange of tacit knowledge.	Mascitelli (2000)	Tacit knowledge and breakthrough innovation	C
New technologies allow cheap and quick experimentation.	Thomke (2001)	Experimentation for innovation	C
Learn from probing markets with early prototypes.	Lynn et al. (1996)	Probe and learn process for discontinuous innovation	E (4 cases)
Lack of familiarity with radical innovations negatively influences customers' evaluation of prototypes.	Veryzer (1998)	Evaluation of discontinuous new products	E (7 cases)
4. Promoting adoption			
Provide pre-launch information to arouse interest in the market.	Easingwood and Koustelos (2000)	Marketing high-technology	C
Customers need to be educated for technology-based radical innovations.	Rice et al. (2002)	Transition to operations	E (12 cases)
	Stump et al. (2002)	Seller-buyer NPD for customised products	E (survey n=296)
Large organisations are more likely to adopt technology-based radical innovations.	Dewar and Dutton (1986)	Adoption of radical and incremental innovations	E (survey n=40)
5. Sustaining commercialisation and realising long-term value			
Initially, pursue many small applications to educate potential users about the new technology.	Rice et al. (2002)	Transition to operations	E (12 cases)

Table II-1: Customer involvement for technology-based radical innovation: literature review

Table II-1 shows how we use the five-phased process model to structure the results of the literature review. It gives a first indication of when and how customer involvement facilitates technology-based radical innovation.

According to extant literature, <u>imagining</u> a commercial application for a technology is in the first place an introspective process with little if any customer contact (Mascitelli, 2000; O'Connor and Veryzer, 2001). Radical product ideas are most often conceived by research managers that combine technological and market knowledge with a lifetime of experience (O'Connor and Rice, 2001). Notable exceptions are the product ideas generated by lead users (Lilien et al., 2002). We emphasise that lead users are identified by applying the four steps that comprise the lead user method and that they are not necessarily current customers or target customers for the product ideas they help to identify. We mention them for the sake of completeness, but we do not research lead users. In contrast, we concentrate on when and how industrial target customers for the innovation under development can facilitate the innovation process.

During the <u>incubating</u> phase, current customers are not necessarily a good audience to define the added value of new technologies (O'Connor, 1998). Day (2002) also finds that straightforward asking current customers' opinion about a radical product idea is destined to produce misleading results. Especially when current customers have a comfortable market position, they will tend to hold on to the technologies they have in use. When defining the commercial value of radical innovations, it is crucial to apply techniques appropriate for uncovering latent customer needs (Leonard and Rayport, 1997). Often, customer feedback is gained in close cooperation with a candidate customer (McDermott, 1999; Moriarty and Kosnik, 1989).

When demonstrating the radically innovative technology in products and processes the customer is involved in the development activities in order to reveal relevant needs and requirements (O'connor, 1998; Stump et al., 2002). Prototypes serve as tangible vehicles for customer involvement, sharing of tacit knowledge and joint problem solving (Mascitelli, 2000). Especially with the new technologies available, quick and frequent experimentation is possible (Thomke, 2001). In extremis, early prototypes can be launched in the market to learn from customer reactions (Lynn et al., 1996). At least two phenomena complicate customer involvement in this phase. First, when evaluating prototypes, customers' lack of familiarity with radical products can take the form of resistance. Veryzer (1998) explains how shortcomings in the product-user interface and aesthetics negatively influence customer evaluations. He suggests inclusion of marketing research personnel in testing activities to help reveal the right information. Second, joint problem solving can result in customers demanding exclusivity or joint patent ownership. In such situations, it is crucial that these negotiations do not slow down the development process.

For promoting adoption of the technology-based radical innovation, pre-launch information is distributed to arouse customer interest (Easingwood and Koustelos, 2000). Technology-based radical innovations require customers to be educated about the underlying technology and the innovation's relative advantage for them as well as for their customers. Customers also need to be trained for appropriate product usage (Rice et al., 2002; Stump et al., 2002). Dewar and Dutton's study (1986) shows that large organisations are more likely to adopt radical innovations.

Finally, for sustaining commercialisation and realising long-term gains a market development plan is required. Especially large firms with a broader resource base, like the ones we concentrate on in this chapter, might be able to pursue multiple applications that will enhance understanding of the underlying technology's potential within the firm and in the market (Rice et al., 2002). For each additional application the five-phased process might start all over again with customers from completely different industries.

The literature review extends the current body of knowledge by showing how each individual piece of research on customer involvement relates to the technology-based radical innovation process as a whole. This exercise results in two contributions. First, the literature overview gives a clear indication how the potential for customers to contribute to the innovation process varies across the different phases. Second, the most important benefits and risks of involving customers in radical innovation are listed according to innovation phase. More specifically, Table II-1 shows that the potential for customer involvement is relatively low in the early phases of radical innovation and that tailored methods are required to prompt needed information e.g. lead user method (Lilien et al., 2002) and empathic design techniques (Leonard and Rayport, 1997). When products start to materialise, the need for customer involvement increases; though it remains crucial to be aware of the difficulties customers experience when evaluating radically new product prototypes. Next, customers need to be educated about the technology-intensive product or process to facilitate adoption. Finally, throughout the interaction with customers and other market constituents, the market is scanned for additional application possibilities to assure the technology delivers long-term gains.

From Table II-1 we also conclude that, although a limited amount of research concentrates on customer involvement for technology-based radical innovation, there exists a balance of conceptual and empirical studies. This is the case for the innovation process as a whole, as well as for each phase separately. The fact that empirical observations corroborate the theoretical contributions strengthens confidence in the validity of the overview in Table II-1.

II.4. Customer involvement for technology-based radical innovation: an empirical investigation

In this section we discuss the results of the empirical investigation. The literature study shows that the need to involve customers and the way how to do this vary across the different innovation phases. We conduct a case-based research aimed at providing a better understanding of when and how industrial customers can contribute to technology-based radical innovation.

II.4.1. Methodology

There are several reasons for opting for case-based research. First, it is crucial for the validity of the findings to ensure that the data are gathered in technology-based projects of a genuine radical nature. Case-based research allows us to carefully select appropriate innovation projects. Furthermore, we study customer involvement in relation to the radical innovation process. Case study research enables us to investigate a phenomenon in relation to its context (Yin, 2003).

II.4.1.1. Case selection

We selected cases that meet three criteria. First, they are cases of technology-based radical innovation. Second, they are situated within large firms. Third, industrial customers are actively involved in the innovation process. These three criteria are held constant across all cases to ensure comparability and validity of the results. We analyse multiple cases in various industries that are currently at various stages of the innovation process. This variety is required to improve the robustness of the results. The sample consists of eight cases identified within three large firms. Base technologies of the cases are electronics, metal transformation and chemicals. Application industries are as diverse as the automotive, consumer electronics and industrial fishing (see Table II-2). Names of the cases are fictive, the information remains unaltered.

Case	Base technology	Application industry
Display Case	Electronics	Consumer electronics
Laser Case	Chemicals	Laser marking
Food Test Case	Chemicals	Food testing
Bumper Case	Advanced metal transformation	Automotive
Hose Case	Advanced metal transformation	Oil transport
Elevator Case	Advanced metal transformation	Construction
Rubber Case	Chemicals	Bulk chemicals
Strong Fibre Case	Advanced materials	Industrial fishing

Table II-2: Cases of technology-based radical innovation

II.4.1.2. Data collection

For data collection we relied mainly on personal interviews with managers. Corporate managers provided contextual information and helped identify relevant cases. Per case, managers that participated in activities involving customers, were interviewed for more detailed information. These respondents could be business development managers, marketing managers or technical staff of the innovation teams. Usually, there were in-depth interviews with two managers per case. In these semi-structured interviews, the respondents were asked to go over the innovation process and point out when and for which activities customer firms were involved in the innovation process and how these customer firms facilitated the innovation process. All interviews were transcribed for analysis following Miles and Huberman's (1994) guidelines. The collected interview data was complemented with secondary material such as intermediate business plans and corporate presentations.

II.4.2. Within-case analyses

Under this heading we discuss the eight cases that make up the empirical data. First, we investigate customer involvement for radical innovation in each case independently. We structure findings to the five-phased innovation model to enable cross-case comparison in the next step of the analysis.

We introduce the cases in short case descriptions – see Box II-1. Per case, we describe the base technology, the innovative technological application studied and the industrial customer(s) involved. Though we are aware that innovation occurs in interaction between firms and not within one firm (Håkansson, 1987), we will for the sake of simplicity refer to the large technology-driven supplier firm as the innovating firm.

Display Case. A large electronics company gains access to a radical display technology. The main business propositions of the new display are its resemblance to paper, resulting in improved readability, and its low energy use. The innovating firm regards it as a promising substitute for paper books and journals, the so-called e-book. The application is developed in a joint arrangement with an industrial customer, an original equipment manufacturer.

Laser Case. The discovery of a chemical that enables high quality laser marking independent of the characteristics of the polymer in which it is used, opens up new business opportunities. Interactions with raw material suppliers and firms that apply laser marking contribute to fine-tuning the technological applications to the target markets.

Food Test Case. A newly discovered chemical enables fast, reliable and easy detection of antibiotic residues in food products. The innovating firm develops a food test targeted to abattoirs. The development team has prepared documentation material to educate target customers and experimented with the product form.

Hose Case. The Hose, Bumper and Elevator Cases are three applications of the same base technology. This technology consists of an advanced approach to integrating steel into thermoplastics. One application possibility is to reinforce plastic hoses with steel. The new hose is aimed for use by oil companies.

Bumper Case. Another application of the steel reinforced plastic technology is the car bumper. Governmental emission restrictions and changing insurance policies make the use of plastic bumpers less desirable. The innovating firm teams up with a bumper manufacturer to develop a bumper that meets these new demands.

Elevator Case. The innovating firm is approached by a large elevator company that is under competitive pressure to reduce the space needed for elevator cables and machinery. The elevator company would like to replace the round steel elevator cable with a flat timing belt-like solution. The elevator belt is developed in close cooperation with the elevator company.

Rubber Case. The innovating firm develops a production technology for the production of rubber at much lower capital and variable costs. However, the quality of the rubber produced is unaltered. Target customers for the rubber try to negotiate favourable conditions while postponing their buying decision.

Strong Fibre Case. The innovating firm develops a radical strong fibre. A net manufacturer prompts the firm for use of the fibre in fishing nets. The fishing net application is explored and completed in cooperation with the requesting net manufacturer and various rope and net manufacturers.

Box II-1: Case descriptions

The analysis departs from eight within-case analyses. Per case, the activities that involve customers are identified and arranged according to Jolly's five-phased process model. Table II-3 indicates when companies involved customers and for which activities. Most projects are ongoing. The phases that they have not reached yet are marked grey to indicate that these are not included in the analysis.

Case	*1.Imagining*	*2.Incubating*	*3.Demonstrating*	*4.Promoting*	*5.Sustaining*
Display Case		Idea testing	Joint development		
Laser Case		Idea testing Application generation	Trial sampling Customer site visits	Customer problem solving	
Food Test Case			Trial sampling Customer site visits	Customer training program	
Bumper Case			Joint development		
Hose Case			Joint development Field test		
Elevator Case	Customer request		Joint development	Customer's customer site visits	
Rubber Case			Trial sampling		
Strong Fibre Case	Customer request	Iterative probing and learning	Joint development	Customer problem solving	

Table II-3: Cases of customer involvement for technology-based radical innovation

II.4.3. Cross-case analysis

In this section, we identify the underlying pattern that shows how customers contribute to technology-based radical innovation, by comparing the eight cases presented in Table II-3. Before discussing the results of this cross-case analysis, we first elaborate on the theoretical framework of the analysis.

II.4.3.1. Theoretical framework

In traditional marketing theory, customers are viewed as having needs or problems while suppliers provide solutions. However, von Hippel's work (2005, 1988, 1978) shows that customers can also contribute directly to 'the solution', i.e. the new product or the innovation. Following this logic of co-creation, we build the analysis on the concepts of solution and problem information. Firms contribute to the innovation process by providing *solution information* when they directly influence the form of the innovation by stating what it could or should entail. Examples include lead users suggesting new product ideas or an innovative firm communicating about the features of its latest technology. Firms share *problem information* when they communicate about the problems they encounter in current products or processes or with prototypes and samples.
We approach the research problem from a knowledge-based perspective (Grant and Baden-Fuller, 1995) by concentrating on which kind of information is shared when suppliers and customers interact with each other. Most of the exchanged information is existing knowledge residing in the customer or supplier firm. However, in the radical innovation process, new knowledge also plays an important role. For new knowledge we distinguish between solution information and problem information.

II.4.3.2. Discussion

For each of the five phases of the innovation process and for all eight cases, we analyse how sharing different types of information results in a knowledge overlap that contributes to the innovation process. Figure II-2 depicts the result of this exercise.

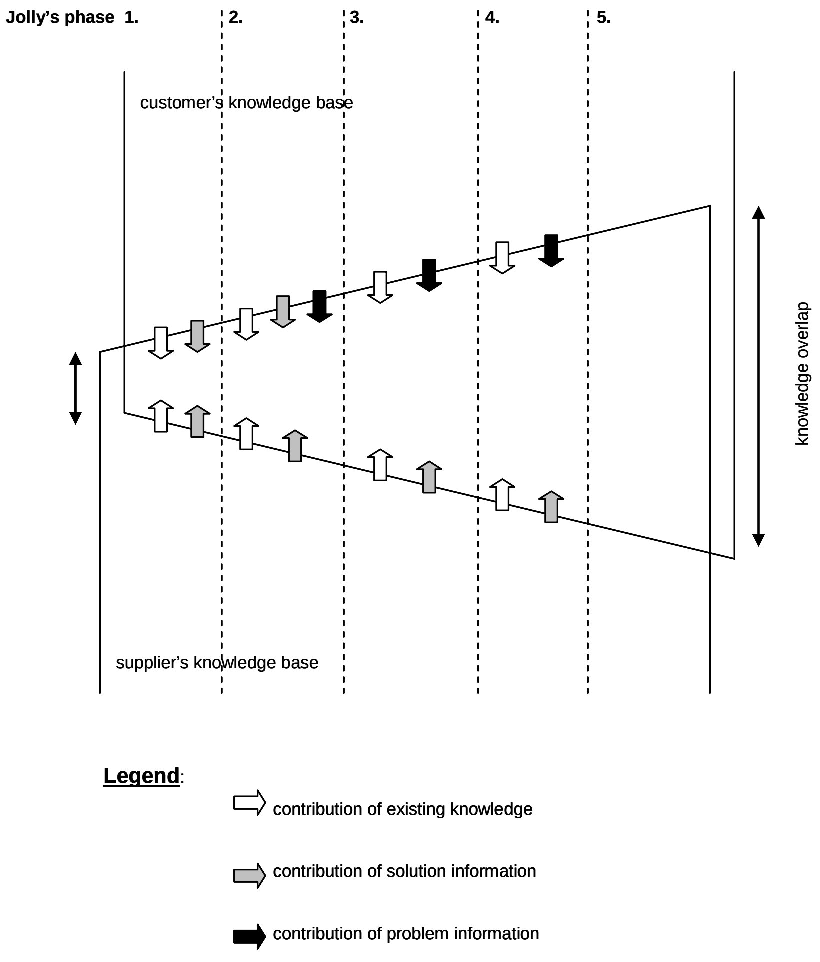

Figure II-2: Empirical analysis of customers' contribution to technology-based radical innovation

Figure II-2 consists of two shapes representing the customer's and the supplier's knowledge bases. By interacting, the overlap between both firms' knowledge bases increases over time, represented by the growing overlap of the two shapes as the innovation process progresses. The white arrows, pointing from the customer and supplier knowledge bases towards the overlapping region, indicate a contribution from the respective firms' existing knowledge base to the shared knowledge space. The grey and black arrows refer to solution information and problem information respectively. The two-sided arrows on the left and right of Figure II-2 indicate the increase of knowledge overlap.

We concentrate on the kind of contributions customers make throughout the innovation process. We argue that if customers contribute to the early phases of the technology-based radical innovation process, they do so by providing solution information. As the innovation process progresses, the customer's contribution is increasingly composed of problem information. In the early phases of innovation, the customer's solution information can inform a supplier of a technological application worth pursuing. Later, the customer's problem information enables the supplier to identify the relevant solution information to realise the innovation. In what follows, we clarify Figure II-2 and provide evidence from the cases (see Table II-3) for the proposition that customer contributions shift from solution information in the initial phases of innovation to problem information in the later phases.

1. Imagining

In most cases, the project managers find the link between the technology and its application possibilities quite obvious and don't involve customers in this phase. They conduct desk research to come to an initial market forecast. Sometimes, a customer request forms the onset for the development of a new application. Note that <u>customer requests</u> are requests for technological applications - not technologies. In both cases the application request is linked to an existing young technology. The customer request is formulated in the form of a new product idea and is thus composed of solution information. A prerequisite for customers to be able to contribute in the early phases of radical innovation is that the technology is known to them. In two cases customers contributed solution information early on in the innovation process by coming up with new, commercially viable application ideas. They were able to do so because, in one case, the supplier had publicly announced his technological invention and, in the other, the technology had already been demonstrated in another application. Unlike private consumers, industrial customers may have the needed competencies to link technological possibilities to market needs.

2. Incubating

<u>Idea testing</u> is an activity for which innovating firms approach customer firms. In the Display Case the development manager looks for an application that is not possible with current display technologies. He hopes that if there is no current solution to a problem, firms will be more willing to incur the extra costs of jointly developing a radically innovative product. He finds an OEM company who had been playing with the idea of e-books but, until then, had not found an appropriate display technology.

Arousal is stirred in the laser market when managers in the Laser Case vaguely announce their latest innovation. The strong reactions of competitors, customers and other market constituents confirm that they might have a breakthrough product. The market feedback motivates the development team to proceed further and it confirms to higher management that the team members' ideas are valued in the market. The innovating firm also learns about <u>additional application possibilities</u> suggested by potential customers.

In the Strong Fibre Case the innovating firm does not only lack experience in the target market of industrial fishing, it also has neither the knowledge nor the infrastructure for rope and net manufacturing. By convincing rope manufacturers to do trials for them, the innovating firm engages in an <u>iterative probe and learn</u> process.

In the Elevator Case customer involvement was less important during the incubating phase since the elevator market was a familiar market. The innovating firm had also been supplying the traditional steel elevator cables to the industry.

For radical technologies the incubating phase is a phase in which the innovating firm learns from customers which technological features are valued in unfamiliar markets. As the Laser Case shows, this can also include active scanning of the market for additional application possibilities. Such new application possibilities are clearly solution-based pieces of information. However, when the supplier takes his new technology to potential target markets the first problems for applying the technology also surface. Hence, in this phase customer firms can contribute by sharing a mix of solution and problem information.

3. Demonstrating

Note that all cases involve customers for the concrete development of their technology-based radical innovations. Especially in the cases in the chemical industry, industrial customers expect to receive free <u>trial samples for testing</u> the innovation's quality and its compatibility. This is also how customers ascertain the value of the innovation. In several cases it forms the onset of disagreement on the price level.

In the Rubber Case the radical technology is part of the process component of the innovation. This highly innovative technology significantly lowers the cost for producing rubber. The rubber end product, however, is not of higher quality than current rubbers. Customers request samples to assure that the quality is not lower either.

Both in the Laser Case and in the Food Test Case customer site visits are made to study the customer's work flow and to guarantee appropriate use of the innovation.

In the Display Case the innovating firm engages in a joint development agreement with the OEM company. At the start of each development stage technical specifications are negotiated for the next prototype. The development manager mentions the tough balance between, on the one hand, gaining useful information on market needs from its development partner and, on the other hand, keeping control over the development activities. Joint development activities in the Strong Fibre Case follow a trial and error process with rope manufacturers joining and exiting the development haphazardly.

In the Hose Case target customers, oil companies, demand a 1 to 1.5 year hose endurance test. A first field test is being set up at a customer site.

In this phase, innovating firms interact intensively with customers. The customer's role mainly consists of providing the development team access to its products and processes and he concentrates on signalling problems without thinking in terms of potential solutions. In many ways, the traditional problem/solution role division for customer and supplier manifests itself in this phase. Customers' requests for additional solutions are also signals of the tough negotiation process for value appropriation that goes on in the background of every joint development process (Vercauteren, 2004).

4. Promoting

A respondent for the Strong Fibre Case views thinking with customers to help solve the problems they encounter while switching to the new fibre, as an activity that is inherently connected to gaining market acceptance for the fibre. <u>Customer problem solving</u> involves educating the customer on the appropriate use of the new fibre. A better understanding of the fibre's technical characteristics and handling properties enables customer firms to correctly understand the innovation's value and increases the likelihood of adoption.

Management in the Laser Case shows a slightly different motivation for offering a customer problem solving service. The innovating firm has a consulting agreement with a laser supplier mainly to keep a foothold in the colour laser marking market. The innovating firm restricts itself to dark on light marking, but shares his technical expertise with laser suppliers and customers mainly for the purpose of relationship management.

In the Food Test Case, customer site visits revealed inappropriate use of the test. Hence, a <u>customer training program</u> is set up.

In the Elevator Case customer problem solving involves <u>visiting the customer's customer site</u>. This means that personnel from the innovating company visit some of the first building sites for placing the new elevator systems. Respondents describe these site visits as instructive and insightful.

The activities involving customers in the promoting phase evolve around solving the last customer problems to open the way for adoption of the newly developed technology-based solution. Again, the customer signals his problems and the supplier accommodates by providing customer training or helping the customer overcome the last hurdles to adoption.

5. Sustaining

During the final phase of technology commercialisation it is possible that all previous phases are carried out again in a totally new application industry with different customer firms as is for example the case for the Strong Fibre technology. Next generation products can be developed either with the initial development partner or with different customer firms as we observed in the Elevator Case. Although all types of knowledge contributions are possible in this phase, they really announce the start of new innovation cycles. This is the reason why we did not depict information contributions in this phase in Figure II-2.

II.5. Conclusion

This study provides an enhanced understanding of when and how customers contribute to technology-based radical innovation. A process model for this particular type of innovation was selected and used to present the findings in a meaningful way. In the literature review, we integrated scattered findings on customer involvement for innovation by linking them to the innovation process as a whole. From the overview a first indication emerges of when in the innovation process customers can contribute, and also of how to assure that customer input is correctly generated and interpreted. Next, a case-based research was conducted with the purpose of identifying an underlying pattern in the way customers contribute to radical innovation. We selected eight technology-based radical innovation projects within large firms and documented when and how customer firms were involved in the innovation process.

Both the literature review and the comparative case study research show a lesser degree of customer involvement in the early phases of radical innovation. Additionally, the empirical research points out that customer requests can initiate the development of radically innovative technological applications. A prerequisite for such requests to occur is that the technology is known in the market. From the case material, we see that this can be part of a purposeful publication strategy or a matter of having other applications of the technology already in the market. The empirical research confirms the importance of customer involvement in the development phase as described in the literature. In all cases, customers were involved in development activities in one way or another. The value of the case research lies in the richness of the list of activities through which valuable customer feedback can be generated. The literature review already showed that customer education is an important activity to promote the adoption of technology-intensive innovations. The empirical cases show that solving any remaining problems that inhibit integration of the innovation into the customer's products and processes is also an important aspect of gaining market acceptance. Both extant literature and the few empirical cases, that reached the final innovation phase, indicate how additional applications need to be identified and developed to ensure the technology's long-term value.

When analysing the general pattern in customer contributions to technology-based radical innovation we assert that if customers contribute to the early phases of innovation, they do so by contributing solution information. This means that their feedback contains direct clues to what the innovation should be. Observed examples of such solution information contributed by customers are suggestions for new application possibilities. As the innovation process progresses the customer's contribution is increasingly composed of problem information. When the innovation materialises and attempts are made to fit it into the industrial customer's products and processes, customer feedback mainly consists of pointing out problem areas and formulating additional demands. The underlying process in this phase is the negotiation for value appropriation. In the final innovation phase, new applications can be suggested as a way to sustain commercialisation of the radically innovative technology. However, we prefer to look at these suggestions as solution information that announces the beginning of yet another innovation cycle.

We identify two potential directions for further research. First, future research could concentrate on studying how the specific characteristics of the radical innovation context influence management of customer involvement in the process. For example, high uncertainty associated with radical innovation merits further investigation. The uncertainty concept could be explored in terms of various sources of uncertainty, e.g. the market and technological uncertainty. Second, the research question could be broadened to study how not only customer firms but also other firms contribute to the radical innovation process. A limitation of the case-based research is that respondents were restricted to managers and employees of the innovating firm. In a research design concentrating on a network of innovating firms it would be appropriate to collect data within several of the involved firms. This analysis could concentrate on identifying meaningful patterns in the way different firms contribute to the innovation process.

CHAPTER III

A MULTIDISCIPLINARY APPROACH TO UNCERTAINTY IN CUSTOMER/SUPPLIER COOPERATION FOR TECHNOLOGY-BASED RADICAL INNOVATION

Abstract

High uncertainty is a dominant feature of the radical innovation process. Customer/supplier cooperation can offer opportunities to deal with uncertainty in the pursuit of radical innovation. At the same time, though, engaging in a cooperative effort also complicates matters. This chapter shows in-depth how customer/supplier cooperation can facilitate technology-based radical innovation via an analysis of the uncertainty involved. The empirical research consists of a single case study. The research has two major aims: to conceptualise the phenomenon uncertainty and to theorise about the relationship between customer/supplier cooperation for technology-based radical innovation and uncertainty reduction. For the conceptualisation of uncertainty we consider several aspects of uncertainty that we generated from different scientific disciplines. The empirical case is investigated in terms of each aspect of uncertainty to generate a conceptual understanding of uncertainty in the specific context of customer/supplier cooperation for technology-based innovation. We also develop a conceptual model that illustrates the complexity of the interrelatedness of different categories of uncertainty within and across firms in

a joint innovation effort. Next, we theorise about the ways the different aspects of uncertainty can be reduced in the cooperation process between a customer and supplier firm. An additional section is devoted to governance issues in the uncertain context of customer/supplier cooperation for technology-based radical innovation. The managerial implication of this research is that the overview of different perspectives on uncertainty can be a first step towards a comprehensive approach towards uncertainty reduction for the realisation of technology-based radical innovation in customer/supplier cooperation.

III.1. Introduction

During the past decade, radical innovation has received the attention of more and more researchers. Even though start-up firms were initially portrayed as providing the flexible business environment in which radical innovation can thrive, a number of authors have argued that large established firms, because of their size and experience, can also make radical innovation happen (e.g. Chandy and Tellis, 2000; Leifer et al., 2000; Sorescu et al., 2003). This chapter concentrates on technology-based radical innovation within large firms in industrial markets. We look at technological inventions that open up radically innovative business perspectives. When aiming for an innovation that represents a more radical change there are many aspects in its development, production, adoption and use that differ so dramatically from 'common practice' that there is a high level of uncertainty in the innovation process. Because of its important influence on the management process, an investigation into the different aspects of uncertainty is desirable. For the identification of different aspects of uncertainty we combine approaches to uncertainty from multiple fields of study.

This results in a multidisciplinary approach to uncertainty in which views on uncertainty from the technology sourcing domain, the innovation management literature and cognitive science are explored and combined. The aspects of uncertainty treated in this chapter can be summarised as: whether the uncertainty can be influenced or not, where it is originating from and how it is related to information and knowledge. This multifaceted conceptualisation of uncertainty is a first contribution of this chapter.

Next, we relate uncertainty to the cooperation process between a customer and a supplier that jointly aim to realise a technology-based radical innovation. The translation of technology into an attractive selling proposition requires adopting a user perspective to identify the technology's economic value. Previous research indicates that interacting with customer firms during the innovation process can facilitate the process in a number of ways (Vercauteren and Vanhaverbeke, 2007; Athaide et al., 1996). One way of integrating a user perspective into the radical innovation process is by engaging in close cooperation with a prospective customer. However, the uncertainty reducing effect in such customer/supplier cooperation for technology-based radical innovation follows only indirectly from extant literature. In this chapter we explicitly research the relationship between the cooperation process and uncertainty. Hence the second contribution of the research in this chapter is that we theorise about the uncertainty reducing effect in customer/supplier cooperation for technology-based radical innovation.

The empirical part of the chapter is a case study about Dyneema®[4], the world's strongest fibre. In the context of the Dyneema® case we show how through customer/supplier cooperation a technology's economic value is defined and

[4] Dyneema® is a registered trademark of Royal DSM NV.

realised. The translation of a radically innovative invention into economic value enables the creation of a new line of business for the inventing firm. We concentrate on an application of the Dyneema® fibre as raw material for the manufacturing of fishing nets for industrial fishing. The purpose of the chapter is to show how technology-based radical innovation can benefit from customer/supplier cooperation. We do this by, first, developing a context-specific conceptualisation of uncertainty. This conceptualisation departs from three aspects of uncertainty that are identified in different fields of study. This multidisciplinary approach results in a more comprehensive understanding of uncertainty. In a second step in the analysis we investigate how the process of customer/supplier cooperation affects each of the three studied aspects of uncertainty. Additionally, we discuss governance issues in the very uncertain circumstances of customer/supplier cooperation for technology-based radical innovation.

The next section starts with a general discussion of uncertainty in radical innovation and continues with the introduction of three different aspects of uncertainty. Section three elaborates on the research methodology for the investigation of the potential role of customer/supplier cooperation in reducing uncertainty in technology-based radical innovation. The applied methodology is a single case study research. In section four, we present the empirical case by discussing the innovative technology, by introducing the two firms involved in the focal customer/supplier cooperation and by describing different business processes in action. In the fifth section we discuss the findings of the analysis of the potential role of customer/supplier cooperation in reducing uncertainty in technology-based radical innovation. The analysis entails further conceptualisation of uncertainty by interpreting the three aspects of uncertainty both in the specific context of technology-based radical innovation and from the view of the customer and the supplying firm. In the after-case discussion of the different aspects of uncertainty deductive and inductive lines of reasoning are used. Particularly in the discussion of uncertainty in terms of the areas it originates from an inductive approach leads to the identification of several particularly relevant categories of uncertainty and a regrouping of the different areas of uncertainty in extant literature to better align them with the context of this research. We develop a conceptual model that illustrates the interrelatedness of the different categories of uncertainty within and across firms. The section ends with a discussion of governance mechanisms in customer/supplier cooperation for technology-based radical innovation. The concluding section summarises the contributions of this chapter, mentions some limitations of the current study and provides directions for further research.

III.2. Three aspects of uncertainty

Because of their radically innovative nature technology-based radical innovation projects face very high uncertainty levels (Desza et al., 1999). The uncertainty does not only derive from the fact that the innovation project is based on a new, unstable technology in a potentially turbulent and rapidly changing technological context. Uncertainty also arises from the confrontation with unfamiliar target markets (Souder and Song, 1998). Uncertainty is linked in extant literature to aspects such as complexity (Kim and Wilemon, 2003) and turbulence (Calantone et al., 2003; Iansiti, 1995), both omnipresent in radical innovation. Suggested areas of complexity and turbulence are the technology and the market, but also organisational and inter-organisational processes such as development and marketing. Following De Meyer et al.'s (2002) classification of projects according to their degree of inherent uncertainty it can be argued that the uncertainty in radical innovation projects resembles chaos. Under chaos even the basic aim of a project is uncertain. Bstieler (2005) defines uncertainty as a lack of clarity about relevant evolutions and whether subsequent actions taken may be successful.

We draw from different fields of study to develop a conceptualisation of uncertainty that incorporates several of the phenomenon's different aspects. First, we consult research in the domain of technology sourcing. In this discipline uncertainty is approached in terms of whether it can be influenced or not. This aspect of uncertainty is referred to as endogenous or exogenous uncertainty. Second, uncertainty can also be approached in terms of the different areas it originates from. This approach is derived from the innovation management literature. Thirdly, in cognitive science uncertainty is interpreted in terms of information and how information is processed.

Endogenous and exogenous uncertainty

A first approach stems from literature that treats technology sourcing issues. Folta (1998) describes a dual typology that is also applied accordingly by other researchers in this domain (e.g. van de Vrande et al., 2006). The two types of uncertainty are based on the firm's ability to influence the level of uncertainty:

- *Endogenous uncertainty* is defined as uncertainty that "can be decreased by actions of the firm" (Folta, 1998, p. 1010). In the technology sourcing literature this type of uncertainty relates to the "inability to assess the value of a target firm, which investments in knowledge will yield products that can be commercialized, or how much time, effort and materials will be required to complete a project" (Folta, 1998, p. 1010). Endogenous uncertainty can be decreased by progressively investing in the project e.g. starting with equity collaboration in an early phase that can be a first step towards acquisition later on. The underlying logic is that each stage of investment reveals additional information that decreases the level of endogenous uncertainty.

- *Exogenous uncertainty* "is largely unaffected by firm actions" (Folta, 1998, p 1011). This type of uncertainty is resolved over time. In the technology sourcing literature market and technological uncertainty are defined as exogenous and industry-specific.

Areas of uncertainty

Another approach to uncertainty is given by Leifer et al. (2000). These authors categorise uncertainty into market, technological, resource and organisational uncertainty. We add findings in extant literature on any of these specific categories to the overview below:

- Market uncertainty

Firms that engage in technology-based radical innovation face very specific and complex marketing problems (Davidow 1986, Shanklin and Ryans 1987, Mohr 2001). Most of the challenges follow from the fact that neither product nor market is fully developed. Ambiguity exists about the type and extent of customer needs that new technology-based products can satisfy (Moriarty and Kosnik, 1989). Unfortunately, potential customers may not be able to articulate what they need either because their needs are present only latently or because they assume those needs can never be met by any supplier (Leonard and Rayport, 1997). In a context of radical innovation, market uncertainty typically relates to “the challenge of understanding markets that may not yet exist or that will be fundamentally transformed by the introduction of the radical innovation” (Leifer et al., 2000, p.75). In sum, these problems make it difficult to determine the size of a potential market and its future evolution.

• Technological uncertainty

According to Moriarty and Kosnik (1989) technological uncertainty is high when the technology is new or when it is subject to rapid changes. New technologies are initially instable in their functional performance. A set of economically feasible applications need to be identified and realised (Leifer et al., 2000). A considerable amount of time and effort concentrates on development activities that include extensive testing, prototyping, designing and redesigning. Technological inventions typically take place in small scale laboratory circumstances. Upscaling the new technology involves designing large scale production systems that can deliver reliable results. Again, this is an undertaking with many unforeseen intermediate outcomes to which no tailored solutions exist. Also, expertise and infrastructure for technical customer support need to be developed from scratch.

• Resource and organisational uncertainty

Resource and organisational uncertainty concerns the unpredictable variability in organisational support and resources allocated for any radical innovation project (Leifer et al., 2000). In large firms, business units constantly compete for resources. Powerful customers are even observed to lobby with their supplier to convince him to continue investing in improving current technologies rather than in coming up with new technologies (Christensen, 1997). This way, resources are drained away from radical innovation projects. Moreover, emphasis tends to lie on the realisation of short term gains. Reward systems direct managers towards less risky projects. Even if a risky project structurally receives funding, support for the project may decline or disappear as corporate goals change or because of staff turnover at corporate management levels. The likelihood of these events occurring increases as radical innovation projects mature towards ten to fifteen years.

A cognitive perspective on uncertainty

Finally, we point out that both of the above approaches build on the basic premise that uncertainty is reduced by receiving additional information. Hence, both approaches conceptualise uncertainty as a lack of relevant information. In a cognitive approach to decision-making Nyström (1974) extends this definition of uncertainty. The author notes that in highly complex decision-making contexts, like that of a technology-based radical innovation, uncertainty is reduced in interplay between content and structure. This means that Nyström (1974) adds the relevance of cognitive structure to the uncertainty definition. A cognitive structure is "defined as a set of partially ordered cognitive elements … which are viewed by the decision-maker as relevant for determining the outcome of a contemplated decision" (Nyström, 1974, p. 134). A cognitive structure is described in terms of two dimensions. One dimension asserts the degree of detail the information in a cognitive structure contains or its differentiation. A second dimension relates to the extent of causal links between these different elements.

III.3. Methodology

In-depth investigation of the role of customer/supplier cooperation in coping with uncertainty in technology-based radical innovation requires a research method that allows for a holistic study of all relevant aspects of the cooperation and the innovation project. A single case study is best suited for this purpose (Stake, 2000). We selected an especially revelatory case (Yin, 2003) in which customer/supplier cooperation was instrumental in dealing with the high uncertainty in technology-based radical innovation.

To ensure that the potential of customer/supplier cooperation for reducing uncertainty in technology-based radical innovation surfaced in the empirical case, we opted for a fully retrospective case. Though this option has the drawback of interviewees having limited recall of the studied phenomena, it does avoid the risk of engaging in the study of any ongoing customer/supplier cooperation that turns out not to be as relevant for the innovation process as initially believed or that is dissolved in the course of the study. Both occurrences are very likely in the context of radical innovation.

For data collection we relied mainly on personal interviewing of managers who were involved in the customer/supplier cooperation. This enabled us to probe into the why and how of actions and circumstances. We strived to interview managers both at the customer and the supplier firm. All interviews were transcribed following Miles and Huberman's (1994) guidelines. The study of secondary information sources was added to the interview data. The websites of the cooperating firms were an important source of such complementary information.

The case analysis, first, entailed interpreting the three conceptual aspects of uncertainty in the context of the case. Iterations between deductive and inductive lines of reasoning (Dubois and Gadde, 2002) lead to a theoretically relevant and empirically valid conceptualisation of uncertainty. Next, we analysed the uncertainty reducing effect in customer/supplier cooperation for technology-based radical innovation in terms of each aspect of uncertainty. Interpretation checks with the interviewees were an important part of the analysis (Miles and Huberman, 1994, p. 275-277). During these iterations between data interpretation and data collection important detailed aspects of the customer/supplier cooperation were revealed by the interviewees. This improved the empirical grounding of our analysis, both in terms of conceptualising and theorising, considerably.

III.4. The Dyneema® Case

In this section we discuss an empirical case of customer/supplier cooperation for technology-based radical innovation. We focus on the innovation process of Dyneema®, a fibre based on polymer technology. The starting point of the case is an invention in the R&D lab of DSM, a large Dutch chemical company. The invention enables the company to create the world's strongest fibre, which offers maximum strength combined with minimum weight. Currently the fibre is used in a whole range of applications. This research concentrates on the introduction of Dyneema® fibre as a new raw material for the manufacturing of fishing trawls.

In what follows, we start with a brief introduction of DSM, the firm where the invention took place. We also give a description of the scientific background of the invention. Then we discuss how the fibre's production was upscaled. A next paragraph is devoted to the application search for the fibre. Subsequently, we introduce Hampidjan, the fishing net manufacturing firm that incites DSM to investigate Dyneema®'s potential for fishing nets. We zoom in on the process of opportunity recognition and the product development process. We conclude the section with a brief overview of DSM Dyneema®'s activities today.

III.4.1. Scientific basis of Dyneema®

III.4.1.1. Introducing DSM[5]

DSM is a large, international chemical company that celebrated its 100th anniversary in 2002. The company is headquartered in the Netherlands, with locations in Europe, Asia, Africa and the Americas. The group has annual sales over EUR 8 billion and employs 22 000 people worldwide. Even though the company was initially government controlled, it was operating as a privately held firm already before the 1940's and was fully privatised in the 1990's. The only

[5] http://www.dsm.com

remainder of the initial government involvement is the name of the company: ‘Dutch State Mines’. The company was originally founded for the exploitation of coal mines. The production of fertilisers from coal coke gas was the onset for the creation of a wide variety of chemicals. Nowadays the company produces nutritional and pharmaceutical ingredients, performance materials and industrial chemicals. DSM’s products are used in a wide range of end markets such as nutrition and health, cosmetics, pharmaceuticals, automotive and transport, coatings, housing, electrics and electronics.

III.4.1.2. Context and aim of scientific research at DSM at the time of the invention

In the 1970’s DSM mainly produced base chemicals and bulk polymers. Research was closely linked to these commercial activities. Since cost price is a major determinant of commercial success of this type of bulk chemicals, process research to develop cheaper or more efficient production processes was the main goal of research at that time. The second target of research activities at DSM in the 1970’s was to improve customer service. DSM tried to augment customer satisfaction by improving processing properties of its chemicals. Bulk chemicals are sold to industrial customers who, in turn, use the chemical as input in their own production systems. Research was aimed at optimising the chemicals’ performance in the specific production systems of DSM’s customers.

III.4.1.3. Scientific research for Dyneema®

At the end of the 1970’s DSM made a surprising discovery when one of its polyethylene laboratory tests produced a remarkably strong fibre-like end product. The molecules in normal polyethylene are randomly orientated and entangled. This way they are easily torn apart. The test product showed a remarkably high parallel orientation of molecules, which offers higher strength. Further investigation led to a gel spinning process in which this effect is purposefully brought about. The raw material for this process is Ultra High Molecular Weight Polyethylene (UHMWPE), a special feedstock now also produced at DSM. The UHMWPE is dissolved in a solvent and spun through a spinneret. In the solution, the extremely long molecules become disentangled. As the fibre is spun and the solvent cools down, up to 95% of the molecules become parallel oriented, with a crystallinity of up to 85%. The result is the fibre with the world’s highest strength-to-weight ratio.

III.4.2. Dyneema® production

DSM patented the fibre and its production process in 1978. The fibre was named Dyneema® after the Greek words for strength - ‘dynamis’ - and thread - ‘nema’. In the early 1980’s the project progressed from a laboratory setting to a new business development project. Significant time and energy was devoted to the improvement and upscaling of the production process. It was not until 1990 that commercial production of the Dyneema® fibre took off in Europe. Since fibre production was not a core competence of DSM, the company initially looked for help with Toyobo, a Japanese fibre producer. This cooperation resulted in a joint venture to build the first Dyneema® test factory in Japan. At the same time the American company Allied Fibres, now Honeywell, was given a license to produce the fibre. The fibre is still produced and sold in the US under the brand name Spectra. In turn, DSM acquired from Allied Fibres the rights to produce UD sheet material, a product patented by Allied Fibres. In this product, fibres are aligned in a specific way to form sheets. By now, Dyneema® production capacity has been expanded several times in Japan, the US and Europe.

III.4.3. Dyneema® applications

A technological invention needs to be translated into a concrete application that serves a market need in order to generate economic value. Fibres can be used for the manufacturing of ropes and cloths. However, DSM's core business was the production of bulk chemicals. The company had no previous experience in commercialising fibres. DSM had to learn about fibre processing techniques and it needed to establish which applications would warrant a switch to ropes or cloths made of Dyneema®. For the purpose of clarity and focus, this chapter concentrates on applications involving rope made of Dyneema®.

One of Dyneema®'s most remarkable properties is its extremely high strength per unit of weight. Therefore, members of the project team initially looked for rope applications where users could save money by saving weight. Consequently, handling applications were scanned to see whether a current user of steel cables or polyester ropes could economise by replacing the steel or polyester by a lighter weight material of matching strength. In many situations switching to rope made of Dyneema® did enable handling activities to take place with a reduced number of workers, with lower fuel costs or with smaller cranes. Gradually, the market learned about the advantages of Dyneema® in various rope applications.

In 1986, the Dyneema® team was approached by Hampidjan, a fishing net manufacturer based in Iceland. They wanted to explore the possibilities of Dyneema® for the manufacturing of fishing nets. The remainder of this chapter concentrates on the exploration of this application and how the application evolved.

III.4.4. Opportunity recognition: the customer's perspective

III.4.4.1. Introducing Hampidjan[6]

Hampidjan Iceland was founded in 1934. With a market share of 75% in Iceland, the company began exporting its products in the 1970's. Initially, export activities focused on the North Atlantic fishing industries, but other major markets have been added since then. Hampidjan Group is one of the largest suppliers to the worldwide fishing industry, serving customers in South America, Southern Africa, Alaska and the US Pacific, Australia and New Zealand. In fact, today around 80% of Hampidjan's Group sales are located outside Iceland. The company is constantly looking for competitive advantages through innovation. Pioneer research and development in both materials and fishing gear is part of the cultural heritage of the company. Hampidjan also has a history of keeping

[6] http://www.hampidjan.is

close contacts and cooperating with skippers and fishing firms to improve products and to innovate.

III.4.4.2. Research and development at Hampidjan at the time of the opportunity recognition

In the fishery industry two parameters drive research activities: the size of the trawl and its towing resistance. With a larger trawl a bigger area can be covered to catch fish. Additionally, a trawl with lower towing resistance can be towed faster and in that way cover a wider area within a constant time span. There is a continuous striving to balance these two factors. In other words, for each raw material that is available to fishing net manufacturers at a certain point in time, the fishing net manufacturers try to improve a net's catch ratio per hour by determining the optimal trawl size and towing resistance. When fishing net manufacturers have been working with a certain material for a longer period it reaches optimisation. At this point a search for a new, more performant raw material is the only way to regain competitive advantage. In the 1970's a conventional material for trawls was High Density PolyEthylene (HDPE). By the early 1980's however, HDPE's properties were fully utilised and there was a need for a new material. Hampidjan was exploring the new high performance materials that were gradually appearing on the market at that time. Initially, experiments to create twines from an aramid fibre looked promising. But in netting twines are usually knotted together to make a mesh and every knot requires that the twine is bent over 180°. Aramid fibres turned out to be too brittle to tolerate bending under such a large angle. Hampidjan was also conducting experiments with HDPE. The experiment involved overstretching the

HDPE in order to improve its characteristics. Even though Hampidjan managed to make twines from overstretched HDPE, all the improvement was lost once again when the twine was knotted into netting. At this point Hampidjan encountered DSM's Dyneema® fibre.

III.4.4.3. Hampidjan's request

In 1986, Hampidjan attended a Chemical Trade Fare in Düsseldorf, Germany, where DSM was presenting its newly discovered fibre. In the DSM booth, personnel of the two firms started to discuss the possibilities of Dyneema® fibre for fishing trawls. Hampidjan already was a customer of DSM buying polymers and had done extensive research exploring the properties of new materials and trying to improve the characteristics of current materials. However, until then, Hampidjan had found no alternative for the predominantly used HDPE. Even though at the time, little was known about Dyneema®'s material properties and no experiments had been conducted for the construction of trawls or netting, in the opinion of Hampidjan personnel, Dyneema® could be a very promising material for the manufacturing of trawls.

III.4.5. Opportunity recognition: the supplier's perspective

At the time of Hampidjan's request there was no full scale production of the Dyneema® fibre yet. The available laboratory equipment allowed for the production of only very modest quantities of fibre. From the second half of 1986 the test factory in Japan started to provide samples that enabled limited customer trials and tests. But these quantities were not nearly enough for the development of a full scale fishing net. DSM Dyneema® was just getting acquainted with the manufacturing of small quantities of ropes. Net manufacturing was not one of its priorities yet. The fishing net manufacturer received some lab samples and the message that they had to be patient for at least another year and a half before DSM Dyneema® could look into fishing net applications.

Also at that time, DSM managers were convinced that Dyneema®'s most important performance parameter was strength per unit of weight. Another characteristic of Dyneema® is its low density, which causes ropes made of Dyneema® to float on water. Hence a fishing net made of Dyneema® would also float, making the strength per unit of weight performance feature irrelevant. The result is that the DSM Dyneema® managers could not understand why Hampidjan's people were so enthusiastic about Dyneema® for fishing nets. The fishing industry was an unfamiliar industry for DSM. Language and cultural differences between the Netherlands and Iceland complicated initial discussions even more. It took a relatively long time before both parties came to the mutual understanding that for this specific application strength per unit of thickness is the determinant performance feature instead of strength per unit of weight. Fishing nets are made out of ropes. By using Dyneema® to manufacture ropes, the strength of an HDPE rope can be matched by a thinner rope made of Dyneema®. Manufacturing fishing net out of thinner ropes made of Dyneema® results in fishing net with less drag in the water than fishing net of similar size and strength made out of HDPE. Thereby a fishing net made out of the sophisticated fibre offers the fisherman the advantage of economising by using a lower power boat for fishing with a net of similar size, or the advantage of increasing his catch by fishing with a boat of similar power but by fishing with a larger net. So for this application strength per unit of diameter is the determinant performance parameter instead of strength per unit of weight. The fishing net application was the first application in which diameter is more important than weight. Consequently DSM managers were unfamiliar with applying the diameter logic to the Dyneema® fibre. Afterwards they discovered that the fishing net application was not the only usage situation in which diameter is more important than weight. Nevertheless, it was during the opportunity evaluation of the fishing net application that DSM managers were first introduced to this logic.

III.4.6. Fishing net development process

This case illustrates how innovation is the result of inter-firm interaction, rather than the outcome of a stand-alone strategy (Håkansson, 1987). Figure III-1 is a simplified diagram of some of the cooperative relations that emerged in function of the development of the first fishing net made of Dyneema®. The top of the figure shows the general supply chain for fishing nets from raw material supplier to fishing firm. The rectangles represent firms. The full line arrows between them represent material and product flows. Above each arrow we indicate what is transferred from one firm to the next. The raw material for fishing nets is thread. Threads are twined once or twice before they can be used for rope manufacturing. Netting is made out of rope. Netting is an open-meshed fabric of ropes twisted, knotted or woven together at regular intervals. Next, the netting is constructed in the shape of a specific net. Net shape requirements vary among others in function of the type of fish to be caught and the boat used.

During the last operation ropes and fastening mechanisms are added to the net to fasten it to the boat. This customised net including ropes and fastening mechanisms is sold to fisheries.

Under the fishing net supply chain in Figure III-1, a simplified picture shows how the development activities took place for the first fishing net made of Dyneema®. In this picture, firms with the same functionalities as the ones depicted in the general supply chain at the top of the figure are placed straight below them. At the time of Hampidjan's request, developing netting was not one of DSM Dyneema®'s goals. The project team had only limited amounts of fibre at its disposal and was initially concentrating on learning how to manufacture perfect ropes out of the newly developed super strong fibre. The team members quickly learned that poorly constructed rope resulted in enormous performance loss. Hence, being able to instruct rope manufacturers on how to process the Dyneema® fibre was essential for its commercialisation. However, DSM had absolutely no experience in rope manufacturing and it was not part of its mission to make it one of its core activities either. Hence DSM Dyneema® had to convince rope manufacturers to undertake trials for them and to report back on what they had learned from the trials. This was a delicate negotiation exercise where Dyneema® fibre samples together with DSM's theoretical knowledge on how to process them, was traded for trial results and reports on possible progress made.

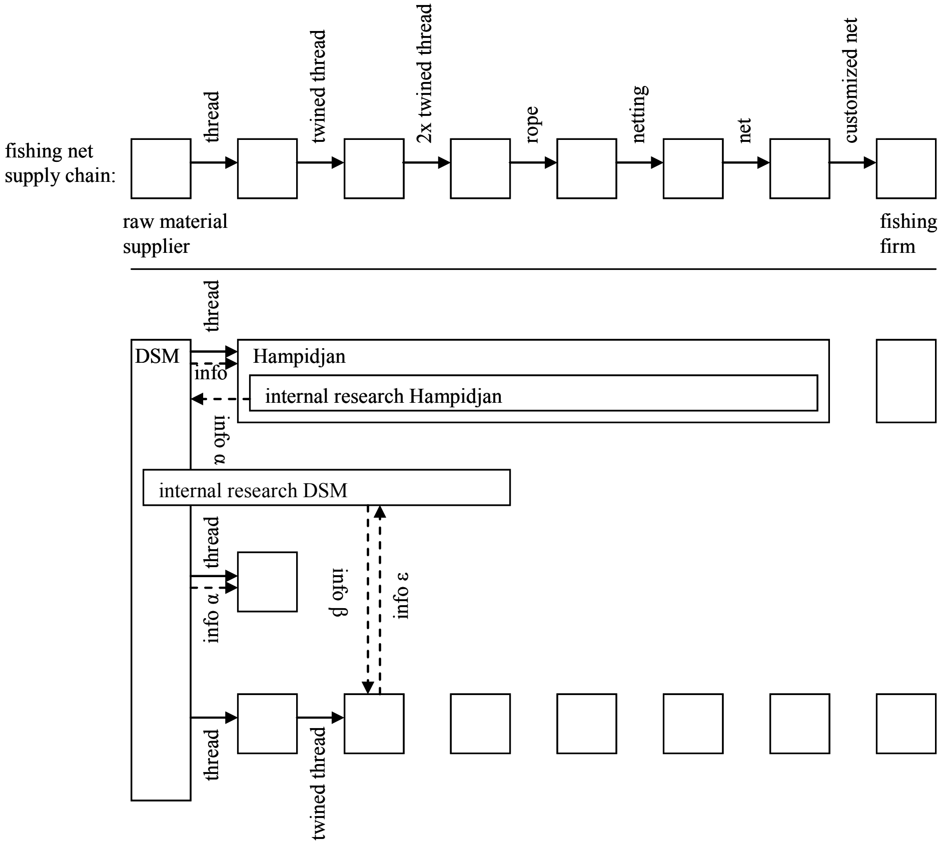

Figure III-1: Dyneema® fishing net development process

In Figure III-1, dashed line arrows indicate information flows. Rope manufacturers, however, were not accustomed to perform testing and development activities so they usually dropped out of the cooperation after disappointing results of first trials. In the early years, initial trials usually did fail. To keep the cooperation going or to start up a new one DSM would try to trade knowledge with firms making them proposals such as "our internal research just find out info β about how to make ropes out of the new fibre and we're telling you first, now you go ahead and share some of your knowledge with us too". Rope manufacturers were sometimes promised a lead or were offered free sample material to persuade them to try something out for DSM researchers who were constrained by limited in-house research capacity and very limited rope production equipment.

When Hampidjan requested DSM Dyneema® to look at the fibre's potential for fishing nets DSM's first concern still was to gather knowledge on rope production. Furthermore DSM had only very limited amounts of fibre at its disposal. So DSM offered Hampidjan a small amount of sample material together with some of the information that DSM had already gained on Dyneema®'s processing properties and the message that Hampidjan was free to do some trials on the material on its own but that DSM, at that time, was not considering pursuing the fishing net application. Hampidjan is however a highly integrated firm. That is why the rectangle representing it in Figure III-1 covers the total width of the fishing net supply chain. The firm also possesses research capacity on most of the steps in the supply chain, enabling it to undertake a significant amount of development activities independently. DSM has a more modest research capacity as the shorter rectangle representing DSM's internal research capacity shows. Initially, DSM and Hampidjan were relatively open about each other's research results. The cooperation started with DSM supplying some Dyneema® thread to Hampidjan along with information on how they thought the material should be processed. Hampidjan did trials with the new material and shared (some) of the lessons learned (info α) with DSM while asking additional questions. Next, internal research at DSM tried to add to the knowledge generated by Hampidjan while trying to solve some of the problems Hampidjan had experienced with the fibre. The technological development process iterated back and forth like this for quite some time. Simultaneously however, DSM

Dyneema® was still working with rope manufacturers in the market. For the purpose of market creation it was even sharing some of the knowledge (info α in Figure III-1) gained from Hampidjan with them. For fear of competition this limited openness in current cooperative relations with Hampidjan and rope manufacturers. But for commercial reasons DSM Dyneema® was spreading processing know-how to create as large as possible a market for its new product. DSM had the difficult task of convincing every firm in the relatively long supply chain to cooperate, before its material could reach end users.

Fortunately, Hampidjan continued its research analysing how to manufacture trawls out of Dyneema® fibre. Richness originated during the cooperation from combining the supplier perspective of DSM Dyneema® on the super strong fibre with the user perspective of Hampidjan on the fibre. During the joint development of the super strong fishing net new problems surfaced, but by jointly addressing these problems an even better value offer was created than DSM Dyneema® could ever have developed independently. For instance, because Dyneema® is a very slippery material, difficulties were experienced with the knots of the fishing net, which shifted when the net was being used. The final solution was a combination of directly addressing the problem and of 'creatively engineering' around the problem. By looking for a more stable type of knot the problem could partially be solved. The remaining knot shifting was dealt with by creatively rethinking the net design. Knots only shift when they experience unbalanced forces. By designing a net that undergoes more balanced forces when used the remaining problems no longer manifested themselves.

Although DSM Dyneema® attempted to overcome the problem, the company admits that it was mainly thanks to the efforts of Hampidjan that it could be solved. For the overall development process, DSM Dyneema® delivered most of the knowledge, especially in the early phases, to keep the process going. Gradually, Hampidjan delivered more and more of the actual work to realise the fishing net made of Dyneema®.

III.4.7. The situation today

It took about seven years before the first fishing net made of Dyneema® was introduced to the market in 1993. Fishing nets made of Dyneema® represent more efficient fishing and a longer net service life. Because of the potentially huge size of fishing nets - the world’s largest midwater trawl net has a mouth opening of 35 800 m^2 and uses Dyneema® material - this market is one of the larger Dyneema® application markets. In the mean time, the advantages of Dyneema® for fishing nets are well understood. Its outstanding resistance to UV light, seawater, abrasion and cutting increases the lifespan of the nets. Nets made of Dyneema® do not absorb water and have high wet knot strength. With low elongation and no shrinkage in water, the mesh size remains stable during fishing. A DSM laboratory called Technicum supports fisheries in identifying the best net for the fishing companies’ needs as part of the DSM Dyneema® service. Besides trawls, other major application areas for Dyneema® are ropes for all sorts of usages and helmets and vests for ballistic protection. The latest application is a high purity Dyneema® grade for use in medical devices.

III.5. Findings

To understand how customer/supplier cooperation can facilitate technology-based radical innovation by reducing uncertainty, we analyse the empirical case in terms of the three conceptual aspects of uncertainty outlined in section III.2. In analogy with Ford (2002), we look at every aspect of uncertainty both from the side of the customer firm and that of the supplier. It is essential to study uncertainty from both perspectives in the customer/supplier cooperation in order to be able to theorise about the uncertainty reducing effect in the cooperation in a next step in the analysis. The contribution in section III.5.1. is twofold. We provide a conceptualisation of uncertainty for the specific context of a customer/supplier cooperation for technology-based radical innovation. We also theorise about the uncertainty reducing effect of the customer/supplier cooperation. Remarkably, the empirical case reveals that extensive contracting is not necessarily a part of customer/supplier cooperation for technology-based radical innovation. We devote an additional section to governance issues under the highly uncertain circumstances of customer/supplier cooperation for technology-based radical innovation.

III.5.1. Uncertainty in customer/supplier cooperation for technology-based radical innovation

Endogenous and exogenous uncertainty

The literature from which we draw the distinction between endogenous and exogenous uncertainty defines technological uncertainty as exogenous. Indeed, also in this empirical case the supplier, DSM, faces exogenous technological uncertainty, for example about the likelihood that a new technology will emerge in the market any time soon that could make its Dyneema® fibre technology obsolete. Nevertheless, an important share of DSM's technological uncertainty in the face of developing and commercialising the Dyneema® technology is subject to its own decisions and actions and is therefore endogenous. For the customer firm, Hampidjan, uncertainty about the potential of DSM's new fibre technology was, before the cooperation, also mainly exogenous to it. However, both DSM and Hampidjan succeed in lowering certain areas of the uncertainty they face by engaging in close cooperation with one another. By participating in the cooperation Hampidjan increases its knowledge about the new fibre technology and even creates an opportunity to try to influence the direction of DSM's development activities. This way Hampidjan's exogenous technological uncertainty receives an endogenous component. DSM, on the other hand, faced largely exogenous uncertainty about the market for fishing nets made of Dyneema® in the initial stages of the cooperation with Hampidjan. Through the cooperation with Hampidjan DSM in its turn gains access to specific market knowledge and a chance to influence net manufacturing practices to better suite its new fibre's requirements. So DSM's market uncertainty gains in endogeneity.

In sum, the empirical case reveals that customer/supplier cooperation creates opportunities for both collaborators to render previously exogenous areas of uncertainty partly endogenous. Hence the cooperation process affects what is endogenous and what is exogenous. The firms attempt to reduce their uncertainty by influencing this endogenous uncertainty. Note, however that in practice the distinction between exogenous and endogenous is less clear cut than the above scenario presumes. In fact, in the cooperation a large area of partly endogenous and partly exogenous uncertainty emerges. What is truly endogenous is shrinking, but so is the truly exogenous. Areas of uncertainty that become endogenous for either firm in the cooperation, through engaging in the cooperation are most likely to be endogenous to the other firm as well. The result is that these areas are subject to the actions of both firms in the cooperation. One of the collaborators might want to prevent the other firm from influencing particular processes because of contradictory interests. Thereby, the collaborating firm makes sure that this area remains exogenous to the partner firm. So unless the goals of both firms in the cooperation match perfectly, the relation between endogeneity and uncertainty reduction is not self-evident.

Areas of uncertainty

In this section we analyse uncertainty in terms of where it originates from. The areas of uncertainty as described by the initial authors relate to rather general domains. On the specific level of analysis of the customer/supplier cooperation certain areas of uncertainty become especially relevant. It is worth introducing them here as separate categories. Hence, we introduce the concepts application uncertainty and transaction uncertainty. In the cooperation process other areas of uncertainty, e.g. market uncertainty and resource and organisational uncertainty, receive different connotations. We discuss the meaning of these areas of uncertainty for both the customer firm and the supplier in a customer/supplier cooperation for technology-based radical innovation.

Application uncertainty:

supplier’s technological uncertainty and customer’s need uncertainty

In a context of radical innovation it is useful to add application uncertainty as a separate category. Application uncertainty is the uncertainty that relates to one specific application possibility of the technological invention with radically innovative potential, namely the application that is investigated within the customer/supplier cooperation. Application uncertainty is the uncertainty about the specific features of an application. For a supplier these features are defined in technological terms. The customer considers them in terms of the functionalities that the features offer. Hence we define application uncertainty as the sum of the supplier's technological uncertainty and the customer's need uncertainty. Here the term technological uncertainty denotes the endogenous component of a supplier's technological uncertainty that relates to its novel technology with radically innovative potential. Especially when such novel technology is involved the supplier is uncertain about the specific technological features of the pursued application. Like the empirical case shows, in industrial markets this uncertainty is further strengthened by the complexities of numerous and potentially customer-specific operations. The relatively long fishing net supply chain presents a sequence of operations that all have to be gone through successfully before an end product can be delivered. Furthermore, fishermen all have differing requirements that influence technical specifications of the product, the fishing net. The supplier has to tailor the more general technological possibilities of the invention to a specific application. Side-effects need to be investigated and possibly circumvented. In technology-based radical innovation a supplier's technological uncertainty is composed of uncertainty about many of the new technology's performance, process and use parameters.

On the customer's side there is need uncertainty. The customer may be unsure about his (and his customers') need for a specific technological application. An application of a radically innovative technology can offer such a novel solution, that it is difficult for a customer to understand its full potential and to assess whether the application is of any value for him and/or his customers. In the case of the Hampidjan/DSM cooperation the customer's uncertainty about his need for fishing net made of Dyneema® is remarkably low. Hampidjan understands the relevant parameters of the raw material for fishing nets so well, that it is able to correctly evaluate the potential of the Dyneema® technology for its application.

Supplier's and customer's market uncertainty

Before we discuss the area of market uncertainty, it is important to note that in this chapter the term 'market' has to be understood differently depending on whose perspective is adopted. From the supplier's perspective 'market' refers to the market of potential customers. From the customer's side 'market' refers to all potential suppliers a customer can choose from.

The very nature of a technological invention often makes it difficult for a supplier to assess the type of customer needs it can satisfy best. For the same reason, it is often uncertain whether target customers will be able to perceive enough of the value offered to be willing to adopt or switch to the innovation (O'Connor, 1998). In handling applications potential customers need to be convinced by DSM of the benefits of switching to a, more expensive, rope made of Dyneema®. The empirical case shows that the reverse situation is also possible in which a potential customer, Hampidjan, needs to convince a potential supplier, DSM, of the benefits of the technology in a specific market.

From the customer's point of view, it is a sensible strategy to compare alternative offers before committing to a supplier. In industrial markets a customer will also try to spread his purchases across multiple suppliers to achieve optimal exchange conditions and to spread his risk. However, because of the radical nature of the offer under consideration none of the available alternatives deliver comparable performance levels. When the innovative offer is not even fully developed yet, the customer has to balance two facts. On the one hand, being among the first to gain access to a technology-based radical innovation could offer the industrial customer a competitive advantage. On the other hand, this would require committing in an early and highly uncertain stage to just one supplier.

Supplier's and customer's transaction uncertainty

In customer/supplier cooperation the potential future economic transactions between the two participating firms are an important incentive for pursuing the cooperation in the first place. Since predicting future business transactions is particularly challenging during technology-based radical innovation we mention it as a separate area of great uncertainty. Both customer and supplier experience high levels of uncertainty with respect to the possibility of establishing future transactions based on the cooperative efforts. Transaction uncertainty from the supplier's perspective means that a supplier in a joint technology-based radical innovation project with a customer experiences uncertainty concerning the customer's ability to reliably estimate the suitability of the offer under development to his and his own customers' needs. This results in uncertainty with respect to the estimated sales volume. During the joint development effort the supplier heavily relies on the market and need information that he receives from the customer. It is crucial for the supplier that he can also rely on the customer firm's sales estimates.

A customer in a joint technology-based radical innovation project faces the uncertainty of whether the supplier will actually be able to live up to his promises. Because of the many uncertainties involved in technology-based radical innovation, the price level is one of the factors that tend to vary considerably throughout an innovation project. From the customer's perspective it is also important to limit uncertainty on other transaction parameters such as time of delivery, customer support, quantity delivered and the constant quality and performance of the goods delivered.

In sum, transaction uncertainty in customer/supplier cooperation for technology-based radical innovation is the uncertainty about all relevant transaction parameters that the customer and the supplier face. This uncertainty is not merely caused by information asymmetries between the parties though. What further complicates this area of uncertainty is that in a joint radical innovation project the customer firm can not guarantee either that his sales estimates are reliable, nor can the supplier guarantee efficient and effective customer support at any time during the innovation process.

Supplier's and customer's resource and organisational uncertainties

In customer/supplier cooperation for technology-based radical innovation resource and organisational uncertainty influence the innovation project in the sense that Leifer et al. (2000) described it originally. The customer and the supplier both experience unpredictable variability in internal organisational support and internal resources allocated for the radical innovation project that they want to realise jointly. Additionally, the case shows that in customer/supplier cooperation resource and organisational uncertainties are not strictly endogenous to the firms involved. Both collaborators hope that by engaging in the cooperation they can benefit from a broader range of resources devoted to the realisation of the innovation project. The joint resources available for the realisation of the radically innovative technological application are partly endogenous and partly exogenous to each firm in the cooperation. Both firms do try to influence the way the resources are used in their own as well as in the partnering firm. But because the customer and the supplier can not direct the way resources are used in the partner firm as they can direct the use of resources within their own organisation, part of their resource uncertainty becomes exogenous by engaging in the cooperation.

Similarly, organisational uncertainty becomes a more complex phenomenon in the context of customer/supplier cooperation. In the cooperation organisational boundaries blur considerably and what emerges is a new organisational form that is neither market nor hierarchy (Helper et al., 2000). Precisely because of this absence of hierarchy, organisational uncertainty receives a whole new meaning when the cooperation is the organisation within which the technology-based radical innovation is housed. Now, organisational uncertainty is also linked to the likelihood of continuation of the relationship.

Uncertainty simultaneity

Finally, note that the above mentioned uncertainties all occur simultaneously and that they mutually influence one another. Personal background and experience may cause managers in the innovation project to be more skilled at or comfortable with controlling some areas of uncertainty, while systematically ignoring others. Nevertheless, all categories of uncertainty must be reduced for a project to become a success. Discussions in various studies mention that the different areas of uncertainty are interrelated (e.g. Leifer et al., 2000; Kim and Wilemon, 2003; Pfeffer and Salancik, 2003). To the best of our knowledge no research explores this interrelatedness in-depth. We illustrate how the four categories of uncertainty, as experienced by both the supplier and the customer, simultaneously affect one another and the technology-based radical innovation project. For this purpose we graphically represent customer uncertainties in one circle and supplier uncertainties in another - see Figure III-2. Within each circle we depict the four areas of uncertainty.

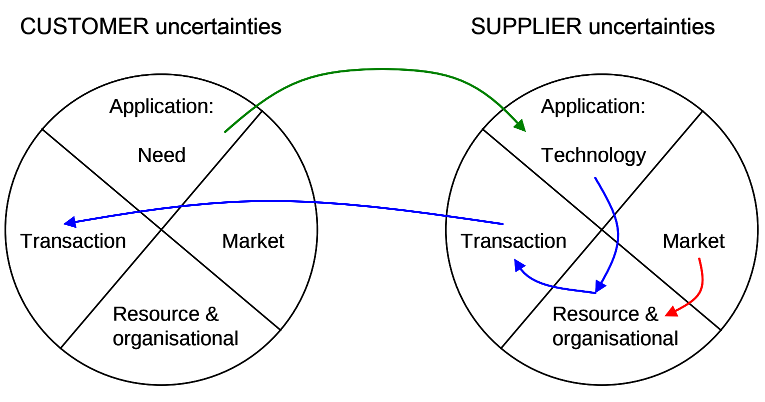

Figure III-2: A model of uncertainty in customer/supplier cooperation for technology-based radical innovation

In Figure III-2, we show the interrelatedness of the different areas of uncertainties. The coloured arrows indicate examples of how uncertainties affect one another in customer/supplier cooperation for technology-based radical innovation. We distinguish between direct and indirect effects. Direct effects are effects that occur within one uncertainty category or at one firm. Indirect effects mean that one category of uncertainty at one firm influences other categories of uncertainties at another firm. There are two types of direct effects. The red arrow shows the direct effect of one uncertainty influencing another at one and the same firm, indicating how internal support is gained after identification and/or involvement of a potential customer (McDermott, 1999). This means that reduced market uncertainty translates into reduced resource uncertainty at a supplier firm. The green arrow is an example of a direct effect within one area of uncertainty but across firms. This arrow indicates how in the case of the Hampidjan/DSM cooperation DSM's high application uncertainty with respect to the fishing net application is compensated by the low application uncertainty of Hampidjan, that is convinced of Dyneema®'s potential for fishing nets. In other words, the potential customer's low need uncertainty has a reducing influence on the supplier's technological application uncertainty. The blue arrows illustrate how a chain of direct effects leads to an indirect effect: e.g. a supplier's technological uncertainty influences the customer's transaction uncertainty. In the Dyneema® case context, at DSM initial technological uncertainty about Dyneema®'s suitability for fishing nets affected resource uncertainty. Because of its high technological uncertainty, DSM was not willing to invest resources in the exploration of the application. In consequence, DSM's transaction uncertainty also increased: initially, it was highly unlikely that DSM would send Hampidjan the requested sample material or provide its support. Hence, Hampidjan's transaction uncertainty also increased.

Figure III-2 gives an idea of the enormous complexity of the different areas of uncertainty affecting a technology-based radical innovation project carried out in customer/supplier cooperation. Complex chains of uncertainty effects influence the project simultaneously and make it difficult to separate cause from effect. These circumstances render the management of technology-based radical innovation in customer/supplier cooperation a particularly challenging task.

A cognitive perspective on uncertainty

When we analyse the period of confusion until DSM understood Hampidjan's interest in the Dyneema® fibre for fishing nets we see that providing additional and relevant information does not necessarily, nor immediately, result in reduced uncertainty for DSM. Another prerequisite is that the involved DSM managers are familiar with the appropriate cognitive structure to correctly process the additional information (Nyström, 1974). DSM was unfamiliar with the cognitive structure that links twine diameter to customer value in the fishing industry. Having approached Dyneema®'s potential only in terms of its strength-to-weight ratio DSM Dyneema® personnel could not understand what the fibre's advantage would be in an environment where the fibre becomes weightless, i.e. in the water. Optimising catch by optimising twine diameter was a general practice within Hampidjan. But it was not until Hampidjan personnel introduced the cognitive structure that holds twine diameter as a relevant parameter, that

DSM Dyneema® personnel recognised Dyneema®'s potential for the trawl application.

Such confusion is not exceptional at the start of any inter-firm cooperation. Typically, the firms involved in cooperation devote too little time and effort to jointly explore the problem or opportunity at hand, since they each assume the partner holds the same problem or opportunity definition (Taillieu et al., 2000). However, as the present case shows, different firms have different thinking practices (Weick, 1979), which can cause the described confusion. In an iterative process during which the problem or opportunity is framed and reframed, such seemingly divergent thinking is reassessed for its true significance (Taillieu et al., 2000).

III.5.2. Governance in customer/supplier cooperation for technology-based radical innovation

In the absence of any form of formal contract constant negotiation was an important managerial task in the Hampidjan/DSM cooperation to keep profiting from the relationship and to make sure that the relationship was continued in the future. This observation holds for both parties in the customer/supplier cooperation and the main responsibility for keeping the cooperation going may shift from one partner to the other during the innovation process. In the early stages of the cooperation Hampidjan was most persistent in pursuing a relationship with DSM. As the cooperation matured, DSM became aware both of the potential value in the fishing net application and of the learning opportunities in its relationship with Hampidjan. Nevertheless, the goals of the two firms did not always match. Hampidjan aimed at realising a competitive advantage by gaining early access to the Dyneema® fibre, while DSM was trying to create as big a market for its product as possible. DSM was not interested in the knowledge and skills needed for manufacturing fishing nets out of Dyneema® just to keep this knowledge proprietary. On the contrary, DSM aimed to spread this knowledge freely in the market to promote adoption of its new fibre. In reaction, Hampidjan gradually adopted a less open attitude towards DSM when it came to discussing technical matters. Now, it was DSM's turn to convince Hampidjan to continue the relationship.

The absence of a formal contract in this cooperation seems contradictory to the logic of transaction cost economics (TCE), but Williamson (1991) warns against uncritical application of TCE in a context of innovation where learning and exploration are paramount. Zajac and Olsen (1993) confirm that "learning gains often increase transaction value while simultaneously increasing transaction costs, and that the value gains often outweigh the transaction cost efficiency losses" (p. 143). This is also the case in the Hampidjan/DSM cooperation. Both parties consider the potential value that can be jointly created at least as much as the costs involved in the cooperation. Helper et al. (2000) argue that in inter-firm cooperation for innovation "failure in the short term will be tolerated if it becomes an occasion for learning that eventually results in improved performance" (p.473). Under the very demanding circumstances of radical innovation gaining trust by showing competence in the face of such opportunities for learning is a more convincing and effective governance mechanism than formal contracting (Nooteboom, 2004). In customer/supplier cooperation for technology-based radical innovation joint exploration is an important driving force of activity. This means that "collaborators jointly explore what they want to do even as they are doing it" (Helper et al., 2000, p. 480) and “what each party wants depends in part on what the others do” (p. 481). The Hampidjan/DSM cooperation showed that tasks and responsibilities are constantly being (re)negotiated in the face of each particular, intermediate challenge at hand, as in the case of the knot shifting problem (see section III.4.6.). Because of the uncertainty concerning contingencies that might influence contract execution, contracting has limited feasibility as a form of governance especially when the aim of the collaboration is innovation (Nooteboom, 2004).

III.6. Conclusion

In this chapter we developed a comprehensive understanding of the role of customer/supplier cooperation in dealing with uncertainty in technology-based radical innovation by analysing different aspects of uncertainty that were generated from different research disciplines. The empirical part of the chapter consisted of a single case research. The case described cooperation between DSM, a chemical firm, and Hampidjan, a fishing net manufacturer. The cooperation was based on DSM’s new Dyneema® fibre technology. We analysed how different aspects of uncertainty were reduced in the cooperation. We conceptualised uncertainty in customer/supplier cooperation for technology-based radical innovation both from the perspective of the customer firm and the supplier. The advantages of this approach are twofold. One, in industrial markets every supplier is also a customer. This chapter indicates the potential for dealing with uncertainty in customer/supplier cooperation for both roles. Hence we provide a guide for firms on the meaning of uncertainty, tailored to each of the two roles they might find themselves in. Second, every firm in an industrial market engages in interactions with its own customers and suppliers. This research offers an in-depth discussion of uncertainty as experienced by the respective counterparts. These insights enable a better understanding of the goals and actions of such counterparts, whether they are customers or suppliers, and can also in that way lead to more successful negotiation and/or cooperation.

First, uncertainty is approached in terms of whether it can be influenced or not. The distinction is made between endogenous and exogenous uncertainty. The cooperation process affected the division between the two in technology-based radical innovation. The cooperation enabled both parties to render some areas of uncertainty partially endogenous that were fully exogenous before. Thereby each firm in the cooperation managed to lower particular areas of uncertainty that were previously beyond its control. Main example from the empirical case was that DSM lowered its market uncertainty by linking with Hampidjan. The latter reduced its technological uncertainty by means of the cooperation.

Second, we investigated uncertainty in terms of the areas it originates from. Extant literature implicitly blends supplier with customer perspectives on different uncertainty categories. In the customer/supplier cooperation process it makes sense to interpret each uncertainty type from the perspective of the supplier and that of the customer. The empirical case also enabled refinement of a conceptualisation of uncertainty into four areas of uncertainty that are particularly relevant in customer/supplier cooperation for technology-based radical innovation. These four categories are: application, market, transaction and resource and organisational uncertainty. Until now uncertainty about customer needs had only been conceptualised as part of a supplier's market uncertainty. The case material showed the relevance of conceptualising a customer's uncertainty about the need for a specific application as the equivalent of the supplier’s uncertainty about an application’s technical specifications. We combined the customer’s need uncertainty with the supplier’s technological uncertainty in the area of application uncertainty. In the cooperation process market uncertainty needs to be interpreted differently depending on which partner’s perspective is adopted. Transaction uncertainty is important in the cooperation since the economic transaction is a fundamental factor in the motivation of the partners to cooperate in the first place. Resource and organisational uncertainty in a cooperation process need to be related to the hybrid organisational form that the customer-supplier cooperation is. The empirical case corroborated all of the proposed uncertainty categories. On the basis of this conceptualisation we developed a conceptual model that explicitly shows how the various areas of uncertainty are interrelated within and across firms. We distinguished direct from indirect effects among uncertainties. Direct effects are effects that occur within one uncertainty type or at one firm. A chain of direct effects leads to an indirect effect. Indirect effects among uncertainties in customer/supplier cooperation for technology-based radical innovation entail, that one area of uncertainty at one firm can have an effect on another area of uncertainty at another firm. The empirical case mainly showed how customer/supplier cooperation lowered uncertainty in technology-based radical innovation through compensating levels of application uncertainty.

The empirical case also offered an occasion to analyse uncertainty from a cognitive perspective. In the initial stages of the interaction between Hampidjan and DSM the fishing net manufacturer contributed information that was relevant for the supplier’s commercialisation of its newly discovered super strong fibre. Nonetheless, DSM did not experience any lowered application uncertainty as long as it was unfamiliar with the appropriate cognitive reasoning to correctly process this new information. It was only after repeated interactions with Hampidjan personnel that DSM personnel succeeded in adopting the cognitive structure from Hampidjan that linked twine diameter to commercial value in the fishing industry. From that moment on DSM faced lowered application uncertainty and started to jointly investigate the feasibility of and potential for fishing nets made of Dyneema® fibre.

The empirical case revealed the remarkable fact that customer/supplier cooperation for technology-based radical innovation is not necessarily subject to any formal contractual agreement. The highly uncertain conditions of such cooperation, render contracting an expensive option with limited feasibility. Firms in the cooperation are more likely to resort to constant negotiation and renegotiation of tasks and responsibilities as a form of governance.

The conducted research has some limitations. By looking at the empirical case as a whole, we observe that relationships other than the focal dyadic relationship also contributed to the innovation process. Figure III-1 even portrays some of these relationships. More importantly, these other relationships also influenced the innovation process in the focal dyad. This indicates that the development and commercialisation process of the radically innovative fishing net seems to have taken place within a network of firms. We did not investigate the network. Instead, we identified the most important dyad and conducted the research from the perspective of these two firms. This study does indicate that further research into technology-based radical innovation from a network perspective could generate valuable findings. As for the findings in this chapter, they can also be transferred to a network perspective. Every industrial firm tries to influence and is influenced by the uncertainties its customers and suppliers face. Further research into such uncertainty constellations could generate additional findings. Another interesting avenue for future research would be to compare the results of this study to the findings of a research into uncertainty in customer/supplier cooperation for incremental innovation.

CHAPTER IV

BUSINESS NETWORKS

IN TECHNOLOGY- BASED RADICAL INNOVATION

Abstract

In this chapter we study how networks of firms are involved in the technology-based innovation process. We investigate the role of networks in innovation by analysing the resource interactions that enable the translation of a new technology into an economically valuable product. These resource interactions are investigated in terms of four basic kinds of resources: products, facilities, organisational units and organisational relationships. We research a longitudinal single case of building a business from a new technology with radically innovative potential. From the case material we identify four relevant sub units of analysis by making the link with the four basic resource types. In the product development process the product is central. Equipment development relates to the facilities of firms. In the sales generation and growth processes organisational resources are important. By taking into account the logic of the business processes that guide networking activity we are able to interpret the involvement of networks of firms in a meaningful way. We find that regardless of the kind of resource the sub processes starts out from networks of firms are involved in resource interfaces that relate all four kinds of resources in technological, organisational and mixed resource combinations. Whether the

innovation entails an incremental or a radical improvement depends on the resource combination it is embedded into. The realisation of a radical application seems to need a more active approach to establishing a relatively elaborate network with a larger variety of actors than incremental applications require.

IV.1. Introduction

Technology-based innovations are products or services that have an important technological component. Such a new product gains value by relating it to other existing resources in an economically valuable way. Especially in industrial markets a technological product needs to fit into a firm's productive system in which technological and organisational resources are combined in an intricate way (Rosenberg, 1982). Moreover, any change in a complex system like that is likely to affect the activities of other related actors, such as suppliers and customers. The introduction of a technology-based radical innovation into an industry can have far-reaching effects on the productive systems of interrelated actors because of the radical change that the new product implies. Such radical change is not self-evident since all the affected actors' future options are constrained by their path-dependent investments and technological trajectories (Dosi, 1982; Dosi et al., 1990). The innovation process can only be successful if the new product is integrated in this network of related resources in an economically valuable way. That is why the innovation process can not be handled autonomously by the innovating firm. Rather, innovation is an interactive process between the affected actors in a network of firms. This view is supported by researchers in industrial marketing and purchasing (e.g. Håkansson and Waluszweski, 2002; 2007; Baraldi and Strömsten, 2006), researchers in strategic management (e.g. Normann and Ramírez, 1993; Ramírez, 1999) and also researchers in organisation science (e.g. Powell et al., 1996; Nooteboom, 2004). The aim of this chapter is to investigate how such networks of firms are involved in the process of technology-based radical innovation.

We study the resource interfaces that drive the innovation process to establish how networks of firms become involved in the innovation process. For this purpose we make use of a research tool named the 4R model (Håkansson and Waluszweski, 2007, p. 17). The tool is based on four kinds of resources of which two are of a technological nature and two are organisational resources. In terms of technological resources, a first kind of resources is products whether as inputs, throughputs or finalised outputs, and a second resource is the physical infrastructure and equipment of a firm, referred to as its facility. For organisational resources the distinction is made between organisational units, a third kind of resource, and organisational relationships, the fourth resource. The 4R model enables the study of interactions or interfaces between resources.
The model allows for the theoretical distinction between technological resource interfaces, organisational resource interfaces and mixed resource interfaces. The purely technological resource interfaces occur when products interact with other products, equipment interfaces with a production facility or when products and facilities interact with one another. Organisational interfaces occur when two organisational units interact, when an organisational unit enters an organisational relationship or when organisational relationships interact with one another. In mixed resource interfaces technological and organisational resources interact with one another, e.g. when an organisation's facility is taken into

account in an organisational relationship or when an organisational unit's strategic goals are translated into its product offer.

In terms of the 4R model the innovation process consists of fitting a supplier's new product into customers' existing resource constellations by tracing the resource interfaces through which integration of the new product can be accomplished. A technology-based radical innovation is expected to affect the resources with which it is combined in a significant way. Because of the radical change involved, it is likely that not only the physical resources with which the innovation interacts directly within one organisation need adaptations, but that also a larger constellation of resources that span different organisations is affected. However, the new technology involved, its unproven economic value and the unpredictability of relevant actors' reactions to the innovation make it difficult to foresee which resource interfaces need to be addressed in which way. We aim to investigate the critical resource interfaces in the innovation process as a way to uncover how business networks are involved in the innovation process.

In the following section we introduce the rationale of the applied research design. We explain the method by which we analyse a longitudinal single case. Then, we elaborate on the case context and the case itself. The next section concentrates on the case analysis. We start by identifying relevant sub units of analysis. Resource interfaces are discussed for each sub unit of analysis. Then we integrate these results in an analysis of how networks of firms are involved in the technology-based radical innovation process as a whole. The paper ends with a concluding section.

IV.2. Research design

The purpose of this research is to study how networks of firms are involved in translating a technological invention into an innovative product. The main unit of analysis is the process of building a business from a radically innovative technological discovery. A single case study research is most suitable for in-depth study of business processes. The case is a technology-based innovation project with radically innovative potential that is situated within a large firm. Note that, even though this case setting also offers possibilities for studying intra-firm relations, we focus on inter-firm interactions as the building blocks of business networks. For analysing inter-firm networks we apply an embedded case study design where, within the single case, attention is given to embedded sub units of analysis (Yin, 2003) as depicted in Figure IV-1.

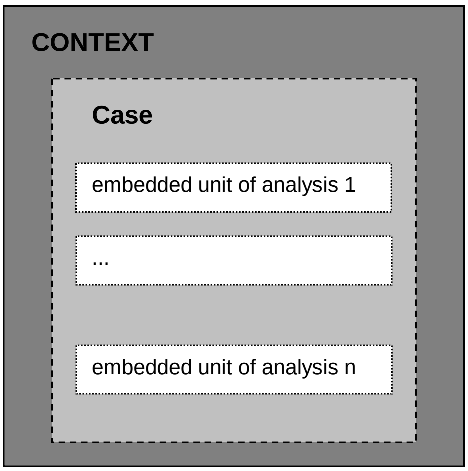

Figure IV-1: embedded single-case design (adapted from Yin, 2003, p. 40)

By analysing resource interfaces in each of these sub units and subsequently comparing and integrating the results to return to the higher level of analysis, which is the process of building a business from technology-based radical innovation, we aim to improve the robustness, depth and transferability of our results. Rather than forcing the well-known sub processes from idea generation to market launch (Cooper, 1990; 2006) of the more linear incremental innovation process onto radical innovation, we prefer to let relevant sub units of analysis emerge from our case. Also from a methodological point of view such an approach is especially appropriate in case-based research (Eisenhardt, 1989; Strauss and Corbin, 1999). The close connection with the richly documented empirical reality of the case permits the identification and development of theoretically relevant and empirically valid sub units of analysis. This is exactly one of case research's important strengths. Hence, identification of relevant sub processes will be the first step in our analysis.

To observe how processes evolve over time we conducted a longitudinal research. We researched the case from 2003 until 2007. The business processes, resource interfaces and business networks are initially studied from the perspective of the focal development team: the managers directly involved in the technology-based innovation project were interviewed for the purpose of data collection. To establish a more representative view we added to this a selection of interviews with firms in the focal team's network. Research that includes the perspective of different firms involved resulted in more representative and robust findings. For every inter-firm interaction we tried to identify the managers directly involved in the interaction. By asking these managers about the aim(s) of the interaction we were able to reveal the critical resource interface(s) in the interaction. The information gained in interviews was often confirmed by information in internal intermediate reports and business presentations. By systematically comparing this information with the possible resource interfaces in terms of the 4R model we gradually revealed how inter-firm resource interfaces lead to the involvement of networks of firms in the innovation process.

IV.3. Empirical case

The selected case is a technology-based innovation project within a large chemical company. When a technological principle was established that would enable the development of a high quality laser additive, resource interactions with different types of firms started to be part of the business development process. In the next paragraph we provide some background information to enable a fruitful interpretation of the case. Then we proceed with a chronological presentation of the case.

IV.3.1. Case context

Under this heading, we introduce the R&D team that realised the technological invention and describe its relation to the corporate parent. The invention's main characteristics and potential economic value are summarised. We also briefly discuss the market for laser additives.

IV.3.1.1. R&D team

The technological invention that lies at the origin of the case was discovered by R&D staff within the laser centre of a large chemical company. The corporate parent firm is composed of four business groups: nutrition, pharmaceuticals, performance materials and industrial chemicals. An important part of its production consists of chemicals in granular form. The laser centre is equipped with four lasers and three to four people with approximately 10 years experience. These R&D people performed development activities for about 25 laser markable materials mainly for the performance materials group of the company and some external customers. The centre was originally also doing work for two other business groups within the firm but when these were sold to other companies the centre’s customer base fell back considerably. In February 2002, a business development manager was appointed to the laser centre to determine a future direction for the group. She looked into possible alternative activities for the centre such as doing job shop work or consultancy. However, neither of these activities fitted within the scope of the corporate parent. She also considered integrating the centre into a business unit as an internal service centre. She even considered a slow phase out scenario for the centre.

IV.3.1.2. Technological invention

In May 2002, two R&D members of the laser centre made a significant discovery. At the time of the discovery several laser additives were commercially available. A laser additive is a chemical formulation that is added to a polymer to enable laser marking. Every single polymer required different amounts of additive for laser marking to be possible. One of the specialities of the laser centre was to determine these relative amounts. Available laser additives had some technical weaknesses: they tended to influence the colour of the base polymer and the laser marking quality would vary from polymer to polymer and, within one polymer type, also from lot to lot. Members of the laser centre had been doing some lateral thinking and came up with a laser additive technology that could generate constant results no matter which polymer it was used in. They established a universal solution for exceptionally clear and reproducible laser marking on virtually any type of plastic. Traditional methods of laser marking with a laser additive meant that plastic particles were carbonised under a laser beam. The new approach does not entail carbonisation of the plastic polymer itself. Instead, the newly developed laser active particles are embedded in the polymer. A laser beam carbonises only the added laser active particles in the compound material. The additive has no effects on the plastic's chemical resistance, colour, mechanical properties or UV stability. The result is plastic material that can be laser marked with constant high quality precision. Furthermore, the laser marking quality is independent of the characteristics of the polymer in which the additive is used. The basic technological principle is that adding the chemical formulation to a polymer enables polymer independent carbonisation. Now, an almost endless list of plastics, from polyolefins to silicone rubbers, becomes laser markable. Because of its stability up to 300°C the additive is suitable for a broad range of production methods such as extrusion and injection moulding. Initial reactions from various market actors signalled that this could be a breakthrough technology.

IV.3.1.3. Market for laser additives

The laser marking market is a niche market. It is growing due to trends like the increased need for tracking and tracing of parts. This trend puts laser suppliers in a comfortable double digit growth position. Rather than concentrating on the number and size of different players in the market for laser additives, we present the different relevant firms in terms of their activities and products offered. A simple schematic, figure IV-2, supports a discussion of the market for laser additives

Figure IV-2 shows the basic firms involved in manufacturing some laser marked plastic part. Generally, there is a raw material supplier delivering the base polymer. An additive supplier makes the additive to enable laser marking on plastics. A master batcher mixes these materials together, after which a compounder composes the material with the desired properties. The resulting material is moulded into a particular shape by the moulder. Next, this part is laser marked by an OEM company or end user of the laser additive which

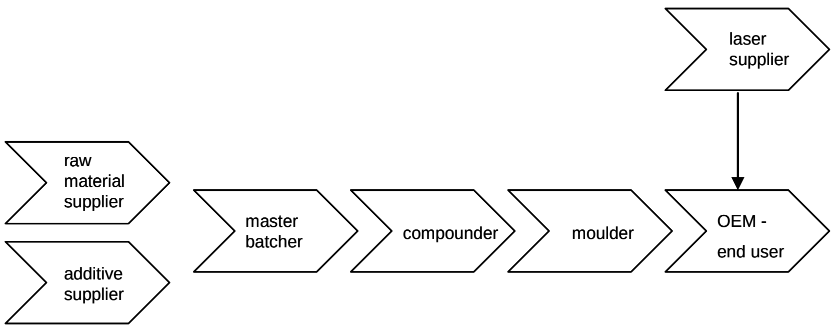

Figure IV-2: Firms in the market for laser additives

(source: adapted from development team's business presentation) acquired laser equipment from a laser supplier. End users of a laser additive are those firms that actually laser mark material with the aid of the laser additive. From the perspective of the development team that tries to commercialise a new additive these are the target customers. Hence, throughout this chapter we will use the terms end user and target customer interchangeably (Vercauteren, 2005).

Though this simple representation is sufficient for our discussion of the empirical case, we do add that in reality different levels of integration are possible. For example, in certain industries moulders also laser mark the moulded parts themselves. Also it is important to be aware of the fact that all the firms in the market for laser additives are possibly 'doing business' with any other firm in the market: buying and selling, competing and cooperating, communicating and negotiating. Combined these two features – different levels of integration are possible in the market for laser additives and any firm can interact with any other - result in a market situation where for example a potentially attractive partner firm is at the same time also a competitor. Among this complex set of entangled firms the development team aimed to find an economically feasible position for itself, based on the technological discovery.

IV.3.2. Empirical case: developing business from technology-based radical innovation

The main process in this case is the process of building a business from a technology-based invention with radically innovative potential. In what follows, we describe the case chronologically in more detail.

IV.3.2.1. The first year: May 2002 – May 2003

The inventors of the high performance laser additive teamed up with the business development manager to commercialise the invention. Soon after the initial technological discovery in May 2002, the team was approached by various types of firms that were requesting information about the new technology. In the next six months a laser company, an additive producer, a master batch producer, and a current customer all confirmed the technology's potential market value. Some of these firms referred to the "breakthrough" character of the new technology. This was a real boost for the development team's determination to actually develop a commercial version of the new additive.

The team generated initial application possibilities from a desk research by the corporate parent's marketing research department, from a related business group that also offers laser additives and from interested companies. The related business group focused on typical industrial applications, such as appliances, electrics and electronics. In these industries the new additive would mean an incremental improvement compared to the currently used alternatives. Additionally, some radical application possibilities were identified. A current raw material customer of the corporate parent saw the technological discovery as an innovation that would enable it to switch from the cumbersome print technology to the more user-friendly and cost effective laser marking technology. This customer is a producer of synthetic corks. Synthetic corks are plastic alternatives for natural cork stoppers on bottles. The realisation of this radically innovative application implied meeting extensive new equipment requirements. At the time, there was no equipment available for laser marking synthetic corks.

Equipment development was not a core competency of the development team or of its corporate parent. From this moment on, the team scanned the market for appropriate partners to realise this application. The team also interacted with a security card producer for whom high precision, high contrast laser marking on security passes would result in improved security guarantees. Another radically innovative application was the use of the additive to enable laser marking on silicone rubbers on which laser marking was impossible before. Silicone rubbers are used in keypads for telephones and computers.

By the end of 2002, a patent application was filed and a business plan was drawn up. The team's direct contacts with potential customers provided a first occasion for trials on customers' materials. These trials generated some initial feedback on technical specifications for the new laser additive. By February 2003 the development team had formed strategic alliances with several laser producing firms. These were alliances that naturally followed from the corporate parent's existing relations. Because of its historical focus, the corporate parent had forged relationships with laser firms that offered equipment for industrial application industries. The alliances enabled the development team to, in the words of the business development manager, "be able to supply the customer with everything he needs to benefit from the new additive". Moreover, these allied firms are also used as gateways to potential customer firms. In May 2003 the discovery was presented at a customer day of one of the allied laser suppliers. The development team considered this to be the official launch of the new laser additive. Some of the laser customers showed enthusiasm about the additive's potential and requested additional information and sample material.

IV.3.2.2. After the product launch: May 2003 – end of 2004.

Several of the interested laser customers were manufacturers of animal ear tags. These firms produce plastic identification tags that are used mainly for cattle. From discussions with the laser firm and tag manufacturers the growing tag industry emerged as yet another interesting application possibility for the new additive. Tag manufacturers were already applying laser marking. In this industry the new additive could be an incremental innovation.

Note that the time span for achieving a first sale of a technical product in industrial markets is just under a year. Secrecy agreements are negotiated and signed before trial and testing activities can begin. Customers run a trial and are urged to send the trial product back to the development team. The development team does an assessment of laser speed and contrast on the trial product and sends the results back to the customer. Based on this information the customer then decides to proceed with the purchase or not. After the product launch, trials were set up with about five of the interested laser firm customers and all of them were requested to report results back to the development team. These were customer firms from different industries. They all experienced various sorts of problems with the first version of the laser additive. From this feedback the development team could identify three general problems. A first problem related to the laser marking speed, which was too slow. Second, the additive did not perform at all with some of the laser equipment used. And third, several firms said that they were afraid that the chemical additive wouldn't mix optimally with the base polymer they were using. They feared that in the longer term the compound material would fail. They claimed that the fact that the chemical additive was based on a different carrier than their own material, posed a problem. This last ‘problem’ is a concern that researchers of the development team immediately disregarded based on their material knowledge. Nevertheless, the fear for suboptimal results seemed to form an obstacle for adoption of the innovation. Since practice proved that the additive’s mixing properties were not influenced by the carrier used, these concerns gradually faded away.

The first two problems really needed to be addressed though. In the laboratory the researchers had worked with the latest laser marking systems. In practice however, a mix of new and older lasers was being used. The first version of the additive performed too slowly or not at all with some of the older laser systems. For a time, the development team considered providing every customer with a new laser together with the additive. Buying a new laser for each customer could actually turn out less expensive than incurring the costs of an additional round of development activities. However, when researchers visited a customer’s production site and saw that a production line potentially contained up to seventy laser machines, the idea of giving away one laser per customer was quickly abandoned. Even if a potential customer was using only one laser, this laser was never used in a stand alone fashion. The simple fact that in industrial applications laser systems are integrated into the production line makes switching to another system quite complex. In many cases, it is even impossible to integrate a different laser system into an existing production line.

Customer site visits also enabled the researchers of the development team to correctly interpret feedback. The potential customer firms were urged to send some of the parts produced with the sample material back to the development team. This way, researchers within the development team could analyse the composition of, and laser marking on, the material to find out about the causes of any unforeseen results. At one firm, adding the new additive to the raw material gave fluctuating results. However, in the laboratory the new additive's performance was already very robust. This meant that the optimal relative amount of additive to be added to a base material was known. This specific concentration level delivered good results in a reliable way. The customer firm was using an injection moulding machine to produce parts. While visiting the customer's production site and studying his work flows and equipment the researchers observed that with this type of machine waste material is typically added to the original feedstock at the start of the production process. Continuously adding waste to the initial feedstock can cause fluctuations in the concentration of the additive in the total compound material. A manufacturer who neglects taking concentration fluctuations caused by adding regrind into account risks ending up with suboptimal results. So the manufacturer incorrectly attributed the failure to the quality of the new additive instead of to concentration fluctuations he unknowingly caused himself. By interacting closely with the customer, analysing his end products and workflows on his production site, the true causes of certain problems were identified. These were problems causes that the potential customer incorrectly attributed to additive properties.

Beginning 2004, the team succeeded in developing an additive that performed with all the laser systems in the market. The new additive was sent back to the participating firms for trials. However, the manufacturers were still not completely satisfied. Even though the additive's performance came really close to the promised result, the manufacturers had different kinds of requests now. The laser marking speed on the first grade of the chemical additive was slower than the speed with which they were initially laser marking their material without the new additive. The second version of the chemical additive enabled laser marking to take place at the same speed as they were initially using. However, having experienced the improvement in marking speed the manufacturers were asking for an even faster laser marking speed so they could speed up their production process. Gradually members of the development team had learned that even though they started off by concentrating on delivering superior contrast with their additive, in most market segments superior marking speed is valued more than improved contrast. In sum, this version of the laser grade resulted in blacker marks but at an uncompetitive speed. Consequently product development efforts were redirected towards enhancing laser marking speed while keeping the additional benefit of improved laser marking contrast.

During this phase, there was a brief attempt at cooperation with a raw material producer to co-develop the next version of the laser additive. The raw material producer had offered to investigate alternative carriers for the laser additive but when promises were repeatedly not kept the development team abandoned the cooperation. The team was simultaneously exploring use of the additive in different polymers and application industries. In some the additive technology was successful, for others more research was needed. At the end of 2003 pressure from internal management to generate sales increased and the development team decided to focus on a number of incrementally innovative applications to generate basic sales. At this time, efforts for the security application were halted. The application required more research than foreseen and sales in this industry turned out to be highly unpredictable because of tendering mechanisms. The team focused on application industries that were currently using laser technology for marking their products. Firms in these industries were familiar with laser technology and had already made the capital investment in the laser equipment. In these applications the new laser additive represented an incremental improvement. The business development manager drew Figure IV-3 to depict some potential applications on a laser technology adoption curve. Applications at the upper right end of the adoption curve are targeted for initial sales. More specifically the electrical and electronics segment and tag applications were attainable application segments for the new laser additive.

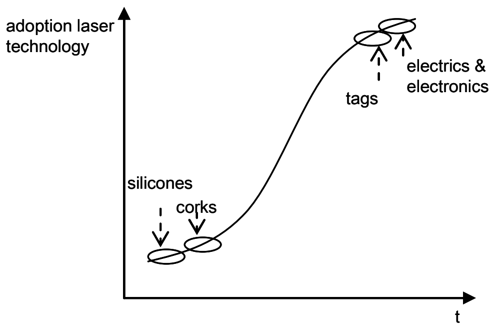

Figure IV-3: laser technology adoption curve

The applications in which the new laser additive represents a radical innovation are situated at the lower left end of the adoption curve. The laser additive enables laser marking on certain materials, such as synthetic corks and silicone rubbers, on which laser marking was impossible before. Efforts to realise these applications had secondary priority from then on since they are not expected to pay off on the short term. They were further developed to secure future growth.

Because of the cumbersome character of the sales process, during the whole year 2004 a service company was hired as a temporary sales force to do prospecting for the new additive on the French market. They generated some important prospects in the tag industry. In October 2004, the team also participated in the biggest, world-wide polymer trade fare. At the fare, the development team was swamped with over 125 enquiries. Before the fare, every interested firm, at its request, received a free sample of the laser additive for trials. To filter out less interested potential customers the team now started to charge a flat fee for receiving sample material.

IV.3.2.3. Beginning 2005 until now

At the beginning of 2005, development of a new, even faster version of the laser additive was completed. The team started scaling up production of this version of the additive and attempted to build a business on this product.

Taking into account that a year is needed to realise a sale of an industrial, technical product, sales efforts of 2004 started to pay off in 2005. Sales were being realised in industries that laser mark ear tags for cattle and lamp fittings of energy saving lamps. The team planned to build on these successes in related application areas. After earlier, failed attempts to cooperate with other firms in the laser market for co-development and/or for reaching customers, by February 2005, a successful deal was agreed upon with a large, renowned raw material producer. The deal was initially a 'joint promotion' agreement where the raw material producer would recommend the new laser grade to its customer base. Later, the cooperation evolved into one where the raw material producer would actually buy the additive to mix it into its material. More recently, the team has allowed agents and master batch producers to distribute the additive. Also, one of the allied laser producers added a new machine to its product portfolio that can be used for laser marking relatively large surfaces at high speed. This laser equipment with big spot size turned out to be particularly well suited for the ear tag application. In this industry, the new laser equipment and the laser additive are jointly promoted.

Currently, the team does not have any sales contracts for repeat orders yet. A big order was obtained at the end of 2005 and negotiations for repeat orders with this customer are still ongoing. Nevertheless other orders start coming in. When comparing business in 2006 to that in 2005, the number of customers, number of orders and total sales has increased by a factor five.

As mentioned earlier, the development team had been trying to realise the synthetic cork application but was blocked by highly specific equipment requirements. Because of the historic focus on industrial applications the development team had allied itself with laser suppliers specialised in equipment for typical industrial applications. As members of the development team became better acquainted with laser marking applications, they learned that laser marking is used in at least two different industries that have quite different systems requirements. In industrial markets laser equipment is integrated in assembly lines. The know-how and equipment of the allied laser firms is in line with these markets' requirements. The synthetic cork application is an example of an application in which laser marking would be used on the packaging of more consumer oriented products, such as foodstuff. The synthetic cork firm had been relying on printing technology for marking its corks, but showed dissatisfaction with the technology's performance. Printing technology puts an ink image on the surface of the cork; laser marking would provide an indelible image right under the cork's surface. This would mean a radical improvement in this industry. Laser marking presents some distinct advantages over ink printing. In mass production it is more cost effective too. Although the initial capital investment costs are comparatively high, they are offset by lower variable costs. Additional savings are achieved due to lower reject and improved flexibility. For applications in the food industry the team also acquired food contact compliance approval for its additive. The team had to find an equipment partner to gain access to the synthetic cork segment. By interacting with potential customer firms their specific system requirements were identified. There was a need for high speed, automated, system integrated laser equipment. Even though the potential of the cork application was already identified in 2002 it took the team until the end of 2005 to find a suitable partner for development of the cork marking equipment. This equipment producer is familiar with both printing and laser marking technologies and automation. The team allied with two more partners for the cork application: a raw material producer, which is a joint venture of the corporate parent, and a producer of injection moulding equipment for producing the corks. Together these four firms will try to gain access to the growing synthetic corks market. Though no actual sales have taken place for the corks application yet, the team now seems to have everything in place to address this market and is presenting its offer together with its partner firms on a trade fare in April 2007. Other radically innovative applications presented different challenges, such as silicone rubbers. Though this application can probably rely on currently available industrial equipment, it requires additional research into the mixing properties of silicone rubbers.

The business development manager herself started prospecting in Japan in 2004. After that, one manager in the Japanese offices of the corporate parent gradually took over market creation in Japan. Also for China, a manager in one of the corporate parent's local offices started developing a market there for the additive from March 2007 on. The US is still handled by the original team in the Netherlands, though distribution of the additive by interested master batch companies is being considered. For Australia and New Zealand agreements have been reached with agents and distributors.

IV.4. An investigation into business networks for technology-based radical innovation

We identify some sub units of analysis to strengthen the results of the case analysis. Since our main unit of analysis is a process, namely the process of building a business from a radically innovative technology, we will be looking for relevant sub processes. Then we investigate the resource interfaces in each of these sub processes to uncover how business networks of firms are involved in the sub process. We start by analysing these sub processes separately. Finally, we return to the main unit of analysis.

IV.4.1. Identification of sub units of analysis

The central problem in the case can be understood as a problem in which the four basic kinds of resources of the 4R model play an important role. In the empirical case a new technology-based ***product***, the laser additive, needs to be fitted into an existing productive system in which the additive is mixed into a base polymer material, shaped into a desired shape and finally marked with the use of laser ***equipment***. The activities in this productive system are spread across different ***firms*** that are linked to each other in inter-firm ***relationships***. The main unit of analysis is the process of building a business from the new additive technology. Since each of the four basic resources plays an important role in this process, for the identification of relevant sub units of analysis we identify four sub processes that each can be closely linked to one of these four basic resources. Pettigrew (1997) defines a process as "a sequence of individual and collective events, actions, and activities unfolding over time in context" (p. 338). Hence, for the identification of the sub units of analysis in the longitudinal case, we code (Miles and Huberman, 1994) events, actions and activities according to the sub processes that are closely linked to the four resource types: products, facilities, organisations and organisational relationships. The result of this exercise is presented in Table IV-1. We identify four sub processes in the empirical case and label them product development, equipment development, sales generation and growth in market scope. Growth in market scope is considered both in terms of geographical growth as growth in the number of targeted applications. Table IV-1 lists the main events, actions and activities

Time	*Product development*	*Equipment development*	*Sales generation*	*Growth in market scope*	
				Geographical	*Number of applications*
2002	- invention of new technological principle for laser additives - first trials on customer material generate technical specifications	- no equipment available for laser marking synthetic corks			- determine initial application possibilities - customer approaches the team for synthetic cork application - silicone rubber application identified - security application identified
2003	- trials generate feedback on problems - customer visits to correctly interpret feedback		- alliances with laser firms - additive launch at laser firm's Customer Day - secrecy agreements with potential customers before running trials	- firms in surrounding European countries show interest	- tag application identified - focus on a selection of applications; security application stopped
2004	- new additive version - development team learns that speed is more important than contrast	- equipment requirements cork application identified by interacting with potential customers	- trials with second additive version - service company hired for prospecting - participation trade fare: 125 enquiries - charge for sample	- US approached by development team - service company prospects FR - business development mgr prospects JP	
2005	- new, faster additive version	- an allied laser firm's new machine fit for ear tag industry - suitable laser marking equipment partner found for cork application	- sales efforts of 2004 start to pay off in ear tags and electrics - cooperation with raw material producer	- agents and distributors for AU and NZ	- additional application possibilities follow from successful applications
2006		- alliances with two more firms to approach the cork industry		- local mgrs start prospecting CN and JP	
2007			- launch of offer for cork application		

Table IV-1: Identification of sub processes in developing a business from radically innovative technology that define each of these sub processes. The first two sub processes closely relate to the technological resources in the 4R model. Product development is the sub process that is most closely linked to the product resource. It is composed of all actions undertaken to develop a market valued product from the fundamental technological invention from May 2002. In the case, product development generally consists of developing an additive from the technology, effectuating trials in the market to generate feedback, interpreting the feedback and fine-tuning the additive to market needs. The equipment development process is closely linked to the equipment and infrastructure, also referred to as the facility in which the new product has to be embedded. Different industries turn out to have different systems requirements for laser marking equipment. The sub process of equipment development groups all the activities, aimed at ensuring development of appropriate equipment for laser marking in existing and new application industries.

The next two sub processes mainly build on the organisational resource types. The sub process of sales generation groups the activities undertaken to reach potential customers and all the actions needed to close a sale. The sub process of growth in market scope consists of actions to generate geographical growth and growth in the number of applications served. In both of these sub processes inter-organisational relationships to other firms are crucial to generate sales or to expand in market scope.

Hence, the case design for this specific empirical case looks like Figure IV-4. We analyse how business networks are involved in the process of building business from a radically innovative additive technology, i.e. the case. The case is situated in a focal firm and in the market for laser additives, i.e. its context. We analyse the case first by investigating the sub processes: product development, equipment development, sales generation and growth in market scope, i.e. the embedded units of analysis. Then we return to our main level of analysis which is the business building process to enable conclusions.

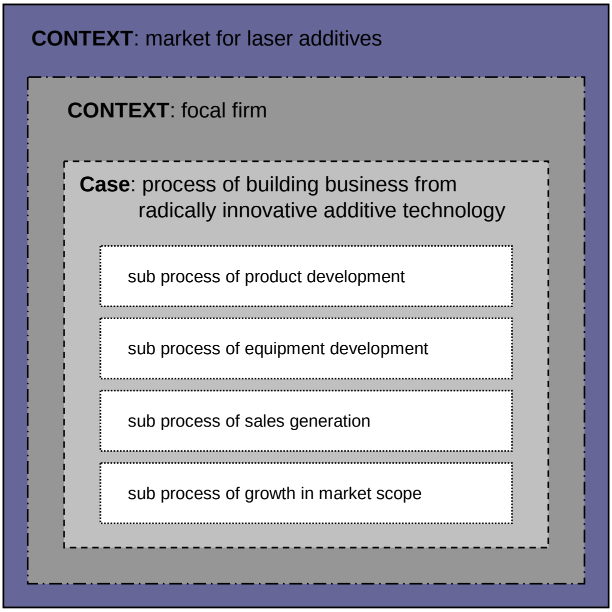

Figure IV-4: Units of analysis in empirical case

IV.4.2. Networking in technology-based radical innovation's sub processes

Having identified four relevant sub processes in the process of building a business from radically innovative technology, we continue by analysing how networks of firms are involved in each of these sub processes separately. For this purpose we concentrate on the central resource interfaces in each sub process. We focus on those resource interfaces which involve a direct interaction between two resources and that affect at least one of them by changing it compared to before the resource interaction. For each sub process we investigate how the main resource within the sub process is related to the three other kinds of resources. Since these resource interfaces stretch across different organisations, studying the interaction between products, facilities, organisational units and organisational relationships will indicate how networks of firms are involved in each of the sub processes.

Product development

The critical resource interfaces that were involved in product development activities are represented in Figure IV-5. The figure shows the logic behind the interactions of the central resource in this process, which is the innovative product, with equipment, inter-organisational relationships and organisational units in the market for laser additives.

Resource interfaces (1), (2) and (3), in the centre of the figure, describe the interaction between the development team and a target customer in the electronics industry in terms of the relevant resource interfaces. This constellation of resource interfaces is involved repeatedly in the context of the product development process and relates the development team to different firms. Every time, resource interfaces (1) and (2) indicate which technical resources each organisational unit brings into the relationship. The numbers represent who took initiative for the interaction. Resource interface (1) represents the initiator. Resource interface (3) is the aim of this inter-firm interaction. In what follows, we discuss the resource interfaces in more detail.

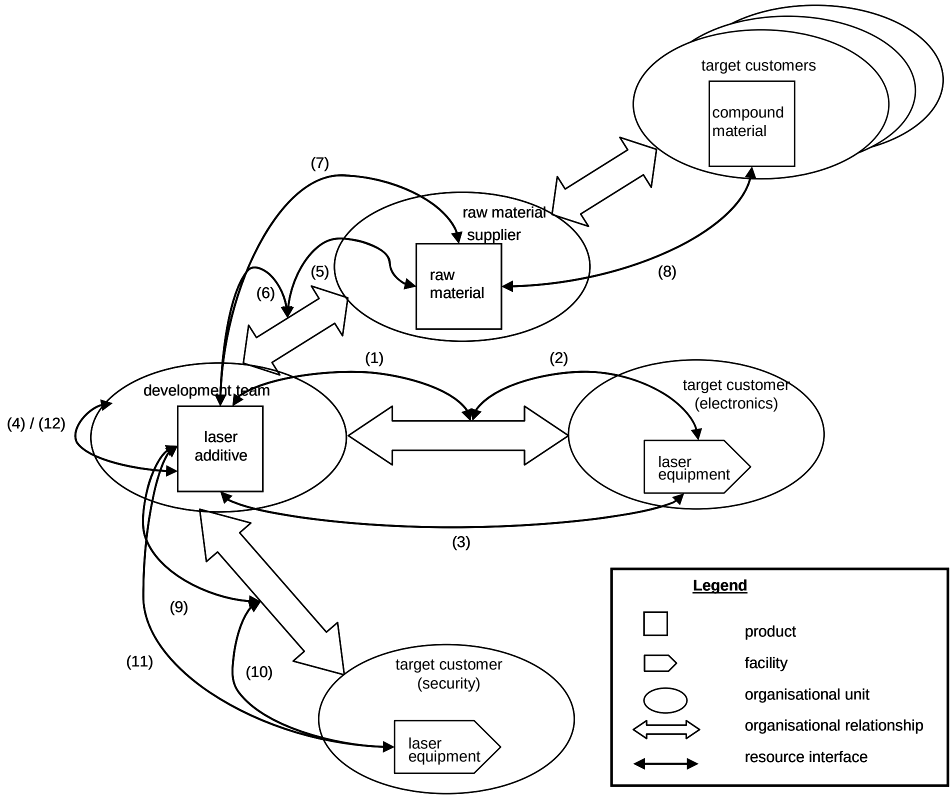

Figure IV-5: Resource interfaces for product development

(1) Based on their innovative product, the focal team started up an interaction with an organisational unit within a target customer firm.

(2) The organisational unit in the customer firm engaged in the relationship as representing the equipment and production infrastructure in its organisation. More particularly, the customer represented its laser equipment which is most relevant to the potential supplier's product.

(3) After several rounds of communication and negotiation both parties agreed to enable a direct technical interface between the potential supplier's innovative product and the potential customer's existing production facility. This technical interface would shed light on the compatibility of the two physical resources and

revealed the adaptations that could be made in product offer and/or customer facility to improve compatibility. In other words, the technical interface revealed whether the innovative product had any economic value for the customer.

(4) As target customer firms provided their feedback on the innovation, there was also a constant interface between the product's technical characteristics and the development team as an organisational unit. The development team needed to decide, as the innovation was changing, if this is the kind of product they wanted to / could offer and the kind of business they wanted to be in. The organisational unit gained its identity from the product under development and, as the figure shows, more indirectly also from the relationships it engaged in (Ford et al., 2003).

The development team was approached by all kinds of firms that are related to the laser marking market. Resource interfaces (5) to (8) describe how a raw material supplier showed interest in the new laser additive technology and offered to engage in a co-development arrangement. The development team responded to the raw material firm's information requests about the laser additive under development, resource interface (6). The firms jointly tested product compatibility, resource interface (7), and the raw material supplier elicited feedback from its own customers on the product, interface (8). As the development team gained experience in inter-firm interactions for the purpose of product development it learned that direct resource interfaces with target customer firms, without an intermediary party, like the raw material supplier, that filters and slows down customer feedback was more efficient. When the raw material supplier also turned out to be less of a valuable co-development partner than initially believed the development team abandoned this cooperation. This shows how difficult it is in unfamiliar markets to assess the quality of potential partners (Beckman, Haunschild and Philips, 2004). From that moment on, the team started to avoid working with intermediaries for product development and tried to get as close as possible to the target customers' facility, cf. resource interfaces (9) to (12). These interactions aimed to enable the technical interface between the ***new*** product and the ***existing*** infrastructures. This was the central resource interface in the product development process. The only way for the new product to gain value is by embedding it into the existing infrastructures in an economically satisfying way (cf. Håkansson and Waluszweski, 2007).

It is also crucial to note that product development activities were not driven by each separate dyad that linked the development team to a target customer's infrastructure. Instead, the team must be viewed as the node via which numerous relationships to a variety of potential usage contexts were indirectly connected to one another. Rather than making choices in terms of which type of customer to serve, the product development process was aimed at identifying the common denominator in the outcomes of all the technical interfaces between 'the new', i.e. the additive and 'the existing', i.e. currently used laser equipment. The aim of the process was to identify the technical specifications of the one product that has economic value in all of these industries and across a wide range of usage situations.

This finding is best illustrated by observing how the development team addressed the feedback from potential customers after the initial launch of the new additive in May 2003. Every customer firm that tried to incorporate the new product into its current production process experienced some kind of problem. However, it was not the case that certain application industries experienced one kind of problem and other industries another. Rather the team looked for more general problem causes and found that addressing speed problems and shortcomings in product-equipment compatibility would enable the additive to create economic value in different industries and usage contexts.

Equipment development

For the equipment development process we focus on the resource interfaces around the equipment in the laser marking market. We observed different constellations of resource interfaces for developments in laser marking equipment in different application industries. More specifically, new equipment was introduced into the tag industry and the synthetic cork industry in differing ways. We discuss each of them by means of Figure IV-6.

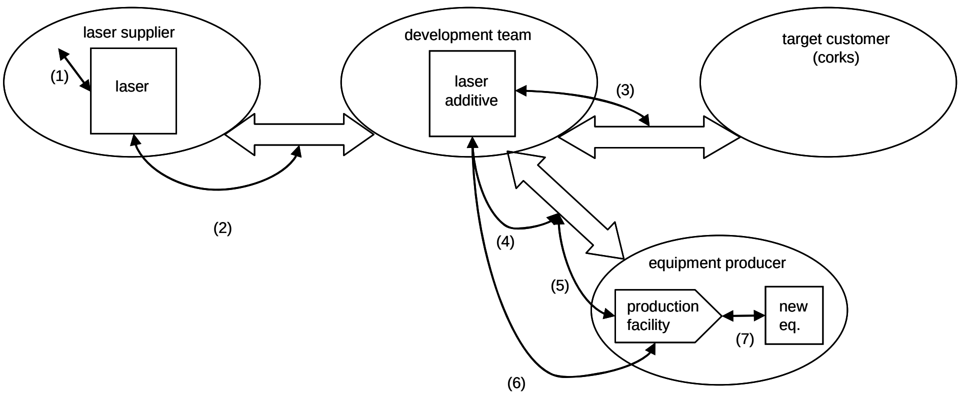

Figure IV-6: Resource interfaces for equipment development

Tag industry

(1) Within a laser supplier firm a new laser machine was added to the portfolio of products. The new machine was originally developed for cutting metal. When evaluating alternative uses for the machine it turned out that this laser was also

particularly well suited for laser marking relatively large surfaces, such as identification codes on animal ear tags.

(2) The laser supplier combined the potential value of the new machine for the tag industry with his relationship with the development team. Both organisations hope to benefit from this development in laser equipment by stressing in their relationships with customers in the tag industry the complementarity of the new laser equipment and the new additive.

Cork industry

(3) The development team interacted with potential customers in the synthetic cork industry to determine the potential economic value of the new additive in this industry and identify the equipment requirements for a laser marking facility for corks.

(4) The development team actively scanned the market for a potential partner that could develop such specific laser equipment. This new laser equipment needs to be compatible with the new additive and meet target customers' equipment requirements.

(5) In these newly established relationships the equipment producer discussed the possibilities he can offer.

(6) Next, a technical resource interface was set up…

(7) ... to enable the development of a new piece of equipment that can be introduced in the cork market.

The analysis of resource interfaces in the case for the equipment development process seems to indicate that new equipment developments involve business networks in a different way depending on whether the equipment is for an existing or a new market. In an existing industry it suffices for the development team to have the relationships that enable it to stay up-to-date with the latest developments in equipment. Then the team can adopt a ***reactive*** attitude to ongoing developments in equipment for existing laser marking markets by making the link between the new equipment, its own product and customers for whom the development may be relevant.

In radically new application industries the development team has to take a much more ***proactive*** role as initiator of the equipment development process. In addition to identifying a suitable equipment partner and convincing it to develop laser marking equipment, the team also has to bring together partners that can supply the needed complementary products and equipment. In the empirical case the development team adds another three firms to complete its offer for the synthetic cork industry: a laser marking equipment supplier, a raw material supplier and a moulding equipment supplier. Partnering with this group of firms enables the development team to offer an integrated solution both for current synthetic cork producers that want to switch from printing technology to laser marking technology and also for current users of natural corks that want to switch to laser marked synthetic corks altogether. Assembling such a complete offer requires considerable, active networking for the identification and scanning of potential partner firms.

Sales generation

The development team gradually engaged in different tactics for trying to sell its new additive. These different approaches sometimes occurred simultaneously. They are combined into the resource interaction figure below.

Organisational links to other firms were instrumental in the process. Chronologically, the different ways of generating sales can be discussed in stages. In Figure IV-7, the first stage concerns the resource constellation to the left of the development team. In the next phase the team engages in the resource interfaces depicted on the right side of the development team. The resource interfaces below the development team denote the most recent development in the process of sales generation. We will discuss the different resource interfaces in the order that they, more or less, chronologically took place.

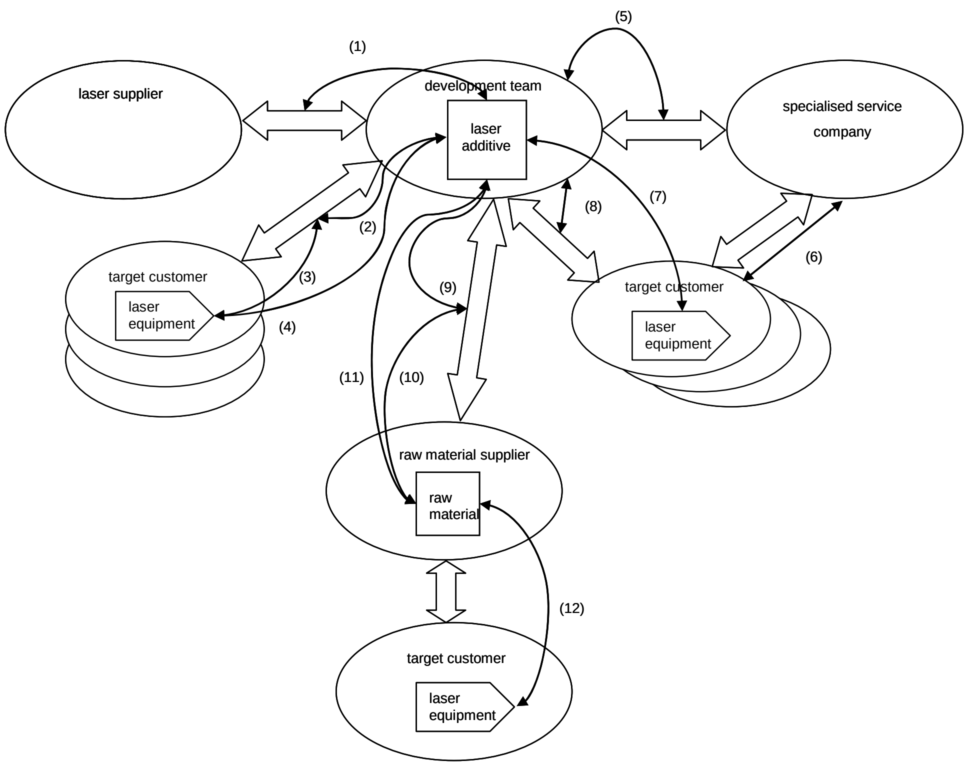

Figure IV-7: Resource interfaces for sales generation

Resource interfaces (1)-(4): tapping into a laser supplier's customer base.

(1) Initially, the development team tried to reach customers via its relationship with a laser supplier.

(2) The development team gained an opportunity to tap into the laser supplier's customer base and used its new additive to create relationships with these potential customer firms.

(3) Some firms showed interest and provided their feedback on the proposed product.

(4) The aim was to enable a technical, physical interface between the new additive and the customer's existing laser equipment. This is an important step in the selling process.

Resource interfaces (5)-(8): generating sales via a specialised service company.

(5) In a next stage, the development team approached a service company that specialises in prospecting industrial markets for new technical products.

(6) The service company scanned the market for potential customers and handled the communication with them.

(7) The actual technical interface was still dealt with by the development team itself.

(8) The service company was hired for approximately a one year period. It takes about a year to establish sales from customer relationships. The development team started to generate sales from the relationships with target customers about a year after it hired the service company to set up these relationships.

Resource interfaces (9)-(12): generating sales via intermediate customers.

In a transition phase to an additional way of generating sales involved several firms, like the raw material supplier in Figure IV-7, linking up with the development team and agreeing to promote the new additive as the additive of choice to their own customers. This informal cooperative arrangement was sustained for as long as it took to get the new additive technically approved by the intermediary firm as well as by the intermediary's own customers. Since technical approval procedures take about a year, in this case, a one year period was gone through by the intermediary firm and, after that, another year was needed to get the approval of the end user firms. In effect, after approximately two years the informal co-promotion agreement was transformed into the genuine distribution arrangement that was the ultimate goal of the cooperation. The resource interfaces for generating sales via an intermediate distributor are summarised by interfaces (9) to (12):

Arrows (9) and (10) indicate that development team and an intermediate customer, a raw material supplier in this example, approached one another. At this stage in the innovation project the team was also approached by firms in the market that wanted to distribute the additive. Hence arrows (9) and (10) can switch order. This put the development team in a more favourable position, since it could choose which firm(s) to work with.

Arrow (11) shows that it is still important to evaluate compatibility of the two products in a technical interface.

(12) Next, a procedure similar to the one the development team went through with its direct customers was gone through by the distributing customer and the target customers to enable the technical interface that is a first step in the approval procedure for a sale.

Whereas initially the sales process and the product development process were intertwined, as the innovation project matures, these two processes became more separate. The development team was able to lessen its control over the customer communication and relationship management activities. This made it possible to involve intermediate parties in the sales process that could concentrate 'fully' on establishing customer relationships and generating sales. The case shows that two very different kind of intermediaries fulfill this task: a service company specialized in prospecting industrial markets for technological products and firms within the laser marking market, such as raw material suppliers and master batchers. In the kind of business networks that emerge in the third stage of the sales generation process, the evaluation of the technological interface between the new product and the existing customer infrastructure also shifts away from the development team. Now, it is the customer organisation itself that evaluates the compatibility of these technical resources.

Geographical growth

Geographical growth of the new additive business has for the main duration of the innovation project been managed by the development team itself. It is not until the sales generation process reaches the final stage of the sales generation process that two additional strategies for geographical growth emerged. One, via personnel in the corporate parent's local offices activities for growth in China and Japan were delegated to local managers. These managers received their training with the development team in Europe. Second, in the sales scenario that involves intermediate customer firms, these intermediaries were selected for the desired geographical coverage of their own customer base.

Growth in number of applications

Figure IV-8 depicts the critical resource interfaces for the sub process of growth in number of applications.

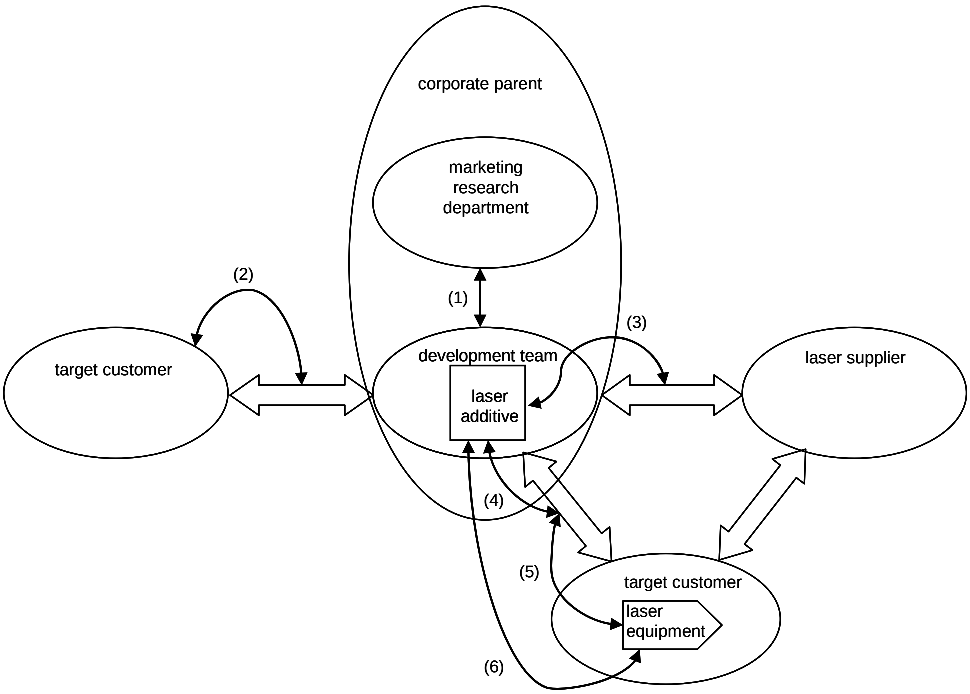

Figure IV-8: Resource interfaces for growth in number of applications

(1) Initial application possibilities for the new additive technology were generated in a desk research study by the marketing research department of the corporate parent of the development team.

(2) As news spread in the market about the new additive technology some current customers approached the team to have it investigate the potential of their technology for their specific application.

(3) Next, the relationship with a laser supplier was used to approach potential customers. Some of these customer firms were situated in application industries that the team had not identified yet. Arrows (4) - (5) and (6) indicate that the potential of every new application has to be verified by building an inter-firm relationship that allows for a direct, physical technological interface.

Next, the team also tries to multiply successful applications into related applications. For example, it tries to multiply from the laser marking application in tags, to laser marking on sport shoes and cable and wire. These potentially new applications use the same base material as tags. Alternatively, the team is also exploring the possibilities of developing from synthetic corks into caps and closures to realise a laser marking application for bottle caps.

The development team started its initial application search relatively close to its familiar markets. The case shows how a growing and ever-changing network of firms enables the development team to explore application possibilities in ever more unfamiliar markets.

IV.5. Findings on the involvement of business networks in technology-based radical innovation

When we return to the main unit of analysis, i.e. the process of building a business from a technological invention with radically innovative potential, we have established that business networks play a crucial role in all of the studied sub processes. Not only do the sales process and the process of growth in market scope benefit from an elaborate business network but also the more technological sub processes like product development and equipment development depend on resource interfaces that span business networks. The analysis of the resource interfaces shows that no matter from which basic resource the innovation process is approached, be it the innovative product itself, the complementary equipment needed to use it or the inter-organisational relationships to other organisations that enable sales generation and growth in market scope, in every case networks of firms are involved in the process.

The product development process can be regarded as being essentially driven by technical interfaces. But the fact that these technical interfaces occur across organisations, mainly supplier-customer, makes the social logic behind the technical interface at least as crucial for the success of the product development process as the technical expertise involved. Also in the equipment development process the social dimension is an important facet of the process. Though, again, the technological interface is the driving force in inter-firm relationships aimed at developing equipment in an existing or for a new laser marking application industry. It may be quite evident that the process of generating sales is dominated by an economic logic. Nevertheless, the case shows that establishment of customer relationships, an activity of a social nature, is key for generating sales of a technical product in industrial markets where it takes approximately one year to get a new product approved by target customers. Moreover, these relationships are permeated by technological considerations. In a similar vein relationship building for geographical growth is mainly driven by an economic logic. The process aimed at increasing the number of applications for the new additive shows again that technical and social drivers are closely intertwined, and that technical considerations tend to drive inter-firm interactions aimed at building relationships within which new technological possibilities are explored. The case shows that the innovation has been formed in a business network in which technical, social and economic considerations are inseparably combined (Håkansson and Waluszweski, 2002, p.48).

This research also shows particularly well how a new business is born into a network and the mutually influencing effect between the innovation, on the one hand, and the network, on the other. The network shapes the new business's identity and, along with the changing identity of the business, the content and structure of the network around it also change (Ford et al., 2003). As the development team develops its product and its relationships, all its relationships also undergo change. Initially the team is approached in a relatively open way by all sorts of firms. However, when the new additive technology starts to fit into existing resource constellations in an economically valuable way it gains concrete economic value. As this economic value starts to appear, the team is also approached differently in its current and new relationships. For example, a related business group within the corporate parent was initially not interested in the new technology. However, as the additive develops, managers within the related business group not only begin to show interest but they also start to fear competition. Organisational units that were initially addressed by the team 'only' to gain access to market information, once responded openly but increasingly start to see a supplier with an attractive offer, a potentially interesting partner and/or a competitor. This also influences the content of these relationships, not only in terms of the kind and amount of information shared but there is also a shift from information sharing to an increased negotiation for value in the relationships.

The empirical case also shows how one resource, the innovative product, can have a different economic effect in different industries. The same additive technology results in an incremental improvement in certain industries and a radical improvement in other industries. This observation relates to the heterogeneity of resources as also described by Penrose (1959). She argued that any single resource can provide a variety of productive services. Håkansson and Waluszweski (2002) stress that a resource's various productive services are made manifest by embedding it in different resource combinations. The value of the additive technology differs according to the resource combination in which it is embedded. Not only does embedding in a different set of resources lead to value that is different in absolute terms, the comparative value improvement between the value offered with the new technology and the value created with the previously used solution also determines whether a new offer creates an incremental improvement or a more radical one.

Finally, in terms of the structure of the business network around an innovation we observe that, not surprisingly, there seem to be more and more diverse partners needed to realise a radical innovation in a new market, compared to realising an incremental innovation in an existing market. For the latter situation we observed how existing relationships can support the introduction of an incremental innovation. Creating a new market for a radical innovation is more likely to involve scanning the market for suitable partners and forging new relationships with quite diverse types of firms.

IV.6. Conclusion

The aim of this chapter was to investigate how networks of firms are involved in technology-based radical innovation by analysing the resource interfaces that drive the process of building a business from a radically innovative technology. We applied a research tool that distinguishes between four basic kinds of resources: products, facilities, organisational units and inter-organisational relationships. These resource types guided the identification of four sub units of analysis in a longitudinal case: product development, equipment development, sales generation and growth. In the analysis of the case we started out from an investigation of the critical, direct resource interfaces in each of the sub processes to uncover how networks of firms are involved in these sub processes. In the product development process a network of firms provides highly relevant feedback on the technological interface between the innovative product and the equipment it needs to become compatible with. The development team faces the challenging task of identifying the common denominator in feedback that is generated in firms from different application industries with facilities that differ both within and across these industries. For the equipment development process existing relationships provide information on updates in equipment for existing industries. A more elaborate network with diverse partners needs to be established in an active way to drive the development of equipment needed to introduce the innovation in radically new application industries. In the sales process sales activities are gradually delegated to a network of firms that spans an ever growing geographical area. For the growth process in terms of the number of applications served, the search for new application possibilities is extended ever more deeply into relatively unfamiliar markets via a growing network of firms.

The analysis of the resource interfaces in the four sub processes of technology-based radical innovation shows that in every sub process technological, organisational and economic considerations result in the involvement of a network of firms in the innovation process. This shows both how a network is forged in line with the business under development and also how this network shapes the business itself. We find that one resource can mean an incremental or a radical improvement depending on the resource constellation into which it is integrated. Finally, we notice that developing an innovation for an industry in which it causes a radical improvement involves a more active approach to forge an elaborate network across a larger variety of actors than an incremental innovation would need.

CHAPTER V

CONCLUSIONS

V.1. Key findings

The research in this dissertation showed that inter-firm interactions pose very specific challenges in the context of technology-based radical innovation. We focused especially on interactions with customer firms. Customer involvement in radical innovation has been a contested issue on the basis of at least two arguments. One is that current customers are observed to urge their suppliers to concentrate on incremental improvements rather than radical innovations (Christensen, 1997). The second argument is based on the notion that radical innovations address latent needs in ways that customers would never be able to imagine (Leonard and Rayport, 1997). The first argument is countered by the observation that radical innovations often reach beyond a firm’s current customer base to new prospective customers in unfamiliar target markets. In such a scenario, interaction with customers is a means to explore habits and needs in unfamiliar markets (Chandy and Tellis, 1998). For the second argument extant literature confirms that traditional market research techniques are not able to solicit customers’ needs for radical innovations. However, more appropriate techniques are becoming available (Leonard and Rayport, 1997; Herstatt and von Hippel, 1992; McQuarrie, 1993). Nevertheless, inter-firm interaction, and customer interaction especially, is a relatively unexplored area in the research of radical innovation – see Table II-1 for an overview of extant literature on the topic. In three scientific studies we covered different aspects of inter-firm interaction for technology-based radical innovation with specific attention for the interaction with customer firms. Because of the learning process in completing a PhD, these studies evolved in terms of research topic, theoretical approach and methodology. The evolution in methodology is discussed in the first chapter. In this final chapter we focus on the evolution in the theoretical approach to both the innovation process and inter-firm interactions as a point of departure for a discussion of the evolution in the research results of this dissertation.

In Chapter II the innovation process was perceived as an essentially supplier managed activity because of the technology push involved in technology-based radical innovation. Hence customer interaction was also mainly regarded as an activity that was controlled by the supplier. We investigated to which extent customers contributed solution and problem information (von Hippel, 2005; 1988, 1978) to the innovation process. The key finding in Study 1 was that if customers contributed to technology-based radical innovation in its early phases, they did so by providing solution information. In the early phases of innovation, customer firms could identify an (additional) application area for the new technology or helped determine its most important performance criteria. As the innovation process progressed, the customer's contribution was increasingly composed of problem information. This problem information concentrated on indicating where and how the innovation failed to fit into the customer's current production system. This information was valuable to a supplier in the sense that these resource interfaces had to be inspected and addressed in an economically valuable way in order to be able to introduce the innovation to the larger market.

Though interactions with customer firms were, at the outset of the research, regarded merely as instances of customer input into the supplier's innovation process, the study showed that a more balanced approach to customer/supplier interaction for technology-based radical innovation was needed. The multiple case research revealed that customer interaction was not necessarily 'supplier managed'. Industrial customers were able to correctly assess the potential value of a new technology for their usage situation and become the initiators of an innovation cycle in which this application possibility is explored. Two conditions enabled customer firms to identify opportunities for radical innovation. One condition is that they should have the relevant technological know-how. Especially highly integrated firms in industrial market have a knowledge base that can enable them to recognise opportunities for radical innovation. The second condition is that the new technology has to be known to these customer firms. This can be achieved by a purposeful communication strategy or by having other applications of the new technology already in the market. In the development phase, innovation could become the joint aim of a customer and a supplier that engaged in relatively close cooperation. However, the firms would still be dealing with a young, unstable technology with radically innovative potential but unproven economic value. In Study 2 we researched how customer/supplier cooperation can facilitate innovation in this highly uncertain context of technology-based radical innovation.

Chapter III reported on the results of Study 2. In this study the innovation process was perceived as an interactive process between a customer and a supplier that engage in close cooperation. The technology-based radical innovation was the joint aim of the two firms. Inter-firm interaction evolved in this study to a more balanced activity than was assumed in Study 1. In the cooperation, responsibilities for initiative, investment and commitment were more evenly distributed among the two partners. Since the link between uncertainty and the cooperation was central in the study's research aim, we invested considerable effort in the development of a relevant conceptualisation of uncertainty. We combined different aspects of uncertainty that were identified in various fields of study. These aspects were: whether the uncertainty could be influenced (Folta, 1998), where it originated from (Leifer et al., 2000; Moriarty and Kosnik, 1989) and how it was related to information and knowledge (Nyström, 1974). These conceptual aspects of uncertainty were applied to and interpreted in the context of the case.

With regard to the first aspect of uncertainty the cooperation process influenced the distinction between endogenous and exogenous uncertainty. By choosing to engage in a close cooperation particular areas of uncertainty that were fully exogenous before became partly endogenous. Through this endogenous component of uncertainty each firm in the cooperation managed to partly reduce its uncertainty. Main example from the empirical case was that the supplier reduced its market uncertainty by linking with a customer. The latter reduced its technological uncertainty by means of the cooperation. Second, the general areas where uncertainty originated from were refined to suit the context of a cooperation process between customer and supplier for technology-based radical innovation. The areas of application uncertainty and transaction uncertainty were introduced and market, resource and organisational uncertainties received a different connotation in the cooperation. This conceptualisation illustrated particularly well how the different areas of customer and supplier uncertainty were interrelated within and across firms. In the empirical case uncertainty was reduced in the customer/supplier cooperation through compensating levels of application uncertainty. The customer understood the value of the new fibre technology for its application and succeeded in communicating this solution information to the supplier after several interactions. This in turn, gradually reduced the supplier's uncertainty about the technical specifications for a new application of its radically innovative technology. A third conceptual aspect of uncertainty took into account that information can only be interpreted as valuable knowledge if a person knows how to combine different pieces of information in a relevant way. These linkages between pieces of information are cognitive structures (Nyström, 1974). In the empirical case the supplier was initially unable to correctly process the solution information that the customer conveyed. It was only after repeated interactions between customer and supplier that the supplier learned how to combine performance criteria in the application industry with the technical characteristics of its new technology in a way that revealed the economic value of the technology in this application industry. Thereby the supplier's uncertainty about whether or not to pursue this application was lowered.

Additionally, the case revealed that extensive contracting was not necessarily a part of customer/supplier cooperation for technology-based innovation. Moreover, the uncertainty involved made contracting an expensive option with limited feasibility (Nooteboom, 2004). Instead, tasks and responsibilities were constantly being (re)negotiated in the face of each intermediate challenge in the innovation process. Such informal procedures were quite sensitive to changes in the context of the cooperation. In the case, the customer's trust and openness diminished after the supplier started interacting with the customer's competitors. This was an important indication of how the innovation process in a dyadic relationship is indirectly influenced by each partner's other relationships. In other words, the case revealed the need to investigate the innovation process as being situated in a network of firms.

Chapter IV reports on a third study. In Study 3 we investigated the role of networks of firms in technology-based radical innovation. In this study the theoretical approach to the innovation process stressed the interrelatedness of the different components in a larger technological system (Rosenberg, 1982, p. 55-80). A new technology-based product, i.e. the innovation, needs to be embedded into potential customers' current technological and organisational systems in an economically valuable way. This requires identifying and adapting the critical resource interactions that enable a fit between the innovation and customers' usage contexts. In Study 3 inter-firm interactions were studied in the context of a network of firms.

We investigated the role of business networks in innovation by analysing the resource interfaces that enabled the translation of a new technology into an economically valuable product. For this purpose we applied a research tool named the 4R model (Håkansson and Waluszweski, 2007). This model was developed for the analysis of business networks. It concentrates on four basic kinds of resources: products, facilities, organisational units and inter-organisational relationships. Products and facilities are technological resources. Organisational units and relationships are organisational resources. Also, four sub processes of innovation were identified: product development, equipment development, sales generation and growth in market scope. The first two sub processes relate to the technological resources. The next two sub processes have a more important organisational component. The analysis of the critical resource interfaces showed that, no matter which basic resource dominates in a sub process, business networks played a crucial role in each of these sub processes. Even the predominantly technological processes such as product and equipment development relied on a network of firms. The realisation of a radically innovative application required a more active approach to establishing a relatively elaborate network with a larger variety of actors than incremental technological applications required. The empirical case showed that an innovation's value varied according to the resource constellation it was embedded in. The relative improvement in value compared to the previous solution also determined whether the innovation was of an incremental or a more radical nature. In the case, both incremental and radical innovations originated from one and the same technology. This research demonstrated the relevance of taking the business network into account in a study of technology-based radical innovation. The study showed how the innovation was shaped in a network of firms, but also how the network itself was shaped by the evolving innovation.

In sum, the three studies in this dissertation revealed that customer and other firms contribute to technology-based radical innovation in a large variety of ways. In the relatively narrow, supplier centred perspective of Study 1 it became already clear that, contrary to the expectations of some researchers, customer firms can contribute meaningfully in every phase of the radical innovation process. In industrial markets, customer firms with broad and specialised technological knowledge bases can identify the latent potential in the new technologies that they are confronted with. Customer firms may be willing to co-invest in a joint innovation process with a supplier. Study 2 showed how such close cooperation facilitates innovation by reducing the uncertainty involved. Since contracting has only limited feasibility under the uncertain circumstances of radical innovation it is crucial to keep the customer interested in the innovation process. The supplier also needs to consider the effect of his other relationships on the customer/supplier cooperation. Study 3 aimed to take such indirect effects of relationships into account by adopting a network perspective for the investigation of inter-firm interaction for technology-based radical innovation. The research showed that not only the sub processes with a clearly social component, such as sales and growth in market scope, rely on a network of firms. Also the technology-driven sub processes of innovation, such as product and equipment development, required a network of firms to enable the identification and investigation of the resources with which the innovation under development needed to be combined in an economically valuable way. From a network perspective, the technological innovation's value varied depending on which resources it was combined with. In some resource combinations the technological innovation presented an incremental improvement while in other resource combinations it brought about a more radical change. It is important to note, that for one and the same technology both levels of innovation can be economically feasible at the same time and that the incremental innovations can create a supportive environment for the more costly and time-consuming radical innovations. Finally, realisation of radical innovation requires a more active approach to establishing a more elaborate network with a greater variety of firms.

The research in this dissertation is complementary to quantitative studies of innovation. Quantitative studies concentrate on researching the extent and the forms in which innovation prevails in society. These studies investigate business networks predominantly in terms of their structure by focusing on parameters such as centrality, connectivity and embeddedness (e.g. Yli-Renko and Autio, 1998; Hagedoorn, 1995). Statistical generalisation was not an aim of the aggregated research in this dissertation. The conducted case-based research did contribute to extant literature by showing in-depth how inter-firm interactions, especially with customer firms, enabled technology-based radical innovation. The research provided a rich account of the possible ways customer firms can be involved throughout the technology-based radical innovation process. The complex phenomenon of uncertainty was explicitly studied in the context of customer/supplier cooperation for technology-based innovation. An investigation based on rich, longitudinal accounts from managers in multiple firms researched the mechanisms that drive network formation for innovation.

V.2. Recommendations for future research

In Study 3 we found that innovation's sub processes were not carried out as sequentially as typically represented by stage-gate models (Cooper, 1990; 2006). Though we came across stage-gate inspired management models in our sample of firms (Ettlie and Elsenbach, 2007), we observed how the various sub processes of innovation tended to, at least partially, take place *simultaneously*. For example, attempts at sales were made immediately after availability of a first version of the innovation. Hence, in technology-based radical innovation, generating sales was not a final activity that took place after development was successfully and completely carried through. In the process of attempting to establish sales, information was gained that, on one occasion, indicated that additional product development needed to be done and, on another occasion, lead to the identification of an unforeseen additional application opportunity. This observation showed how the various sub processes took place simultaneously. Since these sub processes were interrelated, at times an unforeseen setback in one of them blocked the innovation process as a whole; at other times an insight generated during one sub process accelerated progress in another activity. This kind of flexibility is described as a must to deal with uncertainty in industrial markets (Fredericks, 2005; Santiago and Vakili, 2005). Further research could concentrate on identifying additional, intra- and inter-firm manifestations of flexibility in the uncertain context of technology-based radical innovation.

We also recommend further research into the distinct *iterative* character of technology-based radical innovation. The iterative character of innovation was also referred to by Jolly (1997). Such iterations contribute to the highly unpredictable character of the innovation process. In Study 2, one respondent referred to Hofstadter's law to describe the iterative character of technology-based radical innovation. Hofstadter's law is "*It always takes longer than you expect, even when you take into account Hofstadter's Law*" (Hofstadter, 1979). The iterations in technology-based radical innovation could take place between sequential processes, e.g. in a supply chain, or between simultaneous processes, e.g. sub processes in innovation. Extant literature refers to iterative processes in different terms and in varying contexts. For example, in the context of marketing technological innovations a probe and learn process is observed (Lynn et al., 1996), for development of equipment von Hippel and Tyre (1995) assign an important role to the process of learning by doing and in networking activity controlled experimentation processes are observed (Ford et al., 2003). For further investigation into the role of iterations in innovation we suggest adopting a learning perspective (Huber, 1991). Iterations in the innovation process could be researched in terms of the extent to which they present oscillation between explorative and exploitative learning (March, 1991) and the extent to which they are an intra-organisational or inter-organisational phenomenon (Brady and Davies, 2004; Larsson et al., 1998).

The empirical cases involved inter-firm interactions that spanned distant geographical areas. Several interviewees experienced the influence of cultural differences. Interviewees did not only refer to the differences in managerial practices across continents. Also cooperation among different European countries was subject to the influences of differing national cultures. Since we observed that such cross-cultural interactions are an integral part of technology-based radical innovation we recommend that research as that of Souder et al. (1997; Souder and Jenssen, 1999; Souder and Song, 1997; 1998), that explores cultural differences in innovation practices, be continued in the specific context of technology-based radical innovation.

The research in this dissertation addressed radically innovative technology-based products in industrial markets and concentrated on the role of inter-firm interactions, with a focus on interactions with customer firms. This research topic contains at least four parameters that can vary to yield additional interesting research foci. These four parameters are: the basis of radical innovation, the level of innovativeness, whether industrial customers or private consumers are involved and whether product, process or service innovations are studied. Many of the possible combinations in these parameters provide interesting research opportunities. We give some examples here. First, besides from new technology, radical innovations can also originate from organisational or economic aspects of the firm. It could be interesting to investigate the role of inter-firm interactions in radical innovations that are based on organisational change or the development of radically innovative business models. This research could investigate the role of benchmarking in the development of these innovations. Second, comparative research into the role of inter-firm interaction in technology-based incremental innovation can contribute to extant literature by emphasising the differences between incremental and radical innovations. Third, it can be useful to research in-depth how private consumers can contribute to innovations aimed at consumer markets. This kind of research might reveal a variety of practices that could inspire managers for developing their own specific tools to solicit current and potentially new customers' needs. Fourth, innovations usually combine product, process and service aspects in varying degrees of importance. Further research could concentrate on the extent and the way in which inter-firm interactions influence each of these components of innovations.

V.3. Managerial implications

This dissertation presented three ever more broadly defined approaches to the role of interactions with customer and other firms in the technology-based radical innovation process. Gradually, the importance of taking the business network of a firm into account became clear.

Managers involved in technology-based radical innovation projects may find customer interactions difficult and cumbersome to deal with. Nevertheless, according to the research in this dissertation such interactions can hold valuable opportunities. In industrial markets, it is useful to investigate customer requests for linking a technology to their usage situation. In interaction with potential customer firms additional application possibilities for the innovative technology can be identified. Managers can benefit from considering the value of a radically innovative technology in unfamiliar industries. Potential customer firms can help managers identify the technical specifications of an application and provide occasions for investigating and adapting the critical resource interfaces that enable adoption of the innovation. It is important that managers recognise this potential in their current and new relationships with other firms. Especially for the realisation of technology-based radical innovations managers need to be able to rely on the goodwill of managers in customer firms but also in firms of complementary products and equipment. Because of the limited feasibility of formal contracting in the highly uncertain context of radical innovation managers are responsible for guaranteeing the continuation of valuable cooperative relationships in a number of other ways. For one, managers need to make sure that their partners in other firms perceive enough of the value in the technological application to see the turbulent radical innovation process through. As long as there is no commercial product available, partner firms experience no direct gains from enabling the supplier to learn by providing him with access to their expertise and infrastructure. Managers in customer and other firms tend to abandon the cooperation when they do not perceive the potential value in the technology. Managers in the supplier firm need to monitor their partners' perception of this value. Second, suppliers and customer or other partner firms can stimulate the continuation of valuable cooperative relationships by gaining trust. In relationships with an important technological component trust is gained by showing competence in the face of the challenges that the radical innovation process poses. Third, managers should also take into account the effect of their other relationships on valuable cooperative relationships. In innovation processes that rely on a network of firms it is important for managers to realise that technological, social and economic interests are closely intertwined. Moreover, as the innovative technology evolves the relationships around it and the stakes of the partners involved also change. In this dynamic context it is important for managers to consider each individual relationship as a part of a larger constellation of relationships. A balance needs to be found between continuing current relationships for as long as they are valuable and developing new relationships. New relationships may provide access to unexplored resource combinations that reveal additional, economically valuable ways of embedding technology-based innovations in application industries.

Last, we do not ignore the demanding managerial context of a radical innovation process whose progress inevitably requires failures, iterations, high costs and a long time span before financial gains materialise. This kind of innovation process benefits from a supportive managerial environment in which learning is stimulated and that provides possibilities for flexible planning and budgeting. Especially the time dimension is a subtle parameter in technology-based radical innovation. Managers need to take the risks into account of investing all available resources in the exploration of one or more technology-based radical innovations. This increases the likelihood of having the project killed by internal management for the complete lack of short or medium term returns. A sensible option might be to invest in technology-based radical innovation to the extent that internal and external circumstances allow it. In a context where short term results are highly valued, as is the case in many of today's large firms, it might be appropriate to consider developing incremental innovations parallel to the development efforts for radical innovation. If the technology's cost structure and the corporate pricing policy allow for the realisation of incremental innovations, successful incremental applications can provide a supportive environment for the more radical technological applications. Dividing attention between incremental and radical technology-based applications can secure gradual progress in the more radical innovations.

APPENDIX: survey to assess potential to radically innovate

RADICALNESS OF THE INNOVATION

1. The product offers

□ **unprecedented performance features** (=> go to question 4)

□ **familiar features** (=> go to question 2)

2. The product embodies familiar features that offer the potential for five- to tenfold improvements in performance.

Highly likely				Highly unlikely
1	2	3	4	5

3. The product embodies familiar features that offer at least 30% reduction in costs.

Highly likely				Highly unlikely
1	2	3	4	5

4. The product creates a new line of business for the firm.

I totally agree				I totally disagree
1	2	3	4	5

5. The product creates a new line of business for the marketplace.

I totally agree				I totally disagree
1	2	3	4	5

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