

Adopting radical innovation from outside: Promoters as the linking pin

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IFSAM-Conference Paper 2006:

Track 6: Technology and innovations in the global economic geography

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Abstract

In this paper we explore how radical innovations from an external source, here user innovators, are adopted by established firms. This research question is examined by a multiple case study analysis in the high-tech field of medical equipment technology. We find that established firms face substantial barriers to adopt radical innovations from outside. Such barriers include the 'not invented here syndrome' and high uncertainties on both the technological and market dimension. Furthermore, the radical innovations departed from the core competencies of these firms. Individuals within the established firms who had both a boundary spanning position and relevant expert knowledge recognized the technological opportunities of the radical user innovations. They convinced top management to invest in the radical innovations which ultimately led to their adoption. The radical innovations became major commercial successes. Based on these findings we offer implications for intrapreneurship research.

Keywords: *Radical innovation, intrapreneurship, promoters*

Introduction and overview

In today's environment of rapid technological change companies can not rely on incremental innovations alone. To sustain long-term competitiveness companies need to develop radical innovations as well. Such innovations typically incorporate new and highly complex technologies, shift market structures, require user learning as they often induce significant behaviour changes on side of the users (Lynn et al., 1996; Urban et al., 1996). Examples of radical innovations are the first mobile telephones, the internet with its first applications, fuel cell driven automobiles as well as medical robots. To enhance the ability to develop and commercialize radical innovations, firms need to leverage external sources of radical innovation besides in-house development efforts (Chesborough, 2003). It needs to be considered, however, that there are severe barriers within established firms to adopt radical inventions from external sources. Externally generated inventions and innovations may become a victim of the 'not invented here syndrome' and therefore be rejected (Vandermerve, 1987; Mehrwald, 1999). Furthermore, radical innovations obsolete organizational routines of established firms and require the development of new routines which is difficult, costly and risky (Hannan & Freeman, 1977; Nelson & Winter, 1982; Tushman & Anderson, 1986). Established firms have less incentive to invest in the development and commercialization of innovations that undermine the value of those assets that they already possess (Ghemawat, 1991; Shane, 2001). In this connexion radical

innovations induce the cannibalization of existing product lines, yet another substantial barrier to invest in radical inventions (Chandy & Tellis, 1998; Nijssen et al. 2005).² Radical innovations are often based on solutions which are completely different to the solution type an established manufacturing firm is specialized in. They are therefore not the logical extension of the established firms' knowledge base and thus difficult for these firms to understand and evaluate (Rosenbloom & Christensen, 1994; Shane, 2001). In addition, inertia induced by bureaucratic structures limits established firms' willingness to invest in radical innovations (Tornatzky & Fleischer, 1990; Acs & Audretsch, 1991; Ghemawat, 1991; Mitchell & Singh, 1993). Finally, the fixedness to the voice of mainstream customers (Bower & Christensen, 1995; Christensen, 1997) can hinder incumbent firms to devote resources for radical innovations. On the other hand established firms have great opportunities to adopt radical inventions. In particular, established firms have financial and technical capabilities which they can harness for the exploitation of technological opportunities based on radical inventions (Galbraith, 1952; Ali, 1994). They also have the economies of scope to spread the risks that radical innovations are associated with (Arrow, 1962; Galbraith, 1968). Furthermore, established firms can leverage their established brand names and business relationships to exploit radical innovations. This reasoning is strengthened by a longitudinal study of Chandy/Tellis (2000) which reveals that in recent years large and incumbent firms are significantly more likely to introduce radical innovations than small firms and nonincumbents.

To overcome barriers for innovation in general and radical innovation in particular the literature emphasises champions as key actors. The research stream on champions (Chakrabarti, 1974; Howell & Higgins, 1990a, b; Howell & Shea 2001; Howell et al., 2005; Maidique, 1980; Markham et al., 1991; Rothwell et al., 1974, Shane, 1994; Markham, 1998, 2000; Markham & Griffin, 1998; Schon, 1963; Shane, 1994) documents that these individuals are very critical for the success of innovations. In addition and extension of these two roles, German research has over the last 30 years developed four additional innovator roles which show a significant influence on the successful outcome of the innovation process. In contrast to the champion and gatekeeper concepts, researchers in German-speaking countries differentiate between key functions and key persons in the innovation process (Gemuenden & Walter 1998; Hauschildt, 1999a; Hauschildt & Chakrabarti, 1989; Hauschildt &

Gemuenden, 1999; Hauschildt & Schewe, 2000). They see the innovation process no longer driven by only one but rather four persons: First, the *power promotor* who has the necessary hierarchical power to drive the project, to provide needed resources, and to help to overcome any obstacles that might arise during the course of the project. Second, the *expert promotor* who has the specific technical knowledge for the innovation process. Third, the *process promotor* who derives his influence from organizational know-how. He makes the connection between the power and the expert promotor and has the necessary diplomatic skills to bring together the needed people for the innovation process. And last, but not least the *relationship promotor* who has strong personal ties not only inside but especially outside the organization, i.e. to customers, suppliers, and research partners. He can therefore be seen as the ambassador of the organization. Although the promotors themselves can strongly influence the innovation success, they are most successful when combining their abilities and contributions. (Dumont Voitel, 1976, Folkerts, 2001; Gemuenden, 1981, 1985; Gemuenden & Walter, 1996, 1998; Gierschner, 1991; Hauschildt & Chakrabarti, 1989; Hauschildt & Kirchmann, 2001; Hauschildt & Schewe, 2000; Kaluza, 1979; Vitt, 1998; Walter, 1998; Walter & Gemuenden, 2000; Witte, 1973, 1977). Research on champions and promotors is mainly focused on the support for internally generated ideas and innovations. However, relatively little is known about the mechanisms how established firms adopt innovations from outside and which role champions and promotors play hereby. This topic has a high relevance as established firms need to increasingly leverage external sources of innovation (Chesbrough, 2003).

To generate new insights how established firms can leverage external sources to enhance their radical innovation capability, we address the following research questions: (1) Which barriers do established firms face when adopting radical innovations? (2) How do established manufacturing firms adopt radical innovations from outside? What key persons facilitate the adoption?

With respect to innovative actors outside of manufacturing firms we focus on users of products and technology. Users have been shown to be a major source of invention and innovation in diverse industry settings (von Hippel, 1988; von Hippel, 2005).

To better understand the adoption of external radical innovations by established firms, we conducted an empirical study in the field of medical equipment technology. The remainder of the paper is

organized as follows. In the next section the applied research approach is specified. Following the findings are presented. Finally, implications of the findings are discussed.

Research approach

In our research we first aimed to identify radical innovations in which firm-external actors, here users, were the original inventors. We then aimed to trace back the adoption process.

Multiple case study analysis

We conducted a multiple case study analysis. The approach of case study research was applied due to the nature of the research questions as well as the relatively little knowledge available in the addressed research field. Case study research is especially appropriate for research in new topic and new technology areas (O'Connor, 1998; Perry, 1998; Stake, 2000; Gillham, 2000; McDermott & O'Connor, 2002; Shane, 2000), where the focus is on understanding 'how' and 'why' questions concerning a contemporary set of events, and the objective is to further develop theory (Eisenhardt, 1989). Multiple cases are generally regarded as more robust than single case studies, in that comparisons across cases allow for a greater validity in the development of insights, and a consideration of their context dependency (Yin, 1994; McDermott & O'Connor, 2002).

Sample and data collection

To study the addressed research questions a key element of our research design was the identification of radical innovations in which users were the original inventors. We thus needed to find a research setting in which radical innovations have been emerging and in which users unfold innovative activities. The industry of medical equipment technology fulfils both criteria and was therefore selected. In this industry a number of radical innovations have been emerging within the last years when new communication and information technologies found their way into the operating room. Furthermore, prior empirical studies show that users (medical doctors) play an important role for new product development in this industry (Shaw, 1985; Biemans, 1991; Luethje, 2003).

We looked at concrete innovation projects as the unit of analysis and applied a multi-case-comparison methodology. For the selection of cases the following criteria were defined:

- (1) Recent state-of-the-art reviews show that innovativeness is best understood as a multidimensional phenomenon consisting of a market, technology, and organizational dimension (Green, et al., 1995; Avlonitis, et al., 2001; Danneels and Kleinschmidt, 2001; Garcia and Calantone, 2002, Gatignon et al., 2002; Dahlin and Behrens, 2005). To select radical innovations, a scale concerning these dimensions was applied (see appendix 1). This ensured that we selected radical innovations from both the user and the established manufacturing firm perspective.
- (2) To gain an in-depth understanding of the adoption process of *external* innovations, cases were selected where preliminary interviews and medical publications indicated that users were the original inventors of the radical innovations rather than established firms.

For the selection a two-stage-filtering process was applied. The first stage contained 9 expert interviews on the basis of a semi-structured interview guideline to identify medical disciplines in which radical innovations had occurred frequently within the last 5 years and in which users unfold intensive innovative activities. Furthermore, stage one included visits of those medical conferences which focused on the application of completely new technologies. In addition, medical journals were screened with respect to emerging new technologies in the operating room. The result of this stage was a sample of twenty innovations which roughly matched the characteristics of radical innovations. In the second stage interviews with users, industry experts, and manufacturers were conducted to gain preliminary information about the role of users and to systematically assess the degree of innovativeness of these innovations. Informants assessed the degree of innovativeness of the new products on a seven-point Likert scale. This scale contained a market dimension, a technological dimension, an organizational dimension, and an environmental dimension (Salomo, 2003). Only those innovations were selected which matched the characteristics of radical innovations by exhibiting a high degree of innovativeness on all four dimensions. This selection procedure ensured that we selected innovations that were also completely new from the perspective of the manufacturing firms. To control for memory bias of informants, only projects were selected whose innovations were introduced to the market within the last 6 years.³ From this multi-stage filtering process resulted four radical innovation projects whereby preliminary research indicated that in these projects users were

the original inventors. The final sample includes a medical robot system, a computer-assisted navigation system for neurosurgery, a computer-assisted navigation system for orthopedics, and a radically new biocompatible implant. The corresponding medical equipment manufacturers are one large established firm, one medium sized firm, and one spin-off of a large German research establishment. Table 1 provides an overview with respect to the selected radical innovation projects.

= Insert Table 1 about here =

Each user-inventor and established manufacturing firm was visited for several days to collect the required data. In-depth interviews on the basis of a semi-structured interview guideline were conducted with user-inventors on the one hand and marketing, R&D, project leaders, executive officers of manufacturing firms on the other hand. The semi-structured interview guideline for user-inventors contained questions with respect to their roles/activities in the innovation and opportunity exploitation process, their motivation for innovative endeavours, their special knowledge and experience, supportive contextual factors, interaction patterns with partners and manufacturing firms, the degree of innovativeness of their concepts, and dynamics of the process. The semi-structured interview guideline for manufacturing firms included questions with respect to the assessment of the innovations in various stages of the innovation process (degree of uncertainty on the market and technology dimension, evaluation of commercial attractiveness, fit with corporate innovation and technology strategy, and fit with core competencies), the role of the firm in the innovation and opportunity exploitation process, the adoption decision and adoption process (why and when did the firm adopt the radical user-invention), key persons/promoters/champions in the innovation process and their executed roles, and finally the success of the radical innovations,. In sum a total of 30 interviews were conducted. Interviews had the duration of 2-3 hours. Each interview was recorded on tape and transliterated.

Data reduction and coding

To code the collected data, a content analysis framework was applied (Neuendorf, 2002; Krippendorff, 2004). Therefore, category systems for key persons/promoters/champions in the innovation process and their executed roles as well as adoption decision and behavior of established manufacturing firms and key was developed. The category systems were developed both deductively (based on existing theories and concepts) and inductively (derived from the collected data). The deductive section was constructed prior to the conduction of the interviews. Categories for promotor roles included the power promotor (key indicator: hierachical power), the expert promotor (key indicator: expert knowledge), the relationship promotor (key indicator: boundary spanning position). Categories for the adoption behavior of established manufacturing firms included the rejection of opportunities, passive adoption (the firm decides to 'keep an eye' on the opportunity and postpones the decision of active adoption to a later point in time), and active adoption (the firm decides to invest in the opportunity and to exploit it).

The inductive component of the coding system reflects the explorative nature of the study. Due to the new topic area, we expected to discover patterns and factors not yet discussed in theory and literature. Each category in the coding scheme was specified with several indicators (see appendix 2 for selected coding tables). The category system was applied exclusively to the transliterated interview protocols. Expert interviews and archival data were used for verification.

Innovation success of the radical innovation projects was evaluated on the technological and market dimension using a seven-point Likert scale. Market success was evaluated by the following indicators: goal achievement with respect to profits, competitive advantage, customer satisfaction, customer acceptance, and an overall item. Technological success was assessed by asking whether the radical innovations met the technical specifications. While rather common in quantitative studies, Likert scales were applied in this qualitative study for a more detailed assessment of the degree of innovativeness and innovation success.

Conclusion drawing and verification

To control for informant bias which can occur due to different corporate functions or hierarchical levels of informants, only those statements were included into the analysis which had a high degree of

agreement between informants. Triangulation of data was applied to validate the information from the interviews (Maxwell, 1996; Amaratunga & Baldry, 2001). We used the following sources for verification: Interviews with 4 experts of the medical equipment industry were conducted on the basis of a semi-structured interview guideline. The guideline contained key issues of our study such as the activities/roles of user-inventors and established manufacturing firms in the selected radical innovation projects and the ultimate success of the radical innovations. Archival data was used to gain quasi-objective data. Especially, internal reports of the established manufacturing firms were analyzed to validate data from interviews. As a final verification of the interpretation of the cases we discussed the results of the study with the interviewees.

Research findings

The findings section of the paper is organized as follows. We first introduce brief descriptions of the cases, before case comparisons and pattern matching are applied.

Brief case histories

Case URS (CN 1)

Radical innovation: Robot for neurosurgery

First medical robot system for neurosurgery world-wide; it has been designed to enable precision surgery in the submillimeter area. A complementary element is an operating cockpit which enabled tactile feed-back for the operating neurosurgeons.

Innovation outside of established firm

In the early 90's the German neurosurgeon Volker Urban started to question conventional technologies for neurosurgery. Based on his experience in the operating room he realized the gap between the need to operate with a precision in the sub-millimeter area and the comparatively low precision performance of current surgical equipment. That gap triggered his search for new solutions. In his inventive process he also looked for technologies outside of the medical domain (e.g. nuclear power plants, cockpit technology) which meet high precision requirements. Based on this explorative search Urban recognized the opportunity to utilize new technologies in microcomputers and robotics for neurosurgery. He called this technological opportunity 'the operating room 2015'.

To visualize his radical invention Urban contacted a graphic artist and a firm specialized in virtual simulations. In September 1995 Urban presented a virtual representation of his concepts on the medical conference 'Medical

goes Electronic'. At the same time Siemens was in preparation of its 150 anniversary celebration and was looking for feasible visions in medical technology that could be presented at this event. Urban contacted Siemens which agreed to finance the development of a first prototype. However, Siemens had not sufficient technological knowledge or core competence for the development of a *medical* robot at that time. In search for a suitable technology partner, Urban identified the Fraunhofer Institute for Production Engineering and Automatization in Stuttgart as a worldwide leading competence center in robotics. He contacted the engineers of that institute and convinced them to develop a first prototype. But the entire budget for this project was provided by Siemens. After one and a half year of intensive development and experimentation a first functioning prototype of a medical robot was presented in October 1997.

Adoption and commercialization

Urban then engaged in additional networking activities. First, he identified leading medical institutes where the medical robot could clinically be tested. Second, he very actively marketed his concept. As a spin-off of the Fraunhofer Institute the firm Universal Robot Systems (URS) was founded. Urban became partner and scientific advisor of this firm and promoted the new device at medical congresses and conferences.

Case SPOCS (CN 2)

Radical innovation: Computer-assisted navigation system for neurosurgery

First computer-assisted navigation system for neurosurgery world-wide. This system allows guidance of the neurosurgeon by providing three-dimensional information in real time.

Innovation outside of established firm

A major problem in neurosurgery was that surgeons were not able to navigate their instruments in the depths of brain antrums. With the conventional mechanical procedure this problem could not be solved. The Swiss neurosurgeon Prof. Reinhard from the University Basel who had already developed the mechanical navigation system was intensively searching for new solutions to this problem in the early 1980's. Based on his prior knowledge about conventional navigation systems, neurosurgery, mechanics (Reinhard was a clock maker before becoming neurosurgeon – he leveraged this knowledge of mechanics for his medical device innovations) and advances in computing, he recognized the opportunity of a computer-assisted navigation system. This system would be capable to guide the surgeon by providing three-dimensional information in real time.

To realize this solution, Reinhard integrated a number of neurosurgeons in his team who had the complementary technological competencies: know-how in computer programming and electronics. Consequently, Reinhard recruited a neurosurgeon with programming skills, and a neurosurgeon with a background in electronics.

Reinhard himself was a clock maker before he became neurosurgeon and therefore had profound knowledge with regard to fine mechanics. The team started with the development in 1983 and achieved to finish a first prototype two years later, no additional external knowledge requiring. In 1985 first trials on patients were successfully carried out. The computer-assisted navigation system constituted a radical departure from conventional medical equipment technology in neurosurgery. Navigation in the depths of brain antrums was now feasible. Furthermore, the precision of neurosurgery was significantly improved. To transform the prototype into a marketable product, the team however lacked the required market knowledge as well as required financial, marketing and sales resources.

Adoption and commercialization

Consequently, Reinhard contacted Aesculap -a German medical equipment manufacturer- that seemed to be able to provide the missing resources. Aesculap had founded a task force in 1987 to explore the potential of robotics and navigation systems in surgery and was therefore alert of emerging technologies. However, computer-assisted navigation systems departed radically from the core competencies of the firm as Aesculap was highly specialized in surgical instruments and endoprostheses. An engineer of Aesculap who had cooperated with Reinhard in past projects was the first to recognize the technological opportunity of the new device. He convinced the vice president of R&D to devote resources for the project and to adopt the innovation. Based on the decision of vice president R&D Aesculap was finally willing to adopt in 1990. Between 1993 and 1994 the topic 'computer assisted navigation system' was put on hold within Aesculap due to doubts about its market potential. In the end of 1994 Aesculap put the topic again on the agenda. In 1995 the first navigation systems were introduced into the market. Aesculap and Reinhard closed a licensing agreement.

Case ORTHOPILOT (CN 3)

Radical innovation: Computer-assisted navigation system for orthopedics

First computer-assisted navigation system for orthopedics world-wide. This system enables a calculation and visualization of the optimal implant positioning in orthopedic surgery without radiation-intensive CT scanning.

Innovation outside of established firm

In the early 90's one of the major problems experienced by orthopedic surgeons was the anatomically accurate positioning of knee endoprostheses. If not positioned accurately, the implants caused severe pain on side of the patients and needed to be replaced after several years. Another major drawback of the conventional procedure was that patients needed to be exposed to radiation-intensive CT scanning to obtain images prior to surgery. These preoperational examinations were time-consuming, expensive, and not-patient compliant. Due to the lack

of appropriate equipment, Prof. Saraglia, an orthopedic surgeon from the University Grenoble, started to search for new solutions. Based on his in-depth knowledge of orthopedics and technological advances in microcomputing he recognized the technological opportunity of a computer-assisted navigation system for orthopedic surgery.

As he was lacking the required technological knowledge he contacted engineers at the University Grenoble who were experts in the field of programming. In addition, he identified another orthopedic surgeon, Frederic Picard, who had a strong background in anatomy. This know-how was crucial to develop the required biomechanical solution for the navigation system. As a next milestone Saraglia started a project with the goal to develop a first prototype. To realize this, extensive funds were required. In a first step the surgeon contacted the European Union (EU) for financial support in 1994. The European Union acknowledged the high potential of the idea and agreed to provide kick-off-funds. By this, the project IGOS (Image Guided Orthopedic Surgery) was born. But these funds were not sufficient to finance the complete project. Consequently, more funds were required. To explore these, Saraglia looked for interested manufacturing firms willing to participate.

Adoption and commercialization

At that time, the medical equipment manufacturer Aesculap was alert of new technological advances in surgery. The linking pin on side of AESCULAP was a physicist who visited the innovators in Grenoble on a regular basis for status meetings. The physicist recognized the technological opportunity that was emerging. Due to his technological background he was able to understand the technical aspects of the new device. He reported the progress and potential of the navigation system to the vice president of R&D. He finally convinced him to invest into the project. The head of R&D approved only a limited amount. In return for the investment Aesculap secured the commercialization rights. With the original funds of the EU and the financial investment of Aesculap it was finally feasible to develop a first functioning prototype in 1997. The prototype was jointly developed by Frederic Picard and Francois Leitner, a computer science engineer at the University Grenoble. After the prototype was successfully tested in 1997, Aesculap adopted the technological opportunity and took over the entire project management. Passing through a number of improvements concerning its user friendliness, the navigation system was successfully introduced into the market in 1999. The lead users Saraglia and Picard agreed on a licensing contract with Aesculap. Today the product is a world-wide standard in orthopedic surgery.

Case IMPLANT (CN 4)

Radical innovation: Biocompatible implant for hernia surgery

Biocompatible implant which enables optimal tissue re-growth in hernia surgery.

Innovation outside of established firm

Surgeons experienced severe problems of patients after implants for hernia repair were inserted. Patients reported that the implant felt like a 'board'. The medical cause for this effect was that conventional implants were not biocompatible in a sense that enabled optimal tissue re-growth. Conventional implants caused the growth of scar tissue which in turn led to the painful 'board'-effect. In 1996 Prof. Schumpelick, a leading surgeon at the university hospital of Aachen, recognized the technological opportunity of a completely new implant with biocompatible characteristics. Schumpelick searched for lighter material technology which was supposed to improve patient comfort. He identified polypropylene as a candidate technology. He furthermore developed the concept of a completely different implant design. The new, lighter material and the new design were supposed to support an improved tissue re-growth process. The opportunity recognition process emerged from own research activities at the university labs.

To testify the medical relevance of his invention, Schumpelick needed to develop a camera system that proved specific characteristics of the abdominal wall. For the development of this camera system engineers with specialized know-how in camera technology were needed. Schumpelick identified such engineers and cooperated with them to develop the system. With the new camera system Schumpelick was finally able to successfully validate his radically new approach. A next milestone was the development of a first prototype. This endeavour turned out to be difficult as Schumpelick lacked the required technical knowledge of textile engineering. Consequently, he contacted the leading institute with textile engineering know-how. After short time, the first prototypes of the new implant were realized by this institute.

Adoption and commercialization

In addition, Schumpelick approached a leading manufacturing firm in the field of medical implants. This manufacturing firm had substantial knowledge in the area of biocompatible materials and implants. In addition, this firm had an excellent reputation in the market. A project leader at the R&D department of this firm who was a medical doctor before signing up for the management role in the firm was first to recognize the technological opportunity. The medical background proved crucial for the understanding of the potential of the new implant. She convinced the vice president R&D to adopt the implant and to advance it for market introduction. The implant was finally tested on its biocompatibility by the manufacturing firm. This firm introduced the new implant into the market in 2002 and concluded a licensing contract with Schumpelick. Today the implant represents a state-of-the-art technique and is world-wide used for hernia repair surgery.

Analysis

We next compare the cases in detail and apply case comparison and pattern matching.

Initial reluctance of established firms

The established manufacturing firms were not willing in this early phase to adopt the user-inventors' technological opportunities. One reason for this reluctance was that in all cases the technological opportunities did significantly depart from their innovation and technology strategies. Furthermore, the technological opportunities did not fit with their established core competencies. Looking back at the radical nature of these opportunities in their early stage, this is not even surprising. In those days an adoption of the radical user-inventions would have meant to build up the necessary technological competencies, mostly from scratch. Furthermore, the established manufacturers were deterred by the high technological and market uncertainties associated with these opportunities. They were confronted with the situation that the prospective markets were yet unknown concerning volume, market share and growth rate and that the medical application of the respective technologies was just emerging. A valid evaluation of their commercial attractiveness was not feasible at that early stage. A second reason for the reluctance of established firms was that the radical inventions were developed by firm-external innovators. The R&D departments looked at these inventions sceptically as they were not developed in-house. The user inventions thus became a victim of the 'not invented here syndrome' (Vandermerve, 1987; Mehrwald, 1999 at this early stage). Combined, the radical nature of the technological opportunities and the 'not invented here syndrome' were key factors that explain why established manufacturing firms did not become actively involved in the early phases of the radical innovations projects and why the user-inventors had to fill in this gap. As established manufacturers did not adopt the technological opportunities, the user-inventors needed to take over an entrepreneurial role, at least temporarily.

The key role of promoters

In three cases promoters played a key role in adopting the radical user innovations (CN 2-4). Table 2 shows the individuals within the established firms who recognized the technological opportunities outside and who met the adoption decision.

= Insert Table 2 about here =

Engineers and a medical doctor who were frequently interacting with university hospitals were the key actors who first recognized the technological opportunities. These actors combined characteristics of an expert promotor *and* relationship promotor. Their boundary spanning role was crucial to learn about the radical innovations that were emerging at the university hospitals. Their expert knowledge in turn was crucial to understand the new technologies and to ultimately recognize the corresponding technological opportunities. This finding strengthens work that emphasizes the role of prior knowledge for opportunity recognition (Shane, 2000). In these three cases the expert-relationship promoters convinced the vice president R&D to provide resources and funds for the radical innovations and to adopt them. The vice presidents R&D met the final adoption decision. They can be regarded as power promoters. The observed adoption pattern is illustrated in figure 1.

= Insert Figure 1 about here =

Changing degree of uncertainty along the innovation process

Established manufacturing firms entered the scene not until the commercial attractiveness of the technological opportunities could be assessed more accurately. How can the behavior of established manufacturing firms be explained in economic terms? Marketing or new business development departments of established firms develop routines for filtering opportunities which are commercially attractive for them. Usually, marketers of established firms assess the potential of an opportunity in terms of prospective market volume, market share, and market growth respectively. In economic terms, it only makes sense for an established firm to exploit an opportunity if this opportunity has the

potential to cover a sufficient share of the market. The reason is that established firms need to amortize both production and transaction costs that are associated with the adoption and exploitation of a given technological opportunity. To amortise production and transaction costs an opportunity needs to have the potential for a critical mass of sales (Baldwin & Clark, 2002). Consequently, established firms will not be interested in the exploitation of opportunities which exhibit low commercial promise.

In the observed cases the ability to assess the commercial attractiveness of the technological opportunities changed along the innovation process. In the early stages the assessment was impeded as ordinary users as a source for market research were not able to imagine and anticipate the radically new approaches and thus to provide valid evaluations. In later stages physical prototypes enabled ordinary users to evaluate the benefit of the new solutions and to articulate purchasing preferences. This information enabled the manufacturing firms to assess the commercial attractiveness of the technological opportunities more accurately. The observed switch of established manufacturers from a passive towards an active adoption behavior can therefore be explained by the decreasing level of market uncertainties along the radical innovation process.

Was the reluctant behavior of established manufacturers the proper reaction? To answer this question, the success of the radical innovations needs to be assessed. In three cases the associated new products turned out to be successful both on the technological and on the market dimension. Consequently, established manufacturers were reluctant to technological opportunities that turned into commercial successes. However, this does not imply that the initial retention of manufacturers was not the proper reaction.⁴ Instead, the manufacturing firms minimized the risk of own investments by this passive adoption behavior. As the commercial attractiveness of the technological opportunities became more apparent, the manufacturers adopted complete prototypes from the user-inventors. By the shift from a passive to an active adoption behavior the established manufacturing firms were able to introduce radically new products in a relatively short time into the market. In the case URS the inventive users became partner of a research-institute spin-off. The innovations turned out to be a market failure. Consequently, the established manufacturers' assessment mechanisms worked properly in this case.

Discussion and conclusion

The study indicates implications for intrapreneurship. It points to individual actors outside of established firms who recognize technological opportunities. These user-inventors recognized the relevance and benefit of new technologies far earlier than established manufacturing firms and peer users. These new technologies became the medical standard in many different medical applications. The inventive users anticipated technological and market trends. They therefore can be regarded as 'lead users' according to von Hippel (1986). Obviously, lead users are a potential source of *commercially attractive* technological opportunities. The characteristics of the lead user-inventors may serve as a guide for the identification of such users and opportunities. Our analysis reveals that the profile of users that are in the position to recognize technological opportunities based on radical inventions differs significantly from ordinary users. First, the inventive users had a high motivation for the development of new solutions. Second, the inventive users in two cases were neurosurgeons which can be categorized as 'extreme users' as they faced the need for extremely high precision. It has been shown that lead users appear augmented among 'extreme users' (von Hippel et al., 2000; Lilien et. al, 2002). Opportunity recognition processes within established firms that are based on radical inventions have been described as difficult and challenging (O'Connor & Rice, 2001; Rice et al., 2001). Our study shows that established firms can benefit from lead users with respect to the recognition of commercially attractive technological opportunities.

For research on champions and promotors our study highlights that expert promotion and relationship promotion can be united in one person and that this combination is crucial for the recognition of technological opportunities outside of established firms. Obviously, such expert-relationship promoters are key actors who facilitate the recognition of technological opportunities and the adoption of the corresponding radical innovations from outside the firm. The implication for established firms is to leverage instruments of human resource management to identify, develop and support individuals who have the capability to recognize technological opportunities outside the firm. Based on the findings of our study this implicates that boundary spanners who are in a privileged position to learn about technological opportunities outside the firm's boundaries also need to have profound expert

whether the identified patterns can be observed in other industries as well. Further research is needed to extend our study to other industries and to test the developed explorative models by large scale, quantitative studies.

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Footnotes

- 1) It has been emphasized that free revealing can also yield economic benefit for the revealer such as a higher value on the job market, higher reputation, or benefits from reciprocal behavior (e.g. Harhoff et al., 2003).
- 2) Empirical studies of CHANDY & TELLIS (1998) and NIJSSEN ET AL. (2005) show that the ‘willingness to cannibalize’ enhances the capability of established firms to develop RI.
- 3) In this connexion it needs to be taken into account that the RI projects had a very high significance for the innovative users and the manufacturing firms. They were thus well remembered from both parties.
- 4) The retention of established manufacturing firms can also be reflected by the low success rates of raw ideas. For example STEVENS & BURLEY (1997) argue that in most industries 3.000 raw ideas are required to generate one *substantially new* commercially successful industrial product.

Table 1: Selected radical innovations

Case	Product description	Innovation success MS: Market success TS: Technological success	Number of interviews
URS	Robotic system for neurosurgery	MS: failure TS: high	8
SPOCS	Computer-assisted navigation system for neurosurgery	MS: medium TS: high	9
orthoPilot	Computer-assisted navigation system for orthopedics	MS: high TS: high	10
IMPLANT	Biocompatible implant	MS: high TS: high	9

Table 2: Promotor roles

Case	Recognition of technological opportunity: Promotor characteristics	Decision of adoption: Promotor characteristics
URS	-----	-----
SPOCS	Official Function: R&D engineer Background: Software programmer Boundary spanning position: Frequent interactions with university hospitals	Head of R&D
orthoPilot	Official Function: R&D engineer Background: Physicist Boundary spanning position: Frequent interactions with university hospitals	Head of R&D
IMPLANT	Official Function: R&D engineer Background: Medical doctor Boundary spanning position: Frequent interactions with university hospitals	Head of R&D

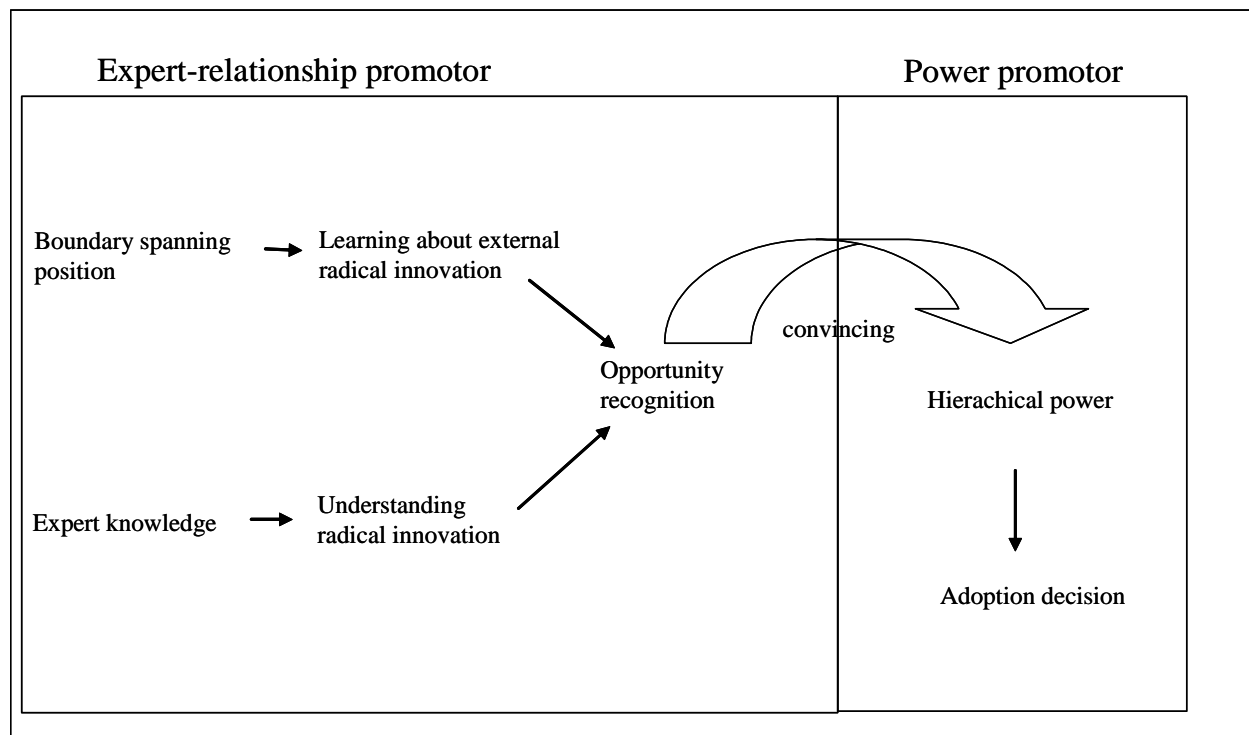
Figure 1: Adoption mechanism

Figure 2: Correct and false adoption decisions of external inventions by established firms

Commercial attractiveness of firm-external invention		high	False rejection of opportunity	Correct recognition of opportunity <i>(CN 2,3,4)</i>
		low	Correct rejection of missing opportunity <i>(CN 1)</i>	False recognition of would-be-opportunity
			Rejection	Adoption
			Adoption decision of established firm	

Appendix

Degree of innovativeness

(1) Market dimension

- New benefit for the user
- Higher benefit for the user
- Degree of newness to users / Familiarity of users with technology
- Degree of required behavior change for users
- Degree of required learning by users
- Degree of change in market structures
- Degree of the creation of new markets
- Potential for competitive advantage
- Degree of market uncertainty for manufacturers
 - Uncertainty about market acceptance
 - Uncertainty about market potential
 - Uncertainty about market growth

(2) Technological dimension

- Degree of newness of technological principle
- Degree of complexity of technology
- Degree of technological uncertainty for manufacturer
 - Uncertainty of feasibility of the technology
 - Uncertainty about the development time
 - Uncertainty about the development costs

(3) Organizational dimension

- Degree of newness to the manufacturer
- Degree of required change in production process
- Degree of required change of competencies
- Degree of required change in organizational culture
- Degree of required change in organizational structure

- Degree of required change of (human) resources
- Degree of required change in strategy