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INNOVATION AND NEW BUSINESS THROUGH MUTUALLY BENEFICIAL COLLABORATION AND PROACTIVE PROCUREMENT

THESE

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RESEARCH PAPERS

Research Paper 1

Hameri, A-P., Vuola, O. 1996. Using basic research as a catalyst to exploit new technology based innovations -a case study. *Technovation* 16(10), 531-539.

Research Paper 2

Vuola, O., Hameri, A-P. 2006. Mutually benefiting joint innovation process between industry and big-science. *Technovation* 26(1), 3-12.

Research Paper 3

Vuola, O. 2006. Big science as a catalyst of new business development. In E.G. Carayannis and P. Formica, *Knowledge Matters: A Networks and Clusters Perspective from the US, Europe and Asia*, MacMillan Press, forthcoming.

Research Paper 4

Vuola, O. 2006. *How Science Can Foster Innovation by Saving Money*. Presented at the 2006 Annual Meeting of the Academy of Management "Knowledge, Action and the Public Concern", August 15, Atlanta, Georgia. Previous version of the Paper was presented at the Association for Public Policy Analysis and Management APPAM, the 2005 Fall Conference, November 3, 2005, Washington, D.C.

ABSTRACT

This dissertation focuses on new technology commercialization, innovation and new business development. Industry-based novel technology may achieve commercialization through its transfer to a large research laboratory acting as a lead user and technical partner, and providing the new technology with complementary assets and meaningful initial use in social practice. The research lab benefits from the new technology and innovation through major performance improvements and cost savings. Such mutually beneficial collaboration between the lab and the firm does not require any additional administrative efforts or funds from the lab, yet requires openness to technologies and partner companies that may not be previously known to the lab. Labs achieve the benefits by applying a proactive procurement model that promotes active pre-tender search of new technologies and pre-tender testing and piloting of these technological options. The collaboration works best when based on the development needs of both parties. This means that first of all the lab has significant engineering activity with well-defined technological needs and second, that the firm has advanced prototype technology yet needs further testing, piloting and the initial market and references to achieve the market breakthrough. The empirical evidence of the dissertation is based on a longitudinal multiple-case study with the European Laboratory for Particle Physics. The key theoretical contribution of this study is that large research labs, including basic research, play an important role in product and business development toward the end, rather than front-end, of the innovation process. This also implies that product-orientation and business-orientation can contribute to basic research. The study provides practical managerial and policy guidelines on how to initiate and manage mutually beneficial lab-industry collaboration and proactive procurement.

Keywords: technology transfer, lab-industry collaboration, public procurement, new technology, innovation process, business development, big science

1 INTRODUCTION

1.1 Background and motivation

Several innovation studies (e.g. Freeman and Soete, 1997; Lindell, 1991; SAPPHO, 1971) have documented the difficulties related to the introduction and commercialization of novel technology. The incubation times for revenues from a new technological development stem from several years to decades, depending on the novelty of the solution. Incremental customer-driven innovations may enter the market smoothly, yet radical initiatives with significant implications to conventional practices seem to take more time to receive full acknowledgement from the markets (Freeman and Soete, 1997). New strategies are needed to catalyze and manage radically new industrial innovation and business development.

Due to their radical nature, many promising new technologies are not commercialized because research and development (R&D) and venture teams lack the support, competence, resources, or corporate culture, structure and processes necessary to achieve commercialization (Bower and Christensen, 1995; Chesbrough, 2002; Henderson, 1993; King and Tucci, 2002; Teece, 1986). Despite extensive research on the determinants of technological innovation, in practice, research outcomes are not always implemented in the actual management practice, are too abstract, may not be implementable at all, or might even be harmful for practice (Allen and Sosa, 2004; Beer, 2001; Ghoshal, 2005; Pfeffer and Fong, 2002). Thus new technology-based companies, as well as corporate venture teams and radical new business initiatives in particular, need practical guidelines and advice on how to survive and prosper in real-life situations when strategic environment and value networks are far from ideal.

This dissertation investigates the systematic use of public research for catalyzing innovation and radical business development. The focus is specifically on *industry-based* technologies and products, and on CERN[1], the European Laboratory for Particle Physics, representing a large-scale basic research center. It is well known that public research has an important role in technological innovation (Beise and Stahl, 1999; Feller et al., 2002; Furman et al., 2002; Mansfield, 1991, 1995; Pavitt, 1998; Rosenberg, 1992; Rosenberg and Nelson, 1994). Universities and other academic institutions have been studied as *sources* of spin-off firms, patents, licenses, new knowledge and spillover effects (Autant-Bernard, 2001; Bozeman, 2000; Bozeman and Crow, 1991; Carayannis et al., 1998; Etzkowitz and Leydesdorff, 2000; Feller et al., 2002; Henderson et al., 1998; Shane, 2002). However, while this research has resulted in a tremendous increase in our understanding of the workings of national and regional systems of innovation, most of the studies have focused on universities and US research laboratories and have treated these institutions as a black box. More research is needed on how public research organizations function as learning environments for industrial companies.

[1] CERN, the European Laboratory for Particle Physics (originally Centre Européenne de la Recherche Nucléaire), has its headquarters in Geneva. At present, its Member States are Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. The European Commission, India, Israel, Japan, the Russian Federation, Turkey, UNESCO and the USA have observer status.

Furthermore, practical guidelines are needed for industry to learn how to collaborate with public research, and for research organizations to learn how to partner with industry. While extensive research has been conducted on industrial *collaboration, partnerships and interaction* with public research, universities, research centers and government and federal laboratories (Bozeman, 2000; Bozeman and Papadakis, 1995; Carayannis and Alexander, 1998; Ham and Mowery, 1998; Hetzner et al., 1989; Joly and Mangematin, 1996; Kaufman and Todtling, 2001; Roessner, 1993, 1994; Roessner and Bean, 1990, 1991; Rogers et al., 1998), there is relatively little research on collaboration with large-scale international research centers. Big science centers, as they are also called, may provide high tech companies with a fertile soil to test the applicability of a new solution to a large variety of technological domains (Hameri, 1996). This, however, is often seen to be the privilege of large and established – as opposed to small and new – partner companies.

Large-scale research labs also have significant *procurement* activity linked to their research programs. The overall benefits of public procurement to innovation and the economy in general have been widely reported (Rothwell and Zegveld, 1981; Dalpé et al., 1992; Edquist et al., 2000), including the secondary benefits of big-science procurement to supplier companies and member state economies (Schmied, 1977, 1982; Brendle et al., 1980; Streit-Bianchi et al., 1984; Bach et al., 1988; Nordberg, 1994; Autio et al., 2003). In general, there is an increasing concern among scholars for the development of more systematic approaches to public procurement practices and procedures as instruments stimulating and fostering innovation (Roessner, 1979; Geroski, 1990; Edquist et al., 2000; Fraunhofer Institute, 2005; Wilkinson et al., 2005). Few studies, however, focus on lab procurement procedures or how to help new companies enter the big-science market.

In summary, there is an important gap in our understanding of business-driven research lab-industry collaboration from the perspective of new and small companies, and radical new business initiatives in particular, and of the systematic use of the lab procurement procedures and practices to foster the new technology-based industrial product and business development. Furthermore, there is little extant research on the very collaboration mechanisms specifically with big-science basic research.

1.2 Focus, scope, and purpose

The dissertation focuses on and is limited to the following:

- *New technology originating from firms*: the study is about commercialization of new technology that originates from industry and not from public research. More specifically, the new technology is provided by a technology company or venture team that is new to the research organization;
- *New product and business development efforts and collaboration with a large international research center conducting basic research*: Being simultaneously a big-science center, a basic research lab, and an international intergovernmental organization, CERN represents a rather rare yet multi-dimensional lab category;
- *The role of the center as a learning environment for these companies and ventures*: Instead of treating the research center as a black box and studying its output vs. input, the study investigates the very mechanism for collaboration, and on how to use the center as a resource for product and business development; and
- *The project engineering and procurement practices of the lab as instruments fostering innovation and business development*: The study focuses on the needs of the lab expressed

through its R&D and procurement activity, and how this engineering and procurement activity could be improved in order to foster innovation for the benefit of both the lab and the new company or venture.

This study thus does *not* aim at assessing nor evaluating lab-industry interactions and technology transfer, neither does it focus on typical technology transfer activity of public research organizations. Furthermore, it does not intend to be another CERN supplier study trying to quantify the economic utility of big-science purchasing to its member states. Instead, it concerns unusual collaboration cases, in which the research lab is systematically approached with the intention to use both its *needs* and *resources* to foster new technology-based *industrial* innovation and business development. The resources and innovations become available to both parties by focusing first on the basic development needs of both the lab and the company.

The study aims to provide practical managerial guidelines for private companies and public research organizations, and at extending theories on technology transfer, new product development, and public procurement. The study also has policy implications not only for CERN and the European innovation environment but also for other big-science organizations and public research labs, as well as innovation systems in general.

1.3 Research questions

The principle research questions resulting from the above literature gap and research focus are the following:

1. How could new technology companies and ventures *systematically approach and use* a big science lab for product and business development purposes?
2. How does the big-science lab operate as a *source of complementary outside resources* for new technology-based companies and emerging businesses?
3. What is the *collaboration mechanism* between the large research organization and a new supplier candidate from the very moment they start to interact?
4. How could public research organizations meet the challenge of *managing costs and risks of technology development and procurement* while also enabling industrial innovation?

These research questions are addressed by four Research Papers (see Section 1.5). The first question is addressed particularly by Papers 1, 2, and 3. Paper 1 deals with the approach issue, i.e. how to introduce new technology to big science, while Papers 2 and 3 focus on its use for the purposes of product development and business development, respectively. The second question is addressed specifically by Paper 3, yet Paper 2 also touches upon the issue from the product development perspective. The third question is addressed by Paper 2 in particular. Finally, the fourth question is the central theme of Paper 4.

1.4 Empirical setting

The Papers and the overall dissertation have resulted from a longitudinal research project that began in 1996. In this study, I applied multiple in-depth case studies, studying technology companies and teams cooperating with a large intergovernmental research organization. Using multiple sources of evidence, the cases were studied on a real-time basis during nine years. The projects take place in large corporations, small and medium size enterprises (SME) and start-ups alike, and cover new technologies in diverse technological fields and industries. The chosen research organization is CERN, the European Laboratory for Particle Physics, and its international big-science project, the Large Hadron Collider (LHC). CERN plays an important role in the European innovation system. *BusinessWeek* recently wrote: "Although it spends less on R&D than the U.S., Europe still has strong points: [...] World-class labs like CERN and Max-Planck complement big corporate R&D from DaimlerChrysler, Siemens, GlaxoSmithKline, Nokia, Philips, and dozens more" (Reinhardt, 2004: 125).

In 2001, the EU-15 devoted the total of €175b on R&D, which is a 15% increase from the previous science and technology statistics in 1997 (EC, 2003b). According to the same statistics, about 25% of all R&D was directed into basic research, of which about 10% was channeled to intergovernmental research projects. This leaves about €4b for major big-science basic research laboratories, which use on average some 25% of their budgets on purchases, making it a market equaling €1b. With these rough numbers it is obvious that the market is small and knowing that it is technologically highly scattered, the sub-projects for component development are small and extremely focused when considered from the industrial point of view. Yet, when at an early-phase, potentially radical innovations may exploit these resources as they may provide the companies with a lucrative possibility to test, develop and commercialize their technologies, while also providing help to basic research achieve its goals. Also, in general, systematic use of public resources for the benefit of new technology companies and ventures is an important issue in Europe and worldwide. This leads to a conclusion that the above-stated research questions are highly relevant, especially as literature (see Section 1.1 above) indicates that most attempts to commercialize radical technology tend to fail.

1.5 Overview of the dissertation

In this dissertation, I address the above research gap and research questions specifically with the four individual Research Papers that constitute the core of this dissertation. In addition to these Research Papers, the following pages of the dissertation discuss the overall theoretical framework and the contribution of the study from the perspective of technology transfer (TT) research. This additional broad framework would not be viable in the context of a single Research Paper. As a consequence, this dissertation is a combination of, first, the four individual Papers that focus on their specific yet interrelated issues, and second, the detailed TT framework and the discussion of the contribution of the Papers to this framework. Finally, the dissertation with its principle research questions, methods, data, and conclusions form a third layer that covers the entire study. This multi-layer logic and structure is visualized in Figure 1.

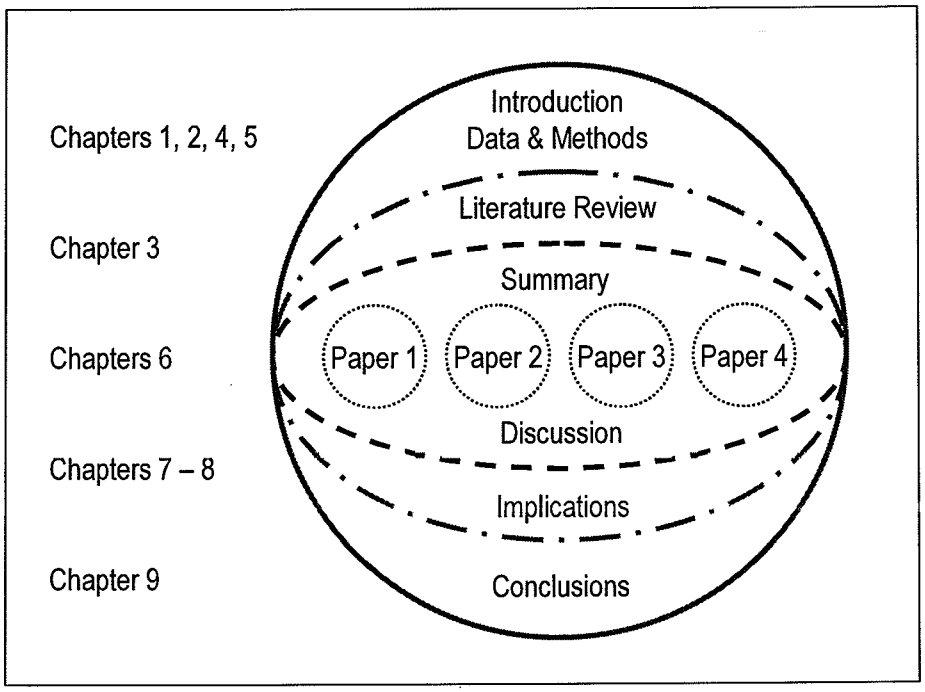


Figure 1. The structure of this dissertation.

In Chapter 2, I provide an overview of the context of the study, i.e. CERN and its particle accelerator mega-project, the LHC, highlighting the distinctive characteristics of this specific environment for industrial collaboration. This is followed by a review of the relevant extant technology transfer research and the definitions of the key concepts relevant to this study in Chapter 3. Next, in Chapter 4, the research strategy and methods are presented and discussed, followed by brief summaries of the case studies in Chapter 5. The Research Papers, which form the core of this dissertation, are summarized and discussed in Chapter 6, focusing on describing their key scientific contribution. Next, Chapters 7 and 8 discuss the theoretical, managerial and policy implications using the technology transfer framework as well as literature on public technology procurement. In Chapter 9, the dissertation is concluded by reflections on its contribution to the original research questions, as well as its limitations and suggestions for future research. A list of all papers and presentations produced during this study – to some of which the chosen Research Papers also refer – is in the Appendix.

2 CERN AND THE LHC PROJECT

CERN is the world's largest particle physics laboratory. Located in Geneva and in operation since 1954, the lab was one of Europe's first joint ventures and includes now 20 European member states. CERN does pure scientific research into the laws of nature, as described in the Organization's founding convention (CERN, 1953):

> "The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available."

The lab is currently undertaking a major engineering and construction effort to complete the Large Hadron Collider (LHC) due to start operating in 2007. The LHC with a 27-kilometer circumference will direct sub-atomic particles into collision trajectories at energy levels never used before, in order to corroborate some of the previsions of the current theories in particle physics. Technologies involved cover many fields of engineering, and some of the collider components are also needed in large quantities. The CERN organization is responsible for the accelerator machine and civil engineering of the five billion-dollar LHC. A major part of the CERN annual budget of roughly one billion Swiss francs (around $800M) is spent on the collider project.

The LHC will be the most powerful particle collider in the world. The launch of this collider will conclude an over 10-year-long design, engineering, and testing phase during which numerous technological challenges will have been solved and components prototyped, tested, installed, and put in operation. As an instrument application, the LHC with its particle physics experiments constitutes an extremely complex technological system with technological requirements that sometimes cannot be solved with even state-of-the art technologies. CERN's LHC project, for example,

- requires around 100 000 man-years to be completed and operational;
- has an overall budget of approximately €4 Billion;
- produces more than 1 million technical and related documents through its various approval processes; and
- involves collaborators, institutes, and industrial partner companies from more than 50 countries.

This diversity is also reflected in the range of engineering skills involved in the project, as the instrument incorporates inputs from practically all engineering disciplines. The multi-technology environment related to particle accelerators can be structured into general technological categories (see Figure 2 for a simplified breakdown). This web of technologies necessitates the presence of a large variety of skills among the scientists and engineers working in experimental basic research laboratories. In total, there are some 6 000 scientific and technological experts working at CERN at any given time. A major part of the detector-specific component and equipment design and construction takes place outside the laboratory at national research laboratories.

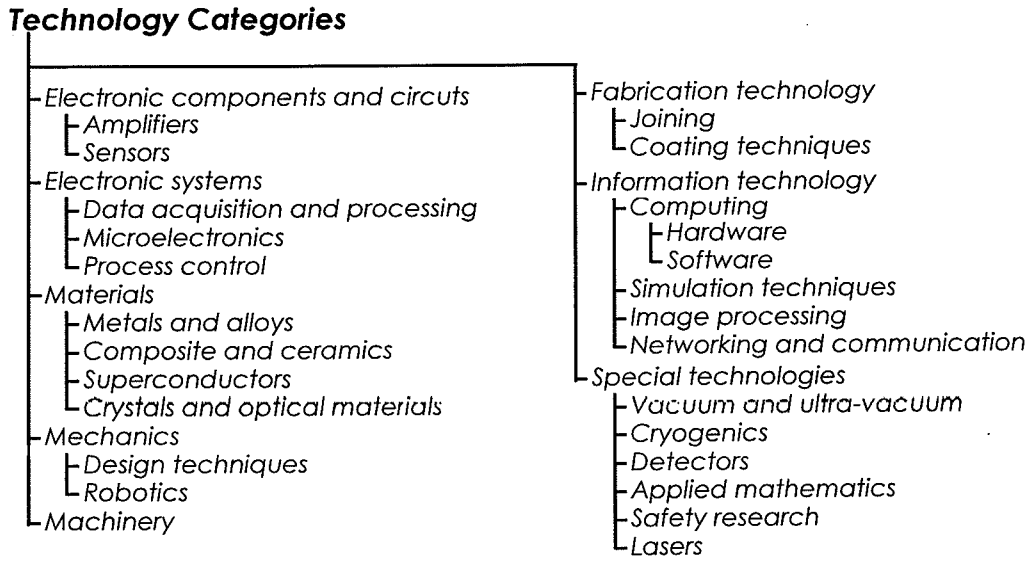


Figure 2. Categorization of engineering disciplines represented in experimental particle physics installations (adopted from Autio et al., 2004).

CERN also has a substantial in-house engineering work force and several specialized technical laboratories for development and testing, for example in the areas of cryogenics, high voltage, radio frequency, and superconductivity. In addition, there are more than 500 universities and institutes within the CERN partner network to execute almost any technical test procedure one could imagine. However, it should be noted that CERN's resources and facilities exist solely for the purposes of fundamental research on particle physics (see the Convention of CERN, 1953), not for industrial R&D, and CERN does not normally conduct commercial or sponsored research. While a clear distinction between 'basic research' and 'applied research' may sometimes be challenging in a typical university or government research lab context (Joly and Mangematin, 1996), in CERN's case it is relatively evident. CERN's mission of fundamental research on particle physics (CERN, 1953) clearly implies that CERN is a basic research laboratory. Also the mode of financing, through public funds, is typical to basic research labs (Crow and Bozeman, 1987).

Despite being a particle physics basic research lab, CERN has engineering activity, which is because an integral part of conducting experimental particle physics research is the construction of scientific instrumentation needed for the research. This instrumentation is increasingly large-scale and complex, and extensive R&D is conducted by CERN and participating universities and institutes. Instrumentation construction and manufacture is increasingly subcontracted to industry. The CERN supplier base holds more than 10,000 companies. Strict purchasing procedures mandated by the CERN Council (CERN, 1999a) oblige CERN to seek multiple supplier candidates and organize tendering competition for all items worth more than a few thousand euros. International competition is extremely tough, as CERN may contact up to several tens of companies for major purchases. Competitive tendering is also applied to subsequent purchasing, that is, each purchase is one-off and in principle the cheapest bidder complying with the specifications wins the contract, whether or not it has previously supplied to CERN. CERN thus

promotes "buying orientation" (Anderson and Narus, 1988) by seeking to obtain the lowest price and using multisourcing in its purchasing.

The official procedure for major purchases starts with an announcement to the member state delegates of the forthcoming purchases, followed by a Market Survey (MS), the selection of the firms to be invited to tender, and a 'call for tenders' (or 'invitation to tender' or IT) (CERN, 1999a). Multisourcing is used especially in the MS phase, which is open to all interested parties, while only the selected bidders, those that receive the IT, can submit a tender. The lowest bidder(s) is (are) awarded the contract, except when there is another bid within a 20% price range originating from a so-called poorly-balanced Member State, in which case the bidder can get the contract on the condition that it aligns the price to the level of the lowest bid.

It has been claimed that these procedures are valid only when purchasing conventional technology and commodities (Hameri and Nordberg, 1999). Similarly to many public organizations, CERN purchasing procedures can be considered reactive, as the purchasing officers are at the mercy of the tenders that emerge as a result of the process, instead of actively or proactively seeking alternative, more innovative or even completely new or radical solutions. CERN practices, however, have many characteristics similar to the recent recommendations and policies for more innovative 'public technology procurement' (Edquist et al., 2000): CERN communicates its long-range procurement needs to member state delegations (although not directly to potential supplier companies) well in advance; It uses unbundling of demand, variants, and prequalification questionnaires (i.e. market surveys, MS); CERN also has project engineers and experts, who are highly educated and have the inclination to test novel technology. According to Dalpé (1990), users with a greater technological capacity are those that can most contribute to the supplier's innovation.

CERN project engineers and experts actually have great freedom to conduct their tasks and responsibilities related to various accelerator sub-components and engineering. During and before the market survey (MS) phase, CERN project engineers often cooperate with companies of their own choice in order to prepare the specifications for the item to be purchased. Furthermore, joint R&D is often done through informal collaboration with these companies, as well as more formally by placing small orders through a process called "Price Enquiry" for the early prototype versions of the end products. All this happens more or less apart from and prior to the official purchasing procedure for the end products. However, when the official procedure takes over and the actual suppliers are selected for LHC components, engineers' freedom is strictly limited by CERN's administrative procedures described above: the project manager is bound to cooperate only with the lowest bidder(s) among all those complying with the technical requirements of the specification (CERN, 1999a).

It is clear that political pressure, personal preferences and company involvement in the specification preparation may heavily bias the selection process (Hameri and Nordberg, 1999). For example, political pressure may lead to the choice of unreliable contractors that may quote the lowest initial price but may eventually jeopardize the whole project. Personal preferences and early company involvement may lead to the exclusion of companies that could potentially be cost-effective but with which the project engineers are not familiar (Hameri and Nordberg, 1999).

In summary, CERN has four characteristics or dimensions that are particularly relevant to this study. CERN:

- Is a public research lab;
- Exists solely for basic research;
- Is big science;
- Has significant public procurement activity.

In this dissertation, I investigate each of these characteristics in terms of their role in industrial innovation and business development. The first three are studied from the perspective of the technology transfer framework developed in the next Chapter, and the fourth from the public technology procurement perspective discussed specifically in Research Paper 4.

3 LITERATURE REVIEW AND KEY CONCEPTS

This chapter briefly discusses the key literature and concepts relating to this dissertation. While based on four individual Research Papers, the dissertation also examines their overall contribution in the area of technology transfer (TT) research. While the key literature relevant to each Paper is discussed in detail in the Papers, an examination of the overall framework literature is undertaken in this chapter.

3.1 Outline of the review

In the following section, I provide definitions for the *key concepts* inherent in this study and its Research Papers, and discuss the most relevant *extant literature*. After discussing and defining the key concepts related to big science, collaboration, technology transfer, and innovation, I review the literature on CERN-industry collaboration. Next, I focus on previous studies on lab-industry interaction, which is extensively researched in the US, and, hence, potentially may help guide also this dissertation. The case lab of the dissertation CERN being a basic research lab, I also discuss the few studies focusing on basic research fostering industrial innovation. I then summarize the findings and draw the conclusions for this dissertation.

3.2 Key concepts

Big science

Big science refers to large-scale research. Organisation for Economic Co-operation and Development (OECD, 1993) describes big science as "a project that addresses a set of scientific problems of such significance, scope and complexity as to require an unusually large-scale collaborative effort, along with the facilities, instruments, human resources and logistic support to carry it out". Big science projects and facilities are of sufficient magnitude to require resources beyond the capacity of any single institution, funding agency or department to build to operate. According to Galison and Hevly (1992: 2), the term 'big' in big science "connotes expansion on many axes: geographic (in the occupation of science cities or regions), economic (in the sponsorship of major research endeavors now costing on the order of billions of dollars), multidisciplinary (in the necessary coordination of teams from previously distinct fields), multinational (in the coordination of groups with very different research styles and traditions)". Furthermore, "big science is big relative not just to what scientists knew before, it is big relative to all science" (Galison and Hevly, 1992: 2). CERN and its particle collider, research instrument *mega-projects,* and particle physics research can be considered big science in terms of their economic and multinational dimensions. In addition, since the data generated by the CERN-based particle physics *experiments* is analyzed in a distributed manner in multiple research institutes and universities all over the world, it is clearly also big science in terms of its geographic dimension.

Large-scale research laboratories such as CERN are sometimes also called *big-science centers* or *big-science organizations*, and large-scale scientific projects (with large-scale instrumentation) such as the LHC are called *big-science projects*. The term *mega-science* has also been used synonymously with big science, in particular before the term big science had gained a more

established terminological status. This is the case for the first Research Paper using the term mega-science instead of big science.

Naturally, mega-projects are also being accomplished outside mega-science. Flyvbjerg et al. (2003) investigating major projects in the fields of transport infrastructure, information technology (IT), power plants, water projects, oil and gas extraction projects and aerospace projects, argue that the promoters of multi-billion-dollar mega-projects systematically and self-servingly misinform decision-makers, the public, and the media in order to get projects approved and built. They show that the common determinant to mega-projects is the largely underestimated costs. For instance, in major transport infrastructure projects, "the difference between actual and estimated investment cost is often 50 to 100 percent, and for many projects cost overruns end up threatening project viability" (p. 11).

Nevertheless, big science is increasingly gaining ground and importance. Large-scale scientific installations were recently dubbed "Modern cathedrals" by the *Economist* (Carr, 2002). In addition to CERN and the LHC, big-science includes projects and labs such as the European Molecular Biology Laboratory (EMBL), the European Synchrotron Radiation Facility (ESRF), the International Thermonuclear Experimental Reactor (ITER), Joint European Torus (JET), and Wendelstein 7-X fusion machine (W7X). There is also a specific umbrella organization for European big science, the EIROforum (http://www.eiroforum.org/), a partnership of Europe's largest intergovernmental research organizations. Other examples of big science include the International Space Station (ISS), the Human Genome Project, and large-scale research and development programs in nanotechnology (Lambright, 2002, 2003). Wolfson (2004) argues that while most big science is traditionally in the fields of physics and astronomy due to the high cost of infrastructure, projects in other fields will increasingly begin to meet the big science definition. Examples may include large, long-term, population ageing and health studies or climate change research initiatives. These run longer than 10 to 20 years, cost hundreds of millions of dollars, are scientifically driven, and are of such a scale and import that a single approval decision would be required at a high level in government (Wolfson, 2004).

Partnerships, cooperation, collaboration, and interaction

There is no uniformly accepted definition of *partnership* in the academic or technology policy literature (Hagedoorn et al., 2000). Coburn (1995) uses the term synonymously with *cooperation*, and defines *cooperative technology programs* as "public-private initiatives involving government and industry – and often universities – that sponsor the development and the use of technology and improved practices to measurably benefit specific companies" (p. 1). Hagedoorn et al. (2000) define *research partnerships* broadly as "an innovation-based *relationship* that involves, at least partly, a significant effort in research and development (R&D)" (pp. 567-568, italics by myself). They note that this definition resembles what others have called a *strategic technical alliance* which is a special case of a *strategic alliance.* Teece (1992) defines strategic alliance as a web of agreements whereby two or more partners share the commitment to reach a common goal by pooling their resources and coordinating their activities (Hagedoorn et al., 2000).

For this study, I use the terms cooperation, partnership, and *collaboration* to describe lab-industry relationships. The unabridged Webster's (1979: 354, 402, 1307-8) and the second college edition of The American Heritage Dictionary (1991: 291, 321, 906) say that partnership is the "state" of being a partner, or "a contract", while cooperation and collaboration are defined as "the act of working together". Furthermore, while both cooperation and collaboration are about working

together, cooperation implies working together toward a common end or purpose, while collaboration implies working together especially in a joint intellectual effort, e.g. scientific research. Partnership refers to more formal relationships than cooperation and collaboration. Companies may cooperate or collaborate with big-science in an informal manner and for a short term, while partnership implies a formal arrangement that is more advanced and established.

Hence, I mainly use the term collaboration to describe the act of the lab and company working together (in a joint intellectual effort), and adopt the term cooperation when to emphasize that the parties share a common end or purpose. Furthermore, I use associate terms 'technical' or 'technological' when necessary to emphasize the technical nature of the interaction. I use the adjective 'strategic' to highlight the strategic importance of the relationship to at least one of the partners.

The focus of the study is in the very *interactions* within the collaboration pattern. Roessner (1993: 39) lists 10 types of interactions between research labs and industry:

- *contract research* –performed by industry, paid for by the lab
- *cooperative research* –done mutually by industry and the lab
- *workshops, seminars, and briefings* –conducted by lab scientists to disseminate information on new or emerging technologies
- *licensing* –of lab technology to industry
- *sponsored research* –done by the lab, paid for by the company
- *technical consultation* –to industry by lab personnel
- *employee exchange* –between a lab and a company
- *use of laboratory facilities* –by industry, to access capabilities not commercially available
- *lab visits* –by industry, to share information and discuss technical problems
- *information dissemination* –to industry through laboratory publications and other documentation

In the case of CERN, only some of these are applicable. CERN being a basic research lab, *sponsored research* is not applicable. Organized formal *employee exchange* does not occur either. Naturally, industry engineers apply for jobs at CERN, and especially younger engineers and students also frequently leave CERN and go and work in industry. Also in one of the case studies (Case 3), a university employee was sent by the university start-up to CERN for a year, yet this occurred entirely due to an industry-friendly one-off project of a particle physics institute affiliated to an LHC experiment. Formally, however, there is no employee exchange between industry and CERN.

Technical consultation may occur, but is not commercially available. In fact, CERN often provides its suppliers with extensive technical consultation, as the pure price competition (when no mutually beneficial strategic cooperation design is applied, see Paper 4) may result in supply contracts with some companies who in the end may not be able to manufacture the agreed products or to reach the required quality, and thus need help from CERN engineers. Since it is not commercial service, but in practice free of charge to the supplier companies, this type of consultation may actually become very expensive for CERN (Nordberg, 1997). Finally, CERN *laboratory facilities* are limited to CERN's own use, or to the particle physics experiments-related use by the CERN affiliated particle physics institutes. Companies, however, may indirectly "use" these facilities by letting CERN (in case the lab agrees or is motivated to) validate and test company prototypes and products, which is the very topic of this dissertation.

In addition, in this study, I also investigate interactions such as ad hoc meetings, telephone conferences and other discussion sessions, tests and test reports, supply of samples and information, and pilot use, as *informal interactions* when they are not formal or contractual in their nature. *Commercial* collaboration (which I consider is always formal) includes supply contracts, deliveries of products and services, joint press conferences and other publicity due to supply contracts, payments for deliveries, and supplier quality awards.

Technology transfer

Technology transfer (TT) is often defined in increasingly broader terms such as "interaction" between two or more individuals or groups of organizations in order to "exchange" technological knowledge (Amesse and Cohendet, 2001: 1459-1460; Autio and Laamanen, 1995). In this study, however, a more narrow and analytically meaningful definition of technology transfer is adopted, proposing that technology transfer mainly refers to what it literally means, that is, 'transfer' of technology. If the term technology transfer refers to too many issues and generalizations, it will become too vague as to provide any useful operationalization of the concept. On the other hand, the term technology transfer does not describe all the variety of research-industry "interactions" and "exchange". Bozeman and Papadakis (1995) propose that instead of "the increasingly worn term technology transfer" we need "language that more accurately conveys the true richness of commercially relevant technical activities in federal laboratories" (p. 72).

It is necessary to make a clear distinction between technology transfer and other types of interaction that were defined above. Technology transfer should not become equal to terms such as collaboration, cooperation, or partnership. As Roessner (1993) notes, "technology transfer is only one-way. It is not joint R&D, not a partnership" (p. 37). On the other hand, technology transfer has to be differentiated from *technology diffusion*. Hawthorne (1978) states that transfer implies agreement and therefore involves payment, while diffusion is the money-free process of the spread of knowledge. By definition, technology transfer is thus more narrowly defined than technology diffusion. Like Roessner's (1993), Hawthorne's definition also implies the one-way nature of the transfer. Rogers (1995), focusing on the *diffusion of innovation,* defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system" (p. 5). Furthermore, he says that diffusion is a special type of *communication* defined as "a process in which participants create and share information with one another in order to reach a mutual understanding" (pp. 5-6). In fact, this definition of communication comes very close to the above-mentioned broad definition of technology transfer as "exchange" of knowledge. As said, there is a danger of confusion when technology transfer is defined too broadly. Diffusion is a special case of communication. And technology transfer is a special case of diffusion (Hameri, 1996). In this order.

It is also necessary to make a distinction between the typical *technology transfer activity* and other forms of promotion activities of public research organizations. The technology transfer office (TTO) focus is typically on one-way transfer. Generally speaking, they do not initiate or orchestrate all kinds of "interactions" and "exchanges" with industry, even less any procurement of new technology from industry (which is one kind of transfer of technology to research). It is unlikely that TTO agendas will be extended to cover all these interactions. They will probably continue focusing on the one-way technology transfer from research to industry. If not, the name of the activity will also likely be different, for instance 'industry liaison'.

This study focuses on new technologies from industry to be used in the research lab. On various occasions in the beginning of the study, when this was referred as 'technology transfer', persons involved in the study automatically understood it as the 'traditional' one, i.e. opposite direction. In practice, the term technology transfer, as well as the term technology transfer office (TTO), often connotes simply to the one-way technology transfer from research to industry. Also academic studies tend to conceive of technology transfer as "the use by an external party of technology or technical information developed by a publicly sponsored contract" (Kingsley et al., 1996: 969).

In this study, I adopt Hameri's (1996) definition of technology transfer as "an active and intentional process to disseminate or acquire knowledge, experience and the related artifacts" (p. 52). This definition implies the real-life nature of technology transfer being one-way and involving acquisition, which is also consistent with Hawthorne (1978) and Roessner (1993), among others. On the contrary, I consider interaction between parties involving an act of working with each other, or continuous exchange between parties, as collaboration, cooperation, or possibly another type of interaction (see the list in the previous section), but not as technology transfer.

In this study, I sometimes use terms such as *traditional technology transfer* or *conventional technology transfer* in order to emphasize a one-way transfer of technology from developer to buyer and from research to industry. I also employ the term *reverse technology transfer* to indicate the direction of transfer is from industry to basic research, which is opposite to the 'traditional' university or lab technology transfer activity.[2]

Technology itself is seen by management research as a strategic asset (Zhao and Reisman, 1992). It can change the structure of an industry and affect the competitive advantage and is released only under special conditions (Porter, 1985; Willard and Cooper, 1985). Technology is conceived of as "a firm-specific information concerning the characteristics and performance properties of the production process and of the product design" and is often decomposed as *research*, *development*, *R&D*, *engineering*, and *manufacturing* (Zhao and Reisman, 1992: 15). The concept of technology does not exist without an implicit model of use. "Technological objects are not something that we can discover from nature: they exist as material artefacts that embed uses. Technological artefacts are artefacts full of meaning" (Tuomi, 2002: 12). In this dissertation, I use the terms *technological artefact* or *physical technology* when necessary to emphasize that it is something concrete and tangible in nature (e.g. prototype, equipment, instrument component, sample) as opposed to mere knowledge or information.

Innovation, new product development (NPD), and the process from technology to innovation

Innovation is defined as "the first commercial application or production of a new process or product" (Freeman and Soete, 1997: 201). This definition is in line with Schumpeter's (1939) view of innovation as the commercial application or "adoption" of an *invention*. It is also compatible with the above-adopted concept of technology transfer as the transfer of knowledge, experience, or artifacts, and not as the transfer of innovation or market-ready products. Typically, it takes several years to commercialize a new technology, even though its developers themselves might consider it ready for the market. New technology developers (scientists, researchers, R&D engineers, etc.) tend to underestimate the work needed to commercialize new technology.

[2] Mansfield (1984) has also used the term 'reverse technology transfer' in the past, yet has limited its use to a special case of "transfer of technology from overseas subsidiaries to their U.S. parents" (Mansfield, 1984: 138).

Commercialization is the very act and process of taking the new technology to the marketplace and starting to make money with it. Commercialization never happens accidentially or automatically, but requires professional skills as well as creativity, intuition and instinct. This is an important point. For example, in its report on science and technology indicators the European Commission claims that "An important support mechanism for the realization of the knowledge-based economy is strong industry-university co-operation. This allows for the rapid conversion of scientific knowledge into commercial innovations with strong social and economic benefits" (EC, 2003a: snapshot 6). This statement, incorrectly, implies that innovation emerges automatically when industry and research are put together, and thus mistakes invention for innovation. According to Schumpeter (1939) "the making of the invention and the carrying out of the corresponding innovation are, economically and sociologically, two entirely different things" (p. 85). Freeman and Soete (1997) say that making the distinction between inventions and innovations is "extremely important" (p. 6). Innovation is essentially "a coupling process", and, consequently, "the crucial contribution of the *entrepreneur* is to link the novel ideas and the market" (Freeman and Soete, 1997: 201). In fact, new technology is rarely used as its designers expected, and can actually play different roles in different social practices. Innovation is, therefore, "more about creating meanings than it is about creating artefacts" (Tuomi, 2002: 13). Technology becomes innovation only when taken into meaningful use in social practice.

This definition substantially differs from multiple sweeping generalizations of the term in the literature. The chosen definition implies that, for instance, a new technology or product that has not yet been commercially applied and adopted is not (yet) an innovation. Hence, new technology may be called innovation only retrospectively, once it has been successfully applied and adopted to a meaningful use in social practice.

Also the radicalness of an innovation can only be known retrospectively. New technology may have radical or disruptive characteristics and performance compared to existing technologies (Freeman and Soete, 1997). Also a business model under development can be radical compared to the mainstream models of the parent company or industry. Third, also some new technology-based development efforts can be called *radical initiatives* or *radical projects*. However, these development efforts are not *radical innovations* until they are successfully adopted and have radical effects on the marketplace.

At the conceptual level, new technology-based industrial innovations are typically divided into two main categories (Freeman and Soete, 1997; Garcia and Calantone, 2002):

- *Incremental* (continuous) *innovations* involve many small improvements. They are product improvements or new products that are, when the R&D is correctly managed, based on recognized customer needs. Most of the industrial R&D falls in this category of innovations.
- *Discontinuous* (i.e., either "radical" or "really new") *innovations* involve big changes and discontinuities. They are typically new to the market and do not address any recognized customer demand. Yet, they result in a step change on the market, thus changing the basis for competition and providing the company with a unique competitive advantage.

New technology may convert either into incremental or discontinuous innovation, depending on the strategy of the organization hosting and developing the technology (Freeman and Soete, 1997). The radicalness thus highly depends on the application or the use of the technology, playing different roles in different social practices (Tuomi, 2002). Furthermore, while not all discontinuous innovations are technological ones, *radical innovations* are based on new

technology or on the synthesis of well-known technical information or components (Garcia and Calantone, 2002; Nelson and Winter, 1982; Utterback, 1996). For instance, some scholars regard the Sony Walkman as a *disruptive technology* (Paap and Katz, 2004), yet detailed research shows that "the first Walkman model was anything but a *radical technological change*" (Sanderson and Uzumeri, 1995: 762, italics by myself). The first Walkman model was simply a recombination of existing technologies and "based far more on market insights than on technological breakthroughs" (p. 762). The success of the chosen commercialization strategy and the business model thus largely determine the radicalness of an innovation. If not yet on the market or in use, a new technology itself cannot be termed 'radical innovation', no matter how radically new the technology itself is.

While the linear model of technological *innovation process* has been severely criticized because it fails to account for feedback loops and stages (Kline and Rosenberg, 1986; Rosenberg and Nelson, 1994), the industrial *new product development* (NPD) is increasingly managed through a linear 'stage-gate' process (Johnson and Jones, 1957; Cooper, 1988; Griffin, 1997). An NPD process, however, is a management tool and does not attempt to explain how innovations emerge or to discuss the concept of innovation. In fact, NPD typically gets involved at the end of an innovation process. The main task of the NPD is to develop a product out of a *product idea.* In the case of new technology and particularly discontinuous innovation, several technology trajectories and many years of research and development typically precede the actual NPD, i.e. before the product-oriented development really starts (Dosi, 1982; O'Connor et al., 2002; Veryzer, 1998). Despite the criticism toward the linear innovation process model, many national level technology policy initiatives, such as the Bayh-Dole Act in the US (see Section 3.5), apply the linear model to the management of federal R&D funding, and consider public research organizations as "treasure chests" (Ham and Mowery, 1998: 663).

3.3 Literature on CERN-industry collaboration

Research on interaction between industrial companies and intergovernmental big-science centers has focused on CERN procurement. This research tradition started in the 1970s when CERN's particle accelerators began to gain size and complexity, and industrial partners were increasingly needed for their construction. The research (Schmied, 1977) took the form of economic studies of the utility of CERN supplier contracts to the Member State economies. In his studies, Schmied (1977, 1982, 1987) attempted to quantify the 'secondary economic impact' generated by big research center supply contracts. He identified four distinct mechanisms through which such value-added could be achieved: First, 'innovation benefits' (increases in sales due to new products, improved products, better quality systems); Second, 'commercial benefits' (increase in sales due to marketing reference value associated with being a supplier to a big-science center); Third, 'maintaining production capacity' (direct financial impact of the supplier contract); Fourth, 'cost savings' (improved profitability through process improvement). In addition, he identified a negative outcome, consisting of opportunity costs due to resource allocation.

In several studies with CERN and the European Space Agency (ESA), Schmied and colleagues attempted to quantify such benefits, using direct interviews with company managers as their primary empirical data. The interviews signaled a total value added per contract ratios ranging from 2.7 (ESA) to 3.7 (CERN) and a total value added per big-science center's total expenditure ratios ranging from 1.2 to 1.6. Approximately one quarter of the value added was, according to Schmied (1982), due to 'innovation benefits', with another quarter attributed to 'commercial benefits'. Using a similar technique (and, apparently, the same data), Streit-Bianchi and

colleagues (1984) arrived at a total benefit – total contractual cost ratio of 3.0. Summarizing, the studies above indicate that the innovation benefits, as generated by international big-science centers, are indeed important. The studies also made a major contribution in identifying some of the mechanisms through which technological advantages can be derived from big-science procurement activity. However, the studies did not provide a detailed examination of the learning and collaboration mechanisms underlying the identified innovation benefits. This limited the applicability of these 'input-output' studies from the perspective of attempting to improve or optimize the aforementioned benefits. Nor did they provide any practical help for new companies to enter, collaborate with, and benefit from CERN and big science.

Later, the development and construction of the LHC in the 1990s resulted in a 'come-back' of research on CERN-industry collaboration, often applying the management perspective and detailed case studies. Autio and colleagues (1996) and Nordberg (1994) discuss the reasons and motivations to participate in collaboration with big science centers such as CERN. They find that, while the normal business-driven incentives are present in dyads involving low tech and commodities, direct financial and profit-making criteria are seldom the drivers in technology-intensive business. The more technology-driven the project is, the more anticipation is on learning and technical expertise. This potential is largely due to the big-science center's ability to document technological trajectories and to provide suppliers with well-defined specifications.

Hameri (1996, 1997) and Byckling and colleagues (2000) discuss CERN technology transfer and find that it "lacks a systematic approach to perform technology transfer and interaction" (Hameri, 1996: 55) and that the technology transfer policy that CERN later developed typically "hinders the application of new big science technology in industry" (Byckling et al., 2000: 76). They argue that the true innovative potential lies in *collaboration* between industry and big science and "the goal of technology transfer activity should be to fertilize the industries of the participating countries rather than to try to obtain additional finance for the research organization" (Byckling et al., 2000: 71). Their case study, however, shows that CERN may offer an uncommonly fertile ground for development efforts.

Vuola (1996) studies how to conduct market research for non-lab-specific technology in the environment that has no prior experience or knowledge on the technology. He focuses on a case of a university-based radical electromechanical technology developed for non-scientific, industrial applications, and finds that CERN may act as a unique platform to identify a broad array of new applications, both industrial and science-specific, for a new technology at prototype stage. This is also when this research project was initiated, continuing this new perspective that is new in at least two ways: First, it is about *systematic* use (instead of 'accidential' benefits) of CERN, and, second, it aims to catalyze *industrial* (and not lab-based) innovations.

The rapid diffusion of one of the most meaningful technological innovations of our recent history, the World Wide Web, has also inspired studies on CERN as its birthplace. It took surprisingly long before the first study was done (Hameri and Nordberg, 1998), followed later by a book from the inventor, Berners-Lee (Berners-Lee and Fischetti, 1999). In addition, in his book on innovation networks, Tuomi (2002) studies the history of the Web in great detail, and argues that while Berners-Lee is often hailed as the inventor of the Web, CERN's user community and meaningful social practice had an important role in the birth of the Web. He regards the inventor as a user among other users. Common to all these studies is their emphasis on the role of the unique CERN environment and infrastructure in the birth of the Web.

Most recently, Autio et al. (2003) have investigated CERN as a learning environment for its supplier companies and the resulting innovation benefits for the suppliers. Studying 154 European CERN supplier companies, the study observed significant development of new businesses, products and services, boosted internationalization of sales and marketing operations, and improved quality among the suppliers. The positive impacts, however, were very much concentrated within only certain supplier contracts. The universal determinants of learning and innovation outcomes were the interaction frequency between CERN and its suppliers firm. Compared to an average supplier, high technological learners were younger, had longer projects, had more previous experience in collaboration with CERN, were more dependent on CERN as a customer, interacted with CERN more frequently, kept promises less frequently, had a greater number of previous projects with CERN, and had more R&D intensive projects.

Consequently, their implications for CERN's procurement policy include the following: CERN's current procurement policy, which selects the lowest bidder, is "probably close to optimal" (p. 51) for most of the procurements; For the technology-intensive procurements suppliers, "CERN can probably do much to enhance the creation of learning and innovation benefits, once the bidder has been selected" (p. 51); To organize for and emphasize extensive and frequent interaction between CERN and its suppliers; In order to boost learning, CERN should allow readjustments of supplier projects' goals while projects are under way; Getting industry involved early on for the development of mission-critical technologies; CERN should consider developing long-term partnerships with selected high-value supplier companies in mission-critical technology areas; and CERN should continue to produce the technological specifications itself and maintain sufficient engineering competence.

The shortcoming of the study, however, is that it focuses on existing supplier companies, that is, those who had succeeded in tendering competitions. It also ignores all companies with total orders less than 25 000 Swiss francs. Hence, the pre-tender developments as well as collaboration modes other than those aiming solely at supply contracts were automatically excluded from the study. No data, nor insight, are presented on possible informal modes of collaboration, pre-tender interaction, or how new supplier candidates, including venture companies, could use CERN's pre-tender practices systematically for industrial product and business development. On the other hand, it is not clear what the cost consequences of the recommendations are for the already increasingly scarce resources of CERN, and whether the recommendations would improve cost-efficiency of the CERN procurement activity.

While the *benefits* of the CERN procurement have been widely studied, the CERN procurement *procedures and practices* and how to effectively manage them have rarely been the subject of investigation. Hameri and Nordberg (1999) attempt to improve CERN procurement procedures and to eliminate political interference by introducing a broker-based model similar to the double blind review process of scientific journals. The broker has a critical role as "the mediator who needs to be recognized by all parties as being reliable and able to guarantee full confidentiality" (p. 460), and who is "a type of 'Elliott Ness of cybermarket', an untouchable and incorruptible officer of law who is not financially dependent on the success or volume of the channeled transactions" (p. 463). This would certainly help decrease chances for political interventions, yet does not provide the answer for the research question. Also Nordberg (1994, 1997) and Vuola (2004) have provided practical recommendations to improve procurement, yet they do not provide any model from the procurement perspective that would reduce costs while enabling innovation in industry since they have not focused their research on the procurement process.

To conclude, it is clear that, while they provide important insight into related issues, earlier CERN studies do not provide answers to the research questions of this dissertation. Three of the cases of this study were recently used as the basis for the construction of a theoretical framework for the above-mentioned study on technological learning (see Autio et al., 2004). The very research questions, however, have remained unanswered. In the following, I review other relevant technology transfer literature focusing on interactions between large research labs and industry.

3.4 Industrial interaction with the U.S. labs and research centers

Public research-industry interaction has been extensively studied particularly in the US. While most of these studies tend to focus on universities and on traditional (one-way) technology transfer, several studies focus on industrial collaboration with U.S. federal research labs. There are 700 federal labs in the United States (Rogers et al., 1998), which makes it possible to conduct survey studies across labs. These significant contributions are relevant to this study for three reasons: First, they are about *labs* (that significantly differ from universities (Schmied, 1987)). Second, they look at various *modes of collaboration* and interaction (other than supply contracts) that potentially may help understand the specific mode of CERN-industry collaboration examined in this study. Third, some of them focus on *the firm perspective*.

Drawn from the original research questions, the focus is particularly on the following issues to provide guidance to the review of the literature on the US research lab-industry collaboration:

- How do *companies use* research labs?
- How do research labs and centers operate as sources of *outside resources*?
- What are the *collaboration mechanisms*?
- How is *industrial innovation enabled through procurement*?

Roessner and Bean (Roessner and Bean, 1990, 1991; Roessner, 1993) and Bozeman and colleagues (Bozeman, Papadakis, and Coker, 1995; Bozeman and Papadakis, 1995) have studied company interactions with US labs with the focus on the firm perspective.

Roessner and Bean (1990, 1991) conducted two surveys with members of the Industrial Research Institute (IRI), the first with 139 firms focusing on externally funded R&D and on relations with university performers, and the second with 84 firms with questions about company interactions with federal labs. Out of the ten different types of interactions listed above, *information dissemination, workshops/seminars, lab visits, and technical consultation* were by far the most frequent ones. These types were also the easiest to implement, least formal, and probably also least costly of all types of interaction. The companies that had had interaction with labs reported high levels of satisfaction with the results for every mechanism except for licensing. *Information dissemination and individual lab visits* showed the most promise of future payoff. This was followed by workshops/seminars, technical cooperation, and cooperative research. *Person-to-person contacts* were reported the most important success factor.

Roessner (1993) later surveyed 68 IRI member firms and found that companies are seeking technical information, expertise, access to specialized equipment, and new technology from *outside sources* in response to greater market pressure, tighter company budgets, and the globalization of competition. CTOs and research directors ranked other U.S. companies as the highest external source. Universities were considered "moderately" or "very" significant, while *federal labs* were ranked only "somewhat" significant. Roessner states that "although this is hardly a sweeping endorsement of the labs, it is much better than the rating given only a few years

ago. During a similar survey conducted in 1988 by myself and Alden Bean, company leaders indicated that they paid little attention to work at the federal labs" (Roessner 1993: 38-39). This implies that companies' interest in research labs has been increasing. He claims that the reason for the increased interest is due to decreasing internal R&D support. As internal R&D support decreases, reliance on outside resources increases. The dominant positive incentive for companies for interacting with a federal lab was "*access to unique technical resources*". Among those few with past experience with federal labs, *informal* interactions such as *information dissemination, lab visits, seminars, and technical consultation* had occurred most frequently. Companies had initiated most of the interactions. Interestingly, 'contract research' was ranked by far as the form of interaction that lead to the greatest payoff, followed by 'cooperative research'. Payoffs from these forms of interaction with labs took the form of *leveraging R&D, access to expertise and facilities, and business opportunity*, in that order.

Bozeman and Papadakis (1995) report on a survey of 229 companies working with 27 US labs, focusing on the companies' initial objectives and motivations for interaction, type of companies, initiation of interaction, and various types of interactions. They found that while private companies and federal labs were involved in a wide array of commercially relevant activities, only one-third of which reflecting traditional concepts of technology transfer. Companies partnered with labs *to take advantage of lab expertise and unique resources, aiming at building precompetitive knowledge, seeking technical assistance, using unique lab facilities, and enhancing their human capital.* Much of the activities of labs involve interaction that is "fluid and *informal*" and the entity transferred is not a finished technology from the lab, but "a prototype, a process or practical knowledge or know-how" (p. 65). Most of the interactions were collaborative in nature; the least reported (barely 5% of the total) type of interaction being technology licensing, i.e. 'traditional' technology transfer. In fact, lab technology transfer staff played only a minor role in the initiation of the collaboration projects. Most common project initiators were company and lab R&D managers and bench-level scientists and engineers. The companies collaborating with federal labs were extremely research intensive with R&D personnel constituting on average 14% of all employees.

To investigate if there are large differences between labs and the university context, I also reviewed Feller and colleagues (2002) survey of 355 firms participating in 18 university *engineering research centers* (ERC) in the U.S. between 1985 and 1990. Their findings indicate that firms participate primarily to gain access to upstream modes of knowledge rather than specific products or processes. The principle original reasons for participation included access to *new ideas, access to ERC expertise, access to specific ERC faculty, and access to equipment and facilities* at the ERC. Licensing inventions developed by the ERC was among the least important motivations for partnership, behind *access to ERC test bed facilities or prototyping capabilities.* The most reported outcomes as experienced by ERC partner firms (40% to 84% of all companies reporting) were the following:

- obtained access to new ideas and know-how;
- received direct technical assistance from ERC;
- influenced the company R&D agenda;
- increased interaction with other firms;
- provided customers or suppliers with improved technical information;
- improved a product or process;
- used ERC facilities or equipment; and
- hired ERC students

Also, less than 5% of the companies commercialized a product or process obtained from the ERC, and less than 3% established a new company or joint venture based on ERC technology or product. In overall, these results in the research center environment are similar to those within the lab environment.

All of the above studies indicate that the traditional form of technology transfer (products *from research* to industry) is not what companies primarily want or seek in research labs and research centers. Nor does the traditional technology transfer seem to be effective. In fact, based on the above findings, the most useful mode of collaboration is one that fosters knowledge and information exchange and facilitates a firm's access to the expertise and unique resources of the lab.

This is further confirmed by U.S. studies on Cooperative Research and Development Agreements (CRADA) conducted when this research project was already ongoing. CRADAs are legal agreements for the sharing of research personnel, equipment, and intellectual property rights (IPR) in joint lab-industry research, each party paying for its own expenses (Berman, 1993). While CRADAs are also intended to attract additional funding for labs, the main objective is to encourage technology transfer to industry. In selecting partners, labs must give special consideration to *small* domestic (U.S.) businesses (Rogers et al., 1998). The underlying assumption when CRADAs were designed was "that these facilities are 'treasure chests', organizations with a great deal of technology that is directly applicable in private industry" (Ham and Mowery, 1998: 663). CRADAs were created by the Federal Technology Transfer Act of 1986 and its 1989 amendment.

Ham and Mowery (1998) report on five case studies of CRADAs between private firms and the US weapons lab Lawrence Livermore National Laboratory (LLNL). Outcomes of the studied CRADAs differed substantially, yet all firms believed that the lab "had valuable technical and engineering capabilities that were not available elsewhere" (p. 672). The main capability was *specialized facilities and equipment.* Wierengo (1994) found that the main advantages of CRADAs to private firm partners are *leveraging R&D resources; access to government facilities equipment, and expertise; and increasing the exchange of ideas through person-to-person contacts*. Furthermore, Rogers and colleagues (1998) survey reveals that "both private companies and their partners in Federal R&D laboratories perceive that the exchange of technological information is one of the main purposes of CRADAs" (p. 82), and also state that "the main function of CRADAs, to transfer technology from a Federal R&D laboratory to its private company partner, is extremely difficult" (p. 87). In summary, these studies confirm that leveraging firm's own R&D through access to the lab facilities and expertise and exchange of technological information are the main reasons for firms to cooperate with the labs. While this supports earlier findings on lab-industry interaction, it significantly differs from the original purpose of the CRADA mechanism.

Even more so, as Ham and Mowery (1998) conclude that lab-industry collaboration is successful when it focuses on *projects for which the lab is an important customer.* They suggest that co-development projects in technologies for which laboratories are major users of the results (equipment, ideas, or services) are good candidates for collaborative R&D mechanisms. Consequently, they conclude that collaborative R&D is most effective for projects that draw on the historic missions and capabilities of the labs. This is in line with earlier findings of Kingsley and colleagues (1996) who argue for the necessary distinction between technology transfer and "technology absorption", the latter referring to the use of technology by participants of a joint

development project. Furthermore, they argue that this phenomenon is rarely studied but is especially important for policy-makers.

However, there is little research focusing on the lab *purchases* (for which the lab certainly is an "important customer"). Furthermore, the very idea of using this procurement as a systematic innovation tool and in such a manner that risks can be managed and cost efficiency improved also is understudied.

3.5 Collaboration with basic research

While David and colleagues (1988) may feel that "the outputs of basic research rarely possess intrinsic economic value" (p. 68), quantitative studies on lab-industry interactions indicate that basic research actually figures prominently in companies' interactions with the US federal labs (Bozeman and Papadakis, 1995). Furthermore, Rogers and Bozeman (1997), focusing on basic research in the lab-industry partnerships, challenge the belief that basic research is the component of the knowledge enterprise most distant from commercialization. While they provide significant new knowledge about the significant role of joint basic research in new product development, they focus on the *role* of basic research in the success of lab-industry interactions, not specifically on basic research *labs*, which would be more relevant to the focus area of this dissertation. No distinction is made between different types of basic research, nor between labs that do only basic research and those that do also other research. This is important because some firms may do basic research in areas such as biotechnology or materials technology, but none in astronomy or fundamental physics.

Furthermore, it is not clear which type of basic research collaboration had produced the reported benefits. The different types are listed (collaborative R&D, formal CRADAs, personnel exchange, resource sharing and use of specialized equipment, licensing of technology, and technical assistance) yet no information is provided on the most successful ones. A similar study focusing on labs doing basic research alone, or on groups conducting fundamental physics, could shed more light on the issues investigated within this dissertation. Nevertheless, an interesting general finding of the paper is that lab-company partnerships in basic research are more successful if the firm is "in command of most of the technical phases of product development while the lab is more narrowly focused to make a specific contribution to the project" (p. 43).

In general, the discussion on technology transfer emphasizes modes of interaction that involve either joint research or technology licensing. However, organized technology transfer from basic research is often marginal. In the case of CERN, organized transfer of the CERN-developed technologies has had a very modest role throughout CERN's history. As mentioned earlier, Hameri (1996) stated that CERN "lacks a systematic approach to perform technology transfer and interaction" (p. 55). For instance, by 2000, CERN had only 16 patents and no income generated by them (CERN, 2000). Only relatively recently, since the end of 1990s, some CERN member states started to push increased levels of technology transfer activity at CERN (CERN, 1999b).

One of the possible reasons for the lack of CERN technology transfer activity compared to the US labs is that in the past Europe has lacked similar legislation and related political pressure, while at the same time in the US, passage of several technology transfer -related acts have taken place (The Bayh-Dole act, the Stevenson-Wydler Act, the Cooperative Research Act, and the Federal Technology Transfer Act and its amendments). Also research on technology transfer from US labs to industry shows that *multi-mission* laboratories are likely to enjoy the most success in

technology transfer (Bozeman and Coker, 1992) and also that *industry R&D funding* is a major factor in technology transfer activity (Rahm et al., 1988). CERN being both single-mission and a basic research lab (with no industry funding) it is no wonder organized technology transfer has not been popular nor successful.

One might argue that the above is not true, as CERN has produced great innovations such as the Web, and also some spin-off firms. The Web, however, is not a result of organized CERN technology transfer activity, as it spread outside CERN through user networks and was not transferred by CERN and its TTO. Furthermore, there is one case study of a CERN spin-off (Byckling et al., 2000) that, to be precise, is actually a spin-off from *university* research conducted at the CERN site and not the result of technology transfer activity. The case study heavily criticizes the technology transfer and related administrative procedures at CERN as hindering rather than facilitating the actual technology transfer.

Furthermore, CERN being a basic research and particle physics laboratory, joint lab-industry research may not exist. Ham and Mowery (1998) argue that lab-industry collaboration should focus on drawing on the historic missions and capabilities of the lab. In the case of CERN, it is not clear what such research projects in the context of fundamental physics would be. It is evident that no firm is interested in joint research in particle physics. Nor is there commercial or industry sponsored research. At the first sight, it might seem that CERN, as a European intergovernmental basic research lab, may not be a useful partner for private firms to develop non-high energy physics (HEP) products: neither substantial technology transfer activity, nor commercial or joint research with industry, and the mission solely focused on particle physics.

In some aspects, CERN might substantially differ from the mass of US federal research laboratories that are typically the sample for the survey studies on lab-industry interaction. There are not similar interaction opportunities for industry with a *single-mission* basic research lab such as CERN. The CERN supplier studies discussed above indicate innovation benefits, yet they tend to focus on supply contracts and treat CERN as a buyer organization and not as a potential strategic R&D partner. Hameri (1996) argues that, despite being a basic research lab, CERN is a fertile soil for industrial collaboration potentially producing "significant technological leverage in the form of new products, processes and services" (p. 56). He also outlines motivations and strategic options for such collaboration. However, no distinction is made between companies with products that are HEP-specific and those developing non-HEP-specific technologies and products.

3.6 Conclusions for this dissertation

While CERN is a basic research lab that does not do sponsored research, it may provide companies with what they need. The literature review indicates that sponsored research together with employee exchange are *the least* preferred forms of interaction with labs, while information dissemination, lab visits, workshops, and technical cooperation and consultation show *the most* promise of future payoff for companies. They are also the most frequent types of interactions. Past evidence also indicates that an average lab technology transfer activity provides neither much outcome nor great motivation for companies, and is actually the least reason for companies to start interaction with labs.

Hence, a basic research lab like CERN, in principle, should be able to provide companies with their preferred collaboration modes. The lack of opportunities for sponsored research or

technology licensing with basic research should not be an obstacle for companies to systematically collaborate with a basic research lab.

The above studies also show that despite extensive (and possibly expensive) efforts particularly to promote technology transfer from labs to industry, the most successful forms of interaction may be those focusing on projects for which the lab is a major *user*. In this role, the lab would be the 'recipient' rather than the 'agent' of technology transfer (Bozeman, 2000). Among the different forms of interaction listed above, the ones in which the lab is a user could include e.g. 'contract research', which is performed by industry and paid for by the lab, and a specific case of 'cooperative research' developing such technologies for which also the lab is a user.

Due to the sheer size of its scientific instrumentation mega-projects, big-science basic research often has extensive procurement activity, important R&D function, and also cooperation with industry. The above-discussed CERN supplier studies also indicate that there are substantial innovation benefits to CERN *supplier* companies. These earlier studies on CERN-industry interaction, however, have almost exclusively focused on supply contracts and supplier companies, thus treating the lab merely as a buyer organization. It has not been studied if these significant engineering and R&D functions could be used for the benefit of companies that are *not* CERN suppliers and are *not* in the HEP business. Nevertheless, while the lab's engineering functions exist solely for the purposes of basic research (particle physics research in the case of CERN) a theoretical hypothesis can be drawn from the above, proposing that a basic research lab and companies could potentially be able to collaborate in such a manner that companies may accrue multiple payoffs through such interactions as information dissemination, lab visits, workshops, and technical cooperation and consultation.

The condition for such mode of collaboration seems to be that it has to serve basic research, for example, particle physics in this case. And the key question is if companies with development needs other than those related to basic research (e.g. particle physics) could effectively collaborate with the basic research lab, and also accrue necessary innovation benefits. The aim of this study is that this should occur in a systematic manner, and not just assuming statistical average benefits will drop out of the box. Subsequently, the other side of the coin is that, if such collaboration is possible, what the lab as a public organization should do in order to initiate and facilitate such cooperation, and to maximize the benefits to both industry and itself.

There are many similarities between the collaboration type investigated in this study within the CERN context and the well-researched US lab-industry cooperative R&D. Although lab-industry cooperative R&D has been extensively studied in the US, previous studies on CERN-industry collaboration have not actively used this knowledge to explain their findings and to understand the multitude and richness of lab-industry interaction. Table 1 attempts to summarize how CERN is unique and how this relates to key findings in previous studies on industrial collaboration with labs, including CERN.

How CERN is unique	What we know about industrial collaboration with labs, including CERN
It is a single-mission lab conducting fundamental physics research alone	The lab is a fertile soil for technological leverage in the form of industrial products, processes and services
The lab is financed through public funds (governments) alone and thus conducts no commercial or sponsored research	Companies actively cooperate with the lab and greatly benefit through access to the lab expertise, resources, technical assistance, and facilities; sponsored research is actually *the least* preferred form of interaction with labs
Being a basic research lab without industry funding, organized technology transfer activity is only modest	Companies primarily aim at leveraging their own R&D and business when collaborating with the lab; they do not primarily seek to acquire lab-based technologies
Its facilities and services exist for the purpose of particle physics research alone	Lab-industry collaboration is successful when it focuses on projects for which the lab is an important customer and user

Table 1. CERN and other public research labs from the perspective of lab-industry collaboration and technology transfer studies.

While CERN has its unique characteristics, they do not seem to be significant in the light of what we know of lab-industry collaboration: Although conducting fundamental physics research alone, CERN is a fertile soil for technological leverage in the form of industrial products, processes and services, just like other labs; While rejecting sponsored research, firms actively cooperate with CERN and greatly benefit from the cooperation through access to the lab expertise, resources, and facilities, just like with other labs; While its technology transfer activity is only modest, it does not matter, as companies collaborating with labs primarily aim at leveraging their own R&D and not at acquiring lab-based technologies; And, finally, while its facilities and resources are not directly available for industrial product development but for particle physics alone, literature actually indicates that industry collaboration with labs in general is most successful when it focuses on projects for which the lab is a user.

Despite its important contributions to our knowledge, however, received technology transfer literature does not seem to be able to provide direct answers to specific the research questions of the dissertation. In particular, while previous studies show that CERN procurement may result in multiple innovation benefits, no practical model exists to manage costs and risks of technology procurement activity. Furthermore, no model is presented on how to maximize the positive yet 'accidential' innovation benefits, or how to accrue the benefits systematically. I use a less lab-specific yet otherwise much used concept of 'Public Technology Procurement' (Edquist et al., 2000), together with the collaboration model developed in Paper 2, as a basis for the discussion on

the procurement procedures. This specific conceptual framework is discussed in Paper 4 in detail and thus not repeated here.

4 RESEARCH STRATEGY AND METHODS

"Yet the confidence in the unlimited power of science is only too often based on a false belief that the scientific method consists in the application of a ready-made technique, or in imitating the form rather than the substance of scientific procedure, as if one needed only to follow some cooking recipes to solve all social problems. It sometimes almost seems as if the techniques of science were more easily learnt than the thinking that shows us what the problems are and how to approach them."

von Hayek (1989: 6)

4.1 Research design

The case study method was chosen as the best way to arrive at an encompassing view of the research problem. Case study is a preferred strategy when "how" or "why" questions, as well as exploratory "what" questions, are being asked about a contemporary set of events (Yin, 1994). The findings of a case study reveal a rich detail of information that is useful for exploration of topics. Hence, case study is particularly useful for addressing contemporary subjects where there is not a knowledge base to draw upon (Bozeman and Kingsley, 1997: 35).

Altogether nine new technologies in nine companies and their collaboration with CERN were studied for this dissertation. The four Research Papers of the dissertation report on five embedded studies of these nine cases. Three of the studies are single-case studies and two are multiple-case studies:

- A single-case study (reported in Research Paper 1) of a radical technology (Case 1) developed for industrial use but introduced to CERN for the commercialization purposes: This study explores the basic idea of using basic research to catalyze industrial innovation, that is, a systematic transfer of industrial technology to basic research for commercialization purposes ('reverse technology transfer'). It provides the rational and direction for the rest of the exploration;

- A single-case study (reported in Research Paper 2) of a long-term technical partnership between the research lab and a new technology venture company (Case 2): The company is technically successful, and initially also seen as a model example for other companies, yet fails in a major tendering competition and is left without a supply contract. The study focuses on this very dilemma as well as on the underlying reasons for failure. This unique case is used together with the first study and literature for the construction of a collaboration model for the above approach;

- A retrospective study (reported in Research Paper 3) of a corporate venture company developing a new technology-based business that substantially differs from the corporate mainstream business (Case 6): This single-case study focuses on the long-term business development issues and the role of big science collaboration within the overall technological trajectory;

- Two multiple-case studies (reported in Research Papers 2 and 4) on seven emerging technologies from seven companies and venture teams and their collaboration with CERN (Cases 3 to 9): This longitudinal research is action-based and thus studied on a real-time basis, providing unique opportunities to gain insight into the actual collaboration mechanisms[3]. It also examines the company product development as well as the lab technology development and purchasing related to the collaboration cases.

Because of the exploratory nature of the study and the objective of generating a descriptive model of undocumented phenomena, the very first insights and preliminary ideas of the model are grounded on the data (Eisenhardt, 1989; Glaser and Strauss, 1967). In this grounded approach, the theory and models emerge from in-depth case studies by taking an informed look into the cases so as to determine what the cases tell us. Glaser and Strauss (1967: 37) propose to the researcher "at first, literally to ignore the literature of theory and fact on the area under study, in order to assure that the emergence of categories will not be contaminated by concepts more suited to different areas". Therefore, the early cases are studied without first developing a theoretical framework.

It has been argued that claiming ignorance of existing literature only disguises the biases that every researcher carries, and the body of literature the researcher knows acts as a cognitive lens shaping his or her perceptions (Strauss and Corbin, 1998). However, while this is not contested, the lack of previous research at the actual focus area of this study at the time the study began in 1996 provides full compliance with the original grounded approach.[4]

Research quality is an integral part of a good research design. Quality can be addressed in several ways. Yin (1994) argues that, as case studies are one form of empirical social research, the four logical tests that are commonly used to judge the quality of any such research design are also relevant to case study research. These tests are construct validity, internal validity, external validity, and reliability:

Construct validity is about establishing correct operational measures for the concepts being studied. It can be dealt with, for instance, by using multiple sources of evidence and having key informants review the case reports. In this study, the former is addressed by the several data sources and modes of inquiry used to explore the subject, and the latter by retrospective interviews that are conducted partly to check the preliminary concepts.[5]

Internal validity is "inapplicable to descriptive or exploratory studies, which are not concerned with making causal statements" (Yin, 1994: 35), and thus would also be inapplicable to most of this research being exploratory by nature. However, it becomes an issue later on when the study moves away from exploration, specifically during the longitudinal multiple-case study. In this study, any threat to internal validity is dealt with by identifying consistent patterns within and across the replicated cases.

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[3] In Research Paper 2, the applied method is called "case studies and experiments", meaning that, while the actual collaboration projects were experimental or pioneering in their nature, the case study method was used to study these experiments. Naturally, it does not mean the use of the experimental research design (Campbell and Stanley, 1963).

[4] Interestingly, recent epistomological discussion on management science (see e.g. Ghoshal, 2005) has come to a conclusion that "a fresh start", i.e. conducting the research without building it on extant theories, could be a solution for the problems especially management research is now facing (see Section 4.4). In this sense, recent literature proposing "a fresh start" come back to the original grounded approach introduced by Glaser and Strauss (1967).

[5] In addition, preliminary findings were informally, yet regularly, discussed with other researchers in this field, as well as with three policy-makers of the national innovation system and the CERN director for technology transfer, who were not directly involved in the study and the cases, but provided their time and insight.

External validity is the ability to generalize to theory. In case studies, a tactic to increase external validity is to conduct multiple-case studies so that the findings are tested through replications. For this reason, this study also uses the replication logic in its multiple-case study. The cases represent several different types of companies from university start-ups to SMES to large corporations. They also include both successes and failures. A way to further increase the external validity is to have contrast across cases, that is, comparing successful from unsuccessful cases within the selection. In addition, while all of the cases are with CERN, several big-science studies (Autio et al., 1996; Hameri and Nordberg, 1999; Nordberg, 1994; Schmied, 1982, 1987; Vuola and Hameri, 2006) indicate that other major big-science labs at least in Europe operate in principle the same way. Furthermore, the literature review (see Section 3.6 and Table 1) indicates that while CERN has its unique characteristics, they are not significant from the perspective of lab-industry collaboration. In the light of extant lab-industry literature, there are no significant differences in how firms successfully collaborate with labs, whether CERN or other. Finally, procurement procedures in public organizations in general, whether big science or not, are similar (Dalpé et al., 1992; EC, 2005; Edquist et al., 2000; Geroski, 1990; Nordberg, 1994).

Reliability, according to Yin (1994), is tested by "demonstrating that the operations of the study – such as the data collection procedures can be repeated, with the same results" (p. 33). However, several other scholars (see e.g. Jorgensen, 1989; Stewart, 1998; Strauss and Corbin, 1998; Toulmin and Gustavsen, 1996) argue that this conception of reliability as repeatability is not applicable to social sciences. Strauss and Corbin (1998) argue that "reproducing social phenomena can be difficult because it is nearly impossible to replicate the original conditions under which data were collected" (p. 266). According to Toulmin and Gustavsen (1996),"it is far rarer for human situations than for physical phenomena to be exactly repeatable" (p. 217). This is especially relevant to innovations and change management situations, as they are practically irreversible and impossible to repeat (Ottoson, 2003). This is also true for this research. It is evident that the data *collection* procedures of this study would be impossible to repeat, at least for these same cases, or any cases within the one-off LHC project.

Strauss and Corbin (1998) propose to rethink reproducibility: "Given the same theoretical perspective of the original researcher, following the same general rules for data gathering and analysis, and assuming a similar set of conditions, other researchers should be able to come up with either the same or a very similar theoretical explanation" (pp. 266-267). In this study, while the data gathering might be impossible to repeat, other researchers in principle would be able to draw the same conclusions from the classified field notebooks, case write-ups, interview notes, and the case-specific folders with material from multiple sources of evidence collected during this research (see Section 4.3).

4.2 Case selection

The focus and scope together with the research questions of this dissertation call for the collection of empirical data on "new technology companies and ventures" that are "new supplier candidates" for the lab (see the Introduction). In other words, a selected case company must represent technology that is new to the lab. Furthermore, if possible, the selected company should not have prior experience with the lab, nor had considered the lab as its potential partner or customer prior to this research, which is important in order to be able to study the interaction from the very beginning of the relationship. This study focuses on the Finnish industry. A member since 1991, Finland is one of the most recent member states of CERN. When it joined CERN, Finland had no

established business relationship with CERN, nor was the Finnish industry generally known at the lab (except for one firm, see Case 2).

Between 1991 and the beginning of this study in 1996, there had been a number of significant efforts to promote Finnish industry at CERN. As a result, Finland quickly became a "well-balanced member state", which means that the industrial return to the member state balances with the member state's contribution to the lab. The well-balanced status, in principle, makes it more difficult for the member state to get its companies accepted as candidates for calls for tenders. This was also the case for Finland during the study. In addition, Finland, in general contributes only 1.1% to 1.3% of the annual CERN budget, which, in general, makes it relatively difficult for Finnish industry to get involved in the CERN purchases. It is clear that if, for instance, five firms are selected as final candidates for a specific tendering, a firm originating from a country that contributes only about 1/80 of the budget and is well-balanced has, in general, little chance to be granted the mere possibility *to submit* a tender, even less to win a contract.

In addition to being young, relatively small, well-balanced, and rather unknown (at least during the early years of this study), Finland is also one of the most remote member states of CERN. Hence, there is clearly no advantage of proximity. It can be concluded that, being Finnish, the case firms should normally have no advantage over other companies when attempting to partner with CERN and be accepted as supplier candidates. Second, being Finnish, the case firms have no advantage over other companies that would make them succeed in any possible collaboration and tendering that may arise with CERN. Quite the contrary, Finland gained the disadvantageous balanced status and was a relatively small member state. The third consequence, yet positive for this research, is that, Finland being a young and remote member state, there were potentially several companies and new technologies that were not yet known to the lab, and, hence, which could be identified and selected as case candidates for this study.

The first two single-case studies differ from the remaining seven cases, as they were the ones used for the framework model development, while the other seven then resulted from action-based research within the developed framework model. The first case was chosen because of its radical nature, and also because the new high-speed electrical machine technology would normally have nothing to do with CERN, being completely new to the lab. This new technology was radical in several dimensions, requiring the development of completely new approaches in several technological domains such as the rotor design, magnetic bearings, flow dynamics, and electric drives. In principle, such machine would normally have little use at CERN, as it is an electromagnetic rotary one, while electromagnetic machines in particle physics experiments and accelerators (such as superconducting magnets) are not rotary (such as electric motors). I found this new technology through experts at Helsinki University of Technology.

The second case is about a company that was the best known – and probably the only generally known – Finnish company at CERN at the time the study started in 1996. The company had technical cooperation with the lab since 1990, i.e. already prior to the Finnish membership in CERN. This company was also considered as the one to become the main Finnish CERN supplier. Hence, it was a natural choice for a single-case study on pre-tender basic research lab-industry collaboration. In particular, because, later in 1997, it failed in a major tendering competition, which tremendously helped understand the boundary conditions and success and failure factors of such collaboration. Table 2 summarizes these two cases used for revelatory single-case studies.

	Type of firm	Size of firm	Age of firm	Lab interaction
Case 1	University spin-off	Less than 10 employees	Less than 5 years	1995-1996
Case 2	Venture initiative of an established corporation in mature business, later a product line, a strategic business line, and a daughter company	15 employees with the venture, around 20000 at the corporation	Over 50 years for the corporation, 15 years for the venture	Since 1990

Table 2. The selection of cases for the two single cases.

On top of these two single-case studies, a multiple-case study with seven cases was employed. These seven cases were then examined real-time over several years.[6] Table 3 summarizes this selection.

	Type of firm	Size of firm	Age of firm	Lab interaction
Case 3	University spin-off	Two employees	Less than 10 years	1996-2001
Case 4	New business area within an SME, later a separate daughter company	40 employees in the new business area, 250 in total	Over 50 years for the company	Since 1997
Case 5	Corporate initiative, later a small R&D team of a business unit	Two in the team, more than 10000 at the corporation	Over 50 years for the corporation, 10 for the venture	1997-2000
Case 6	Corporate venture of an established engineering corporation	Ten with the venture (production outsourced), more than 20000 at the corporation	Over 50 year for the corporation, 10 for the venture	Since 1998
Case 7	Spin-off venture of an established SME in mature business	Six employees with the venture (production outsourced), less than 500 in total	Less than 5 years	Since 1999

[6] In addition, as said, one of these cases (Case 6) was used for an in-depth single-case study in Research Paper 3.

Case 8	SME, later acquired by a large foreign corporation	100 employees	10 years	Since 2000
Case 9	Corporate venture of an established corporation, later a corporate initiative, then a small R&D project, and then finally spun out	Ten with the venture (production outsourced), more than 20000 at the corporation	Over 50 years for the corporation, less than 5 for the venture	2001-2003

Table 3. The selection of cases for the longitudinal real-time study (Cases 3 to 9).

Case candidates were found by using three sources: by examining national technology reviews; by contacting technology experts at technical universities and a regional incubator; and by interviewing managers and executives at large corporations. The main criterion for the case selection was that the company or venture had to have new technology and business initiatives that were new to CERN. Naturally, the company or its venture team had to accept the very idea of having collaboration with the lab, and also take a firm decision to go for it. In addition, a theoretical sampling strategy was employed, i.e. cases were chosen so as to ensure sufficient variance along theoretically important dimensions within the research problem (Eisenhardt, 1989). The main dimensions were considered to be the type and size of the company (the literature review indicate that large corporations succeed better than SMEs, yet this study focuses on radical projects new business initiatives in all kinds of companies), and the technological field and the industry sector (the literature review indicated that lab-specific partners are most successful, yet this study focuses on technologies not known to the lab).

While all of them were not equally successful with their innovations and business initiatives, fortunately none of the case companies was lost for the research purposes. For the sake of confidentiality, company names are not documented here. For the same reason, the Research Papers do not explicitly mention the country of origin of the case companies either.

4.3 Data collection and analysis

Being an exploratory study, the general strategy for analyzing the data was to develop case descriptions (Yin, 1994). The data for the first single-case study were collected through an extensive literature study and multiple interviews of CERN engineers and managers in 1995. This market survey-type case data were analyzed for the purposes of this study in 1996. The second single-case study was conducted in 1996-1997, yet was further analyzed in 2004-2005 after two retrospective face-to-face interviews with two key business managers of the case company. Using explanation-building strategy (Yin, 1994) for the analysis, the case description analyzes the venture development in chronological order since the 1980s and the reasons for its failure with CERN. The final single-case study was conducted and analyzed both real-time (since the initiation of its CERN collaboration in 1998) and retrospectively (in 2005-2006), including three face-to-face interviews of three key managers of the venture in 2004. Again, chronological description of the technology and venture development was used for the analysis.

The multiple-case study was naturally the most time-consuming part of this research. It was conducted in real-time since 1996 using multiple sources for the data collection together with an

action-based approach. The rest of the section below summarizes the data collection procedures. The analysis used pattern-matching within each case and replication logic across the cases. Case descriptions were prepared for each case following the same chronological structure: the case firm and its new business initiative, including the type, origin, and form of the new business initiative, as well as relevant information on its status at the moment it is introduced to CERN; the new technology in question and its key functional characteristics; the main events as well as outcomes of the CERN-company collaboration in a chronological order; and finally, the current status of the case company.

The field study lasted for nine years in total, with the most intense data collection occurring during 1996 to 2002, when staying at CERN on an almost regular basis. In the case companies, the persons involved in the study represented several organizational levels from top management to project managers at corporate level, as well as managing directors, project managers, and marketing, sales and technical personnel of the ventures. On the CERN side, they included all organizational levels from members of the directorate to project managers, purchasing officers, technical experts and laboratory personnel.

During a period of almost five years from 1997 to 2001, I attended the project meetings that took place between the lab and the case companies at both CERN and company premises, internal meetings at the case companies, and also the CERN Finance Committee meetings, which are inter alia the decision-making body for all major purchases and technology transfer issues. The internal meetings at the case companies concerned project planning, strategic planning, and funding application and tendering preparations. I also discussed strategic and project issues with the company participants both before and after each CERN-company meeting.

The findings reflect the observation of and participation in these meetings, the actions taken by each party, and data from numerous emails, phone calls and faxes with and between those involved, as well as the resulting notes, remarks and assumptions for initial insights and their analysis that followed the data gathering. Each observed interaction was noted in a chronological order in a field notebook, and original copies of full notes, write-ups, and documents were saved in case-specific folders. While emails were saved in the email server, some of them regarded as the key ones were printed out to be stocked in the case folders concerned. Additional archival sources of data included official minutes of meetings, CERN documents (both public and internal), CERN administrative procedures, technical reports and specifications, contract and purchasing data, as well as companies' funding application forms and original tenders, and company brochures, data sheets, academic publications, and other information on the technologies and businesses concerned. Furthermore, retrospective face-to-face interviews of key managers in case companies (cases 2, 5-8) were conducted during 2004 to 2005. The interviews were semi-structured and aimed at checking key facts and at testing preliminary findings.

Of all the sources of evidence, personal involvement in the cases real-time was definitely most useful and informative. It is difficult to imagine any better way to get into details of the cases, case companies, the lab, and their interactions, including unspoken information and small important steps. In addition, systematic data collection during the real-time involvement produced data automatically in chronological order, which facilitated later analyses.

4.4 Post-study remarks

Management research and education have recently become subject to increasingly severe criticism. Scholars argue that research results and theories have had little practical impact (Pfeffer and Fong, 2002), are "unimplementable" (Beer, 2001), or even harmful for practice (Ghoshal, 2005). Managerial implications, when based on research using data on past innovation cases, may quickly lose their validity and relevance in today's rapidly changing business environment (see examples e.g. in Kim and Mauborgne, 2005: 9-10). Managers themselves are well aware of the problem. John S. Reed, the former CEO and chairman of Citigroup and the New York Stock Exchange, and member of the board of MIT, recently stated that, in management education and research, "with the exception of the areas of mathematics or finance there really have been no changes or advances since the sixties" (in Augier, 2006: 89). He argues that "the trouble with most of the research in business schools now is that it is all professional within silos and it is designed for individual academics to further their careers. It doesn't really attack the problems of business" (Augier, 2006: 89).

While the impact of research to practice may be poor due to separation of research from practice, the other side of the coin is that practice has also had poor impact on research. John Reed continues: "the intellectual disciplines there in the business school don't really keep track of the advances in practice; they keep track of what's going on in the narrow disciplines and what is being published in various journals" (in Augier, 2006: 90). Also scholars themselves argue that learning from experience and engaging uncertainty have become "hard to those of us who have been trained to believe that we are smarter than everyone else" (Brydon-Miller et al. 2003: 21).

A recent study by Allen and Sosa (2004) also observes that, in the past, most of the contributors to the *IEEE Transactions on Engineering Management*, a major technology management journal, were "experienced managers providing their thoughts on how to best manage engineering matters. Gradually, however, and due to the influence of a handful of influential actors in universities, the nature of the response and the nature of the Transactions changed" (Allen and Sosa, 2004: 391). During 1954 to 1963, some 60% of authors were from industry, with an additional 10% or so being government employees. Most of the papers on management issues were based on professional managers' own experience and wisdom they had accrued. That has dramatically changed. Today, the share of authors from both industry and governments totals less than 10% of all authors. Allen and Sosa (2004) consider that management journals have begun to view management at an increasingly abstract level, and propose a shift to lower levels of analysis to achieve increasing detail.

For several years now, scholars call for a necessary paradigmatic change in social sciences (see e.g. Brydon-Miller et al. 2003; Flyvbjerg, 2001; Greenwood and Levin, 1998; Reason and Bradbury, 2001; Whyte, 1991), and in management science in particular (Beer, 2001; Clegg and Ross-Smith, 2003; Friga et al., 2003; Ghoshal, 2005; Harmon, 2006; Ottoson, 2003; Pfeffer and Fong, 2002; Toulmin and Gustavsen, 1996). It is claimed that this current state of research is due to the past half-century-long attempts to make business studies, as well as social science in general, accepted as a branch of science (Friga et al., 2003; Ghoshal, 2005; Schlossman et al., 1998; Toulmin and Gustavsen, 1996). Although very different from natural science, social science, established not earlier than in the 20th century, adopted positivistic paradigm from the established science (Ghoshal, 2005; Toulmin and Gustavsen, 1996).

Ghoshal (2005) argues that this has been an error: "Unfortunately, as philosophy of science makes clear, it is an error to pretend that the methods of the physical sciences can be indiscriminately

applied to business studies because such a pretension ignores some fundamental differences that exist between the different academic disciplines" (Ghoshal, 2005: 77). Within social sciences, this "hubris of physics envy" (Clegg and Ross-Smith, 2003) has led especially management research to "increasingly adopt a narrow version of positivism together with relatively unsophisticated scientific methods to develop causal and testable theories" (Ghoshal, 2005: 86) and has also led it "increasingly in the direction of making excessive truth-claims based on partial analysis and both unrealistic and biased assumptions" (p. 77). In order to "reverse the trend" Ghoshal (2005) proposes 'a fresh start', that is, starting on a fresh ground instead of on dominant ("bad") theories, which in some sense is similar to the grounded approach of Glaser and Strauss (1967).

Reason and Bradbury (2001) argue that "a participatory worldview...is emerging at this historical moment" (p. 1). This worldview is "a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes" and "seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people" (Reason and Bradbury, 2001: 1). Other colleagues (e.g. Brydon-Miller et al. 2003; Greenwood and Levin, 1998; Toulmin and Gustavsen, 1996; Whyte, 1991) have come to similar conclusions, proposing direct involvement, participation and action as a solution, and also as a necessity, when aiming at conducting social science that has true practical relevance. According to Brydon-Miller and colleagues (2003) and Reason and Bradbury (2001), participation and action are now increasingly applied to research practice in diverse fields, for example, community development, organization and business, management, economics, education, anthropology, healthcare and medicine, social work, and the human social, psychological and transpersonal sciences.

This 'new worldview', however, is not so new and radical as one may think.

Kurt Lewin (1946), with his revolutionary social experiments, attempted to generate knowledge of a system, while, at the same time, trying to change and develop it. John Dewey (1933) conducted field experiments in education and argued that research has to be demonstrated to produce desired outcomes in practice. Chein and colleagues (1948) argued that the scientist's job would be too simple and easy without any responsibility for the proper application of his/her discovery. They illustrate this argument with the case of the physical sciences: "Ordinarily the scientist's job comes to an end, as far as society is concerned, when he has made some technological advance or some socially applicable scientific discovery. It is up to society to make use of this development" (p. 44). They take the "atomic scientist" as an example, and propose that scientists redefine their job to include "not merely teasing out the secrets of nature but also directing the application of his discoveries" (p. 44). Scientists need to be responsible for the proper application of their discoveries. The other side of the coin is that, research problems "must grow out of the community life" (p. 44).

However, the origins of this "new worldview" go actually much further back in the history of science. Francis Bacon, one of the founding fathers of modern science (or "new philosophy"), and main actors of the scientific revolution (Lindberg, 1990), wrote in his 1607 booklet "Thoughts and Conclusions" that "the divorce between the two activities, speculation and experiment, has always obtained. But if the two could be joined in a closer and holier union the prospects of a numerous and happy issue are bright indeed" (Bacon, 1607: 98). If this separation was not new in Bacon's epoque, neither it is new today.

Bacon held that science must be recognized by its works and that truth is revealed and established through the testimony of actions: "practical results are not only the means to improve well-being but the guarantee of truth. The rule of religion, that a man should show his faith by his works, holds good in natural philosophy too. Science also must be known by works. It is by the witness of works, rather than by logic or even observation, that truth is revealed and established" (Bacon, 1607: 93). Similarly, modern scientists propose participation and action and argue that research results have to be tested in action. Jorgensen (1989) states: "It is difficult to imagine a more severe test of the accuracy or dependability of an idea than that it pass the test of use in everyday life" (p. 38). Brydon-Miller and colleagues (2003) emphasize that important in social science is "relevance, social change, and validity tested in action" (p. 25)

Hence, today's dominant conception of social science is actually rather new in the history of science, only 50 years or so. Originally, the modern science was seemingly participative and action-oriented, thus providing a natural link between research and practice. Management research, in particular, while considered as one of the "practice-oriented fields" of social science research (Yin, 1994: xiii), has become increasingly abstract, and also decreasingly contributed to by managers themselves. And yet, both prominent scholars and leading business managers claim it has had poor practical effect during this very same period. Today, scholars propose that social science should return to epistemologies of practice and validation through action.

While the recent vivid discussion calls for humbleness and reflection among all of us who do research, at the same time, it partly provides support to the research strategy chosen for this dissertation. Being based on practical contemporary problems, using participation and involvement among other ways to gain a detailed insight into the research problem, and aiming at changing practice through the implementation of its models and theories, I believe that this study meets, and partly also reconciles, the requirements of both the "conventional" social science and the "new emerging worldview". Indeed, while the commonly agreed criteria for validation and reliability discussed in Section 4.1 were met within this study, the developed collaboration model was also applied and tested in the "use of everyday life" during the longitudinal action-based phase of the study.

5 CASES

This Chapter provides brief summaries of the nine lab-industry collaboration cases studied for this dissertation. The first two cases were used for two individual single-case studies and thus differ from the remaining seven cases, each of which a brief single-case report is presented here despite the fact that they were subject to a longitudinal multiple-case study (Yin, 1994).

The first case represents a case of a radically new technology that is new also to CERN. The brief description below (Case 1) focuses on describing this technology in question. The detailed case study is presented in Research Paper 1 and is not repeated here. The second case is a retrospective single-case study of a long-term partnership between CERN and its preferred supplier candidate, a venture company that is successful during their multiannual pre-tender R&D cooperation but then fails in commercial terms when CERN's official tendering procedure takes place. The description below (Case 2) summarizes this case in a chronological order, and provides also background information on this supplier candidate and its new business initiative.

The remaining seven cases form a multiple-case study. Each of these seven case histories below (Cases 3 to 9) follow the same chronological structure: First, it begins with a brief description of the case firm and its new business initiative, including the type, origin, and form of the new business initiative (project, start-up, corporate venture, daughter company), and background information on its status at the moment it is introduced to CERN. Second, the case history continues with a brief description of the new technology and its key functional characteristics, without going into unnecessary technical details and revealing any confidential information. Third, the description summarizes the main events as well as outcomes of the CERN-company collaboration in a chronological order. Finally, the current status of the case company is briefly described.

Case 1

High-speed electrical machine technology was developed as a result of research cooperation between two technical universities. A start-up company was founded in 1988 to develop and commercialize this radical new technology. The technology was radical in several dimensions, requiring the development of completely new approaches in technological domains such as mechanical rotor design, magnetic bearings, flow dynamics, and power electronics-based electric drives. The basic idea was to rotate the electrical machine directly at the speed the application requires and avoid the use of gearboxes, shaft couplings, and their lubrication and cooling/heating systems. In addition, size and weight of the entire drive system could be reduced by up to 95 % by increasing the rotational speed. In 1995, the venture company started to market their technology to various turbocompressor applications, yet was open to all new potential applications. This is when a market research was conducted at CERN to study options for new alternative application areas.

Case 2

A large state-owned corporation in the metal industry started to develop superconductors in the 1980s because of a specific customer need that radically departed from their normal basic metals

business. A venture company was established within one of the business divisions. One single supply contract provided the venture with the income and funding, as well as internal support, needed for normal operation and development throughout the 1980s. In the end of the 1980s, the company needed new customers and application areas. It initiated cooperation with CERN in 1990, several years before the LHC was even approved, ultimately hoping to supply its technology to the LHC.

CERN quickly became one of the main raisons d'être for the company. CERN considered it as one of the most potential suppliers, as it was the best performer in many technical tests that CERN conducted on samples and prototypes. Several years later, however, after more than five years of joint R&D, testing and piloting, an international tendering competition was organized and, as a result of a tough price competition, the company was left without a supply contract, and CERN left without products of the highest quality.

Case 3

A small university spin-off was established to commercialize a unique way of measuring temperature within extreme thermal ranges. Based on electronic transport in nanostructures, a technology concept for a calibration-free nanothermometer had been developed at a university laboratory. This meant that the underlying scientific principle was known at the time of the project, but the product itself was yet to be developed. The plans for future business were optimistic and one of the scientists was engaged to run the company and to continue R&D, still mainly at university premises. In 1996, the venture was looking for potential customers, although the technology was still at a laboratory mock-up stage.

After the introduction of this technology to the CERN cryogenic laboratory, it immediately placed an order for a few thermometers for its R&D, testing and piloting purposes. CERN's ultimate need was several thousands of measurement points along the 27-km-long cryogenic LHC accelerator machine, which was seen by the start-up and its investors as a great business opportunity. However, the original delivery schedule for the products was far too optimistic. During the following two years, while the start-up continued R&D, engineers at CERN and within its university and laboratory partner network tested some early prototypes in typical application environments as well as in harsh conditions under heavy radiation and magnetic field. After another two years of product development by the venture, the first actual thermometers were delivered to CERN. In addition, due to extra funding from a national physics institute, a researcher from the partner university was transferred to CERN to help with the testing and piloting at the CERN premises. The testing eventually provided the spin-off company with valuable information and, furthermore, promising evidence of the possibilities to apply the technology to a much wider temperature ranges than originally foreseen.

However, lack of resources prevented the company from fully exploiting the full potential of the collaboration, e.g. the use of the lab facilities, scanning new applications and users, etc. As doubts about the venture's industrial production capabilities increased, CERN decided to purchase a conventional thermometer system from an established lab supplier. This decision was eased by the fact that one of the CERN member states proposed to provide the needed calibration service as its national contribution to the LHC project, thus making the calibration-free feature lose its competitive advantage at CERN. Nevertheless, while there was no large contract with CERN in the end, the collaboration provided the company with some test results and user feedback, and

also helped it get contacts with and inquiries from other research laboratories. By 2005, however, the venture had not grown any bigger.

Case 4

A medium-size warehouse truck manufacturer began to develop fully automated electric trucks, so-called automatic guided vehicles. Representing a completely new business model for the company, it separated this new emerging business from their conventional mainstream business area. Instead of selling standard products, such as forklifts, the new business required customized turnkey solutions, including the design, installation, programming, and running of customer-specific complete systems to handle material flow at the customers' premises. Fully automated systems naturally required also extensive use of information technology, which also was a new technological domain for the company. In 1997, after more than 10 years of existence, the new business initiative had remained relatively small, with an annual turnover of only a few million euros, which was marginal compared to the mainstream business.

At that time, a group of CERN engineers worked on the future challenges on the transportation, installation and positioning of the largest and heaviest of the LHC machine components at the CERN premises. The company, together with two small and medium size companies (SME), which specialized in overhead crane engineering, brainstormed a solution to CERN's need that radically departed from CERN's own ideas. CERN's preliminary specifications were based on its past experience on its own in-house-designed vehicles. Several discussions between engineers of both parties resulted in a new functional specification, which was open also to new technology variants. Intense interaction between engineers at CERN and in the company and its partners continued along with the official purchasing procedure, and the company was finally qualified for the official tendering. Finally in 1999, the company won the tendering competition for which CERN had contacted more than 80 companies and short-listed 14. However, it took almost a year before the contract was signed, as CERN retrospectively made several modifications to the specifications, and the company did not agree on them without price increases.

Later, however, when deliveries finally began, this specialized transportation and installation vehicle became a kind of a model and an icon of CERN's intense and innovative interaction with industry during the LHC project. A good example of this is the pictures of the vehicle that were permanently put on the CERN web pages. By 2002, the turnover of this new business area, which by then had become a separate daughter company, had tripled from the 1996 level and the number of employees grown to over 100. The profitability of the business area, however, remained modest or even negative. The CERN contract was not very profitable either, and while it clearly produced significant reference value for the entire company, a major problem with it was that no clear market and need for such equipment had been identified outside CERN. Since the development of the technology was based solely on the CERN need, there were no new customers and applications for the new technology in order for the company to cash in from its R&D investment.

Case 5

A large state-owned energy company known for its generous investments in research and development acquired a scientist specialized in an optical fibre-based measurement technology. This technology made it possible to measure e.g. temperature and vibration in hundreds of points

along one single optical fibre. Several years of R&D followed. The technology was piloted in many real-life settings with potential customers, yet the breakthrough did not take off. The corporation went through major changes and began to focus on its core businesses, was re-organized and prepared to merge with another major energy company. The R&D resources were heavily cut and managers started to put pressure on R&D teams to generate income, although most of them lacked sales, marketing and business experience. In 1997, while still at a prototype stage, the now two-person team was willing to start selling the technology as such.

Several potential applications from high-voltage to firefighting were found at CERN. Talks with CERN engineers started, and, while interest genuinely rose, reactions from the venture team members were slow. In one case they even recommended a competitor's product, considering it better suited for the application. At the same time, the corporation experienced a major merger, and the future of the venture project became uncertain. In 1999, the venture was allocated no more additional resources, and the team continued R&D with very limited resources, mainly from public sources. Another application at CERN was found at the end of 1999 and, as the technology was completely new and there were no ready products, CERN requested for a prototype demonstration. The venture, however, questioned the necessity of the demo and wanted to make directly a sales deal. They felt pressure to generate sales in order to have funds to cover both past and future R&D. The price quoted, however, was so high that the CERN engineers lost interest and the project never took off. In addition, the engineers felt business communication difficult due to the strong research-orientation of the venture team members.

Yet another two applications were tried during 2000. This time the venture managed to get internal corporate funding for a demo at CERN. The technology was installed into the LHC prototype accelerator to measure temperature in the extremely demanding environment of a world-record vacuum and temperatures close to 0 Kelvin. The results proved the technology too good: while it did enable temperature measurement inside the LHC machine in locations that had not been possible before, and several potential CERN users visited the measurement site to see the results, the results also revealed problems indicating that the LHC machine did not perform as designed. No official test report was published although it was agreed in the beginning, which was unfortunate for the venture. Nor did collaboration continue, as it was found out that there was no budget for the purchase.

However, the other cooperation project, which concerned the radiation hardness of some of the measurement system components, proved useful for the venture. The following year, new corporate management decided to discontinue corporate R&D. Most of the R&D staff were fired or outsourced, and the rest distributed to business units. Several IPR and new business initiatives were spun out. All development efforts concerning the case technology were stopped, however, the technology and the venture team were the rare ones to remain in-house. Today the technology is part of a special in-house measurement toolkit used in service business cases.

Case 6

A large engineering corporation became familiar with a new metallurgical production technology that was originally developed for military purposes several decades earlier. It started R&D and business development on it in the end of the 1980s. A corporate venture company was established in 1992 to continue the development. By 1998 the company had received a number of small orders, yet had no finished products. The corporation experienced a number of changes and a

major merger. As the market for the venture was not the same as that of the corporation, pressures increased for the unit to focus exclusively on specific intra-corporate needs and thus to act as an internal technology supplier instead of developing its own business on the global market place, in spite of the fact that the latter was clearly the venture's own objective.

In 1998, the company heard about the LHC project and CERN's needs for complex thin-wall items. Project engineers at CERN were invited to evaluate the new technology as an alternative technology to conventional ones such as casting, welding, and forging, for the production of a series of thousands pieces of this demanding component. Sample parts were produced and submitted to the CERN engineers for rigorous metallurgical testing that was managed by them yet carried out in research laboratories, institutes and companies within their partner networks. These tests produced significant new information for the company on the quality and properties of the new production method. Some of the tests were so specialized that they would not be commercially available within the company's own R&D partner network. CERN took care of all the testing procedures, yet the company supplied the sample material, and also produced a thorough test report. The company considered the report valuable not only for furthering R&D but also for marketing purposes.

Because the results were promising, a small series of prototypes was ordered to be installed and piloted in a 'real-life' setting. Although the direct value of the order was moderate, it helped the company to gain credibility within the corporation and among its business partners. In addition, collaboration with CERN helped the company get additional public R&D funding for their overall development efforts. All this was important, as, at the same time, the corporation was going through a major merger, and thus external references and support were needed to simply avoid being killed off by the corporate management. The superior quality of the technology convinced CERN engineers, and, in 2000, the company was invited to a tough tendering competition for the supply of the whole quantity. Purchasing officers of the lab contacted several tens of potential suppliers worldwide for the purchase of this item. In the end, the venture company was the lowest bidder, and could beat conventional techniques not only technologically but also in price.

As the total number of parts needed was large, this deal helped the firm develop its serial production capacity, and thus represented a critical step toward serious business and profitability. The production started in 2001 and continued for almost five years. This was indeed the serial product the venture company needed, being the largest single delivery of this technology in its more than 50-year-long development history. Years later the venture was awarded with a prestigious supplier award for "having not only met CERN's stringent requirements" but exceeding them "in terms of technical performance and cost efficiency". The corporate CEO also estimated that this deal had improved the entire corporation's image "to a larger extent than previous full-page advertisement campaigns in the Financial Times". The venture company with its advanced networked business model was a forerunner in the corporation that itself was now trying to move toward service-oriented knowledge business. After several years of having been considered too radical, the venture company's networked production, performance-based pricing, and service products were now seen as a model for the entire corporation.

Case 7

An SME in welding machinery had decided to apply its technical expertise in power electronics to the industrial power converter market that was completely new to it and naturally outside its core

business. A venture, in the form of a tiny daughter company, was established in 1998, with its own 6-person R&D and sales but access to the parent company's advanced new production technology enabling highly flexible and cost-efficient manufacture of both small and large production series. The newly founded venture was very much technology-driven, e.g. with no actual market research done, yet enjoyed great enthusiasm. It received a few orders for one-off customization projects, and was sponsored by the owner who had priorities other than quick return on investment. However, the venture had challenging technological and business objectives: to transform its system component-based power electronics expertise into independent industrial power converter products meeting highest industrial standards and requirements.

At CERN, on the other hand, long-term R&D for power converters had been ongoing with several partner companies, most of which were well known to the research community. CERN engineers were happy with their partners and not extremely keen to consider companies or technology choices other than those chosen or developed by them, yet the venture was introduced to them, up to three years later than the others, having no previous contacts with the lab. However, the venture found the lab requirements for the converters to be very much in line with what they expected the general market to require within the next five years. In spite of the lab engineers' initial resistance, an informal low-profile collaboration was started and the venture developed the first prototype based on the lab's functional specification. The lab conducted multiple tests on the prototype on its premises and at its own cost. Lab engineers rejected the design, on the grounds that their requirements were too demanding for the small venture coming from a strange industry sector. However, the venture continued the development with the second and also third generation prototypes, the latter being partly financed by the lab as a result of an official tendering competition for prototypes that the venture won. The venture soon applied some of the developed techniques to other customer projects and product offerings.

During the informal collaboration, each participant covered its own costs. Collaboration with the lab, however, helped the venture to attract public R&D funding for product development purposes. Two years later the official tendering procedure revealed the venture to be three times less expensive than the established partner initially preferred by the lab engineers. The venture was awarded contracts by the lab to produce several hundreds of units, which has provided the venture with a possibility to start serial production of its own products. The venture also felt that the contract allowed them to "take a breather" and do necessary strategic planning and marketing to ensure future business growth. The reference value has proved helpful for the marketing efforts of the venture as well as for the entire parent company. In addition, the lab later selected the venture for its prestigious Golden Hadron Award.

Case 8

A small company specialized in dosimeters was a result of a management buyout (MBO) from a large control instruments company in the early 1990s. It soon brainstormed a radical new product based on the use of a microchip as a radiation detector. They started to develop it, the management team being encouraged by very optimistic plans for a quick success. However, the projected sales and progress were still not realized after five years of intense R&D that had taken a major part of the company's R&D resources. Major changes in the management and in project resources followed, yet the project was not killed off. There was a clear need for concrete business results and getting the product finished when contacts with CERN were established in 2000.

At the same time, CERN was seeking to change its dosimetry service provider. The new technology the venture represented would automate service processes and thus make the conventional dosimetry service obsolete, an option not foreseen in CERN's specifications. As a result, the company was not complying with the specifications and was not invited to tender. An alternative way was needed to start collaboration with CERN in order to get it familiar with the new technology. The answer was to focus on neutron dosimetry; a kind of marginal niche market that did not interest the mainstream service providers and that was not covered by the tendering either. The company agreed to provide CERN with prototype dosimeters and related reader equipment and software. CERN then tested them, at its own cost, in its unique laboratory facilities and with different doses and types of radiation. The results were documented and reported to the company, and provided significant new information for further development. More importantly, the test procedure, and the short pilot use that followed, made CERN experts and managers in the dosimetry service well acquainted with the new disruptive technology. This collaboration also attracted additional public funding for the development work at the company.

Some 18 months passed without any contacts between the parties. The company continued its R&D efforts, yet the prototypes remained at CERN. In 2003, the company received CERN specifications for a new tendering. Some months later the company was awarded a contract for a complete renewal of the CERN dosimetry system. This was the first major contract for the new technology and the venture. The latter considered the deal as the breakthrough of this new business model that replaced the conventional service procedures with a fully automated system. The reference was valued highly on the general marketplace that began to grow rapidly due to the US homeland security issues. Visibility in the media gained respect both externally and internally. The venture was bought by its competitor in 2002, and two years later by a large American corporation.

Case 9

A venture was founded within a large telecom corporation in order to commercialize new generation web-based management information systems. Soon after the Internet bubble burst in 2001, most of the corporate venture projects were either killed off or sold, as the corporation aimed to refocus on its core business. The venture was transformed into a minor business development project within one of the company sales and marketing departments. It survived mainly because of its close contacts with several major customers and its understanding of their business processes. However, venture's new service model required significant changes to business models and key business processes of the corporation, which made it difficult to test and pilot the new technology and the business model with existing customers. Key account managers also refused to take the risk of radical changes in existing processes, customer interfaces and the business culture.

The venture started cooperation with CERN that was regarded as a neutral customer in no-man's-land. Main partners were CERN's management information system group and a particle physics experiment sub-community with some 40 research institutes. The institutes, including for instance MIT in the USA, Saclay in France, INFN in Italy, Weizmann Institute in Israel, KEK in Japan, Dubna in Russia and Nanjing University in China, worked together to construct a major LHC experiment while being thousands of miles apart and spread over the world in 10 countries. This was seen as a fascinating environment for the venture to pilot its prototype technology and service processes. This network of experts provided the company with valuable user feedback and also

both technical and process-specific experience. Several technical problems were also solved and, from the technical point of view, the service product was seen ready for commercial launch. Based on the results collected from the collaboration, wider implementation at CERN and in its network was planned later the same year, and the pilot use had raised interest also in some of the member universities and institutes.

However, because of the lack of resources and required business process changes, the venture could not start the actual ramp-up phase of the implementation. At the same time, the venture had to invest much of its resources to defend its existence, as the corporate went through a major merger. Soon after, the project was terminated and the technology shelved. The venture team continued for some months as a part of a small business development unit, which was soon terminated as well. CERN later developed a similar management system on its own. Less than a year later, the venture team left the company and the core members founded a start-up company, yet the technology remained shelved in the company.

The next Chapter summarizes and discusses the four Research Papers and their analyses of the above cases.

6 SUMMARIES OF THE RESEARCH PAPERS

The four Research Papers selected for this dissertation are the following:

1. "Using basic research as a catalyst to exploit new technology based innovations -a case study" (published in *Technovation*);
2. "Mutually benefiting joint innovation process between industry and big-science" (published in *Technovation*);
3. "Big science as a catalyst of new business development" (in E.G. Carayannis and P. Formica, *Knowledge Matters: A Networks and Clusters Perspective from the US, Europe and Asia*, MacMillan Press, forthcoming);
4. "How Science Can Foster Innovation by Saving Money" (presented at the Academy of Management 2006 Annual Meeting).

The first paper introduces the basic idea of systematically using big science / basic research as catalyst for industrial innovation. It also develops preliminary process models for how to introduce new industrial technology to a big-science center and also how the technology may evolve within the big-science context over time, including the possible application categories for new technology when aimed at replacing conventional solutions. The categories are termed 'R&D applications', 'Special applications', and 'System applications'.

The second paper is a result of a multiple-case study that followed the above discovery. Through a real-time inquiry of seven multiannual experiments (preceded by a single-case study as a grounded-theory investigation of an unsuccessful collaboration case), the paper investigates seven new product development (NPD) processes in industrial companies collaborating with big science, and how the collaboration evolves over time. It then demonstrates that when the collaboration is based on strategic and practical needs of both sides, the NPD process merges into big-science development process during the phases of prototype development and testing and piloting. This type of collaboration that mutually benefits both parties generates major innovation and cost benefits to the both, potentially exceeding those typically accrued from traditional supply-demand B2B dyads. The joint process model and key guidelines are presented.

The third paper is a single-case study focusing on new business development. It investigates a small venture company introducing its new technology to a big-science center and the actual collaboration and business development patterns that follow. It discusses the complementary resources, meaningful use, and social practice that big science can provide to the venture company and its new business creation efforts.

The last paper then switches to the big-science perspective, and provides guidelines and a model for the big-science center and policy-makers on how to organize the procurement activity in order to promote the above mutually benefiting collaboration. The central theme is how to manage the cost and risks of new technology procurement while also fostering industrial innovation and new business development. This a central question not only for big science centers but also in recent 'innovative procurement' initiatives for instance in European Union.

Major findings of each Paper are presented in greater detail in the following sections. The section numbers correspond to the Paper numbers (1, 2, 3, and 4) used above.

6.1 New technology to big science to catalyze industrial innovation

This Research Paper presents the basic idea and process of how to introduce new technology to a complex big science basic research environment in order to catalyze commercialization of the technology. The central theme of the approach is on the understanding of all the possible applications and implications that the new technology shares when implemented to replace conventional solutions. The big science center as a potential user and customer of the new technology with the related technological domains is systematically mapped to establish technological trajectories, which overlap with the possible applications. This mapping provides the framework for detailed application analysis with pointers to the right people responsible for the potential application area.

The paper develops the necessary tools to conduct such mapping. First, it develops the flow chart describing the mapping process. In practice, this is also the basic model for how to *enter* big science with new technology (an illustrative case example of the flow chart is in Fig.1 of the Research Paper 1). Next, the paper develops a two-dimensional application matrix with one dimension covering all related big-science technology domains, and another one covering all application areas for the new technology. The former can be obtained e.g. through the lab purchasing office, having a detailed set of 'activity codes' for items typically purchased by the lab. The latter includes all potential applications areas, including other than those planned by the company but which have been proposed for instance in literature. Often innovators themselves are perplexed by the sophisticated techniques and see only few applications for their innovation. An illustrative example of the matrix is in Fig.2 of the Research Paper 1. Each application candidate is studied whether the new technology meets the technology trajectories of big science. Finally, application categories are developed according to the nature and scope of the potential application. For instance, an application at CERN could be a high energy physics (HEP)-specific instrument requiring HEP-specific R&D efforts, or it could be part of a regular air conditioning system that is not directly related to scientific instrumentation. Three characteristic application categories for new technology were identified:

1. *R&D application* involves research and development collaboration with the big-science center aiming to design specific sub-components in order to fulfill the requirements of future scientific instrumentation. Participation requires research-oriented strategy with patience to adapt to the rhythm of big-science projects. The innovation potential is significantly higher than in other applications, yet, so are the related risks. These kinds of projects serve as a logical continuation to the development process that precedes any new technology before it reaches the application level. Big science provides the innovators with a unique environment to improve the technology along with other fore front technology development activities.
2. *Special application*, i.e. the new technology at its present design and possible prototypes fulfils the requirements of the science center concerning a specific and non-standard application. Typically, these applications may not have counter examples in industry, as they are bound to the scientific instrumentation or to a peculiar operational environment far from conventional ones (e.g. operation in very low temperatures or in space). From the big science point of view the new technology provides them with a

novel and, sometimes, with an economically and technologically attractive solution to an existing problem. For the technology provider the special application establishes image related benefits, increases experience, and provides the innovation with an interesting test-bench for the new technology. Yet, the application may require extra design and engineering work, which may cut direct profits.

3. *System application* acts as a part of a larger system where it could be used to replace conventional and standard solutions because of its outperforming economic and operational properties. Big science may not be interested in the application, as the system is purchased as a complete delivery and/or it is part of the infrastructure (ventilation, telephone network, heating, escalators, etc.) and not directly contributing to scientific results. Therefore direct collaboration with system manufacturer or system supplier is required. With the system manufacturer the collaboration means design co-operation together with acting as a component supplier. Prospects for voluminous implementations with reasonable profits are potentially present in system applications.

The threefold classification of the potential applications provides also perspective to understand the evolutionary aspects of a new technology. Entering the market takes place concurrently along several potential application trajectories. Some may enter directly from the R&D phase to a system component or it may take long time before a specific application turns into a state-of-the-art practice. The paper claims that performing the technology mapping procedure with big science may significantly catalyze the innovation process from technology artefact to the market. Once the first prototypes of the new technology artefact have been developed, then the R&D-based collaboration becomes critical to further exploit the innovation. It is in this phase, from the in-house development to R&D-based real-world implementations, when collaboration and mapping the application potentiality with big science enter into picture. This step is crucial in all innovation processes.

The paper thus proposes that the true application potential of an innovation can be discovered through systematic research work and mapping in the big-science context. The proposed systematic approach investigates all the potential applications (pre-screening), of which the most potential ones are further studied (feasibility study). The case data indicate that this approach helps make contacts with the right people and without major time delays, and provides the lab with an alternative novel solution to their specific instrumentation problem.

6.2 Mutually beneficial joint innovation process

This Paper is based on an in-depth multiple-case study. One of the studied cases is a revelatory case of an unsuccessful collaboration. Based on the case evidence, the Paper develops a mutually benefiting innovation model that integrates industrial and big-science R&D at moments when they best catalyze technological innovation by matching specific needs of both sides and facilitating their joint efforts during the cooperation. The multiple skills, diverse assets and technology validation practices of big-science may generate, when needs of both sides are clearly defined and well coupled, a fertile ground to enable and boost industrial innovation. The big-science center benefits from the cooperation through access to cutting edge technologies at competitive prices and through manufacturing prospects, which both bring optimal performance per cost ratio in instrument design and production. At the same time it generates meaningful social practice and input into industrial innovation processes. A successful matching process includes: industrial scouting and scanning to find applicable new technologies in the industry; assessment of related business development needs in order to find and create the right motivations for mutually

benefiting cooperation; identification of functional specifications for big-science instruments; and an active match-making of needs, motivations, people, and timing.

First, a framework model is developed for the mutually benefiting R&D cooperation. While it was known at that time that big-science *procurement* may yield positive economic impact and learning benefits for Member State industries, and how to *enter* big science (Research Paper 1), no model had earlier been presented for a systematic use of the "hidden" resources of big science for the benefit of industrial innovations, or on how industry could accrue benefits systematically throughout all phases of collaboration. Samples in survey studies had been limited to supplier companies. Pre-tender CERN-industry cooperation in particular had not earlier been researched.

The revelatory single-case study on an unsuccessful collaboration case investigated aspects of pre-tender cooperation and the actual tendering process, and their influence on the final outcome and satisfaction (i.e. mutual benefits). The case (Case 2) revealed the following among other things:

- *The best company does not necessarily win.* Although technically the best, the company did not win the contract. This was a great disappointment to the company, but also to CERN. Thus the cooperation did *not* in the end provide CERN and the LHC with the best possible know-how and technology available on the market.
- *Too dependent on CERN.* The company had heavily invested in the CERN relationship, as it considered CERN as a potential customer. The company's sales and growth estimates were largely based on the assumed future business with CERN. As a consequence, the future of the venture became highly uncertain when corporate management learned that no business had resulted from the cooperation with CERN.
- *Involvement very early does not guarantee success.* The cooperation had lasted for more than five years before the actual tendering phase, which is a significant investment for industrial companies in general, and for a small venture in particular. The length of the joint effort should be limited to the minimum possible, i.e. companies should not be involved too early in the *concrete* development and testing work.
- *Too supply-centric.* In this case, the company surely benefited from CERN's unique environment, cooperation and testing facilities, etc., yet the outcome of the cooperation was not perceived satisfactory by either of the partners. The motivation for the cooperation was too focused on a possible CERN supply contract.

It was also concluded that the cooperation cannot be mutually benefiting or "win-win"[7], if it is not based on the needs, or more precisely, on the strategic needs of both big science and the partner company. Traditional modes of supply-demand B2B, technology transfer and commercial research relationships would not apply. Win-win is realized only if the needs of both sides match. Table 4 describes the basic needs on strategic level as well as the related needs on the practical level in case of CERN.

[7] 'Win-win' cooperation in this context refers to a mutually benefiting cooperation where both of the parties benefit through the cooperation and also attain more than they would without it.

Basic strategic needs	
CERN	• maintain its position as the world's leading laboratory • develop and build best-in-class HEP instruments
industry	• growth and profitability through innovation • create value for shareholders and customers
Consequential practical needs	
CERN	• need for new technologies for HEP projects • work with the best partners
industry	• development and commercialization of new technologies • external resources for R&D facing internal resistance

Table 4. Basic strategic and practical needs of industry and CERN.

The case findings together with extant literature on new product development (NPD) and big science-industry collaboration, as well as the framework of systematic technology mapping and application analysis introduced by Research Paper 1, were used as basic elements to build the model. The typical industrial NPD process chart was chosen as a basis for the model illustration. In this process, big science (sub) component development process and the industrial NPD process merge into one common process at the prototype development phase, i.e. at the moment when both big science and the company are assumed to need a joint effort to achieve their goals. The goal of big science is to apply the new technology to the production of research instrument components, whereas the company's goal is to use the technology to generate growth and profit in its main target markets. However, they both potentially need the same technology, and their interests meet at the "prototype development" and "testing and validations" phases. It is assumed that these two phases are the most fruitful phases for mutually benefiting cooperation. This also means one should look at new technologies in the industry that are in the prototype phase or latest in the testing and validation phase.

The framework model then was tested with a longitudinal study of seven collaboration cases (Cases 3-9). These are the only cases generally known having systematically used the above collaboration approach at CERN *and* that represented technologies new to CERN. The cases provide support to the model but also further refine it. The main findings concerned issues relating to pre-tender collaboration, timing, savings in R&D costs, the tendering phase, conflicts with CERN administrative processes, the role of third party brokerage, and production prospects. Low-profile informal expert-to-expert type of communication and exchange was found to be a good way to start the cooperation, as it becomes more complex and strict when/if money and administrative procedures get involved.

Important learning and information exchange between experts occurred especially during the pre-tender cooperation phase. The cooperation projects provided the companies with expertise, testing, users, and piloting, and, in some cases, breakthrough sales contracts and valuable references. In the latter cases, big science became the small, new, marginal market needed for the initial commercialization of new technology. Timing was very important, especially from the big-

science perspective. Since new business initiatives are very eager to get the first breakthrough contracts for their new developments, they are also very much motivated to get their prototypes tested, validated and industrialized. This motivation together with the availability of regular national funding for industrial R&D may significantly save big-science R&D costs.

These companies, which have their end market outside the big-science center but may need big science collaboration and references to get there, are very much motivated to engage in joint R&D even at their own cost (especially if part of the costs was covered by national R&D funding). Those of the case companies that did participate in tendering were also the cheapest bidders even in tough competition, in spite of the fact that they were newcomers without previous experience of CERN tendering procedures and practices. In all of the cases, third party help and coordination was needed to ensure the right strategic match and manage the *joint* process throughout the life cycle up to the win-win outcome. This external effort was found to cover many of the tasks of the "entrepreneur" whose crucial contribution "is to link the novel ideas and the market" (Freeman and Soete, 1997: 201).

Problems were also identified. In two of the cases the big-science center took the company's product idea and started to develop it on its own. The companies concerned were not informed of this, nor asked for tenders for the products. It could be argued that this is the consequence of an informal (non-contractual) approach. However, these cases were the only ones where official administrative agreements and procedures were indeed applied as early as during the testing and piloting phase. Hence, it is argued that the collaboration should be kept as informal and expert-to-expert as possible, avoiding big-science administration as much as possible. More important, it was found that big science *does* cooperate with many companies during the R&D phase but in many cases with those specialized in research instrumentation or those with limited production capabilities even though ultimately large quantities would be needed. This may lead to an expensive component design lacking the production perspective, and thus also to a design that ignores alternative new production technologies.

6.3 Big science as a catalyst of new business development

The third Research Paper, based on a single-case study of a small corporate venture company (Case 6), suggests that through collaboration with a big-science center, a radical technology venture that has only limited internal support and resources may grow into a new business with the help of a set of complementary resources directly and indirectly accrued from business-oriented partnership with the research center, in particular when combined with the meaningful use within the practice of center's complex social network. The paper takes the venture team perspective rather than that of the corporate management or a research center, investigating the complementary resources the venture is able to accrue as catalysts for business development from the big-science collaboration.

The complementary resources accrued include testing facilities, laboratory equipment, neutral test results, and specialized technical expertise, as well as long-term pilot use and valuable user feedback. Furthermore, the case indicates that the needed external resources also include additional government R&D, which, while not directly provided by the research organization, is indirectly attracted by the fact that the company collaborates with an external research organization. In addition to these complementary resources, big science may provide the initial market and breakthrough supply contract, as well as references that are valuable not only on the marketplace, but also in relations with strategic partners and internally across business units.

These may not be the same 'complementary assets' in the narrow sense of the term as per Teece (1986) who emphasizes the role of manufacturing capabilities as complementary assets in successful commercialization of innovation. Actually the case company had already gained access to complementary manufacturing and R&D capabilities through strategic alliances and partnerships with leading companies and organizations with critical specialized expertise.

Using Tuomi's (2002) concept of innovation as *'meaningful use in social practice'* to explain the case, the case study indicates that big science provided the case technology with a 'social practice' in terms of users and testers of samples, prototypes, and end products at the big-science center and within its partner network. This use was also 'meaningful' in terms of the high reference value, and also in terms of many leading engineers, scientists and partner laboratories that were involved in the project. The 'meaningful use' of the new technology in the big science setting is not just about big science acting as a market or a customer as in a classical business-to-business (B2B) relationship. The lab know-how, expertise, pilot use and laboratory facilities on the site and within its partner network, together with its reference value, are considered unique compared to venture company's usual B2B customers. It is proposed that the big science may act as a catalyst of new business development.

Naturally, the big-science center is not the only external resource and partner along the long trajectory from technological discovery to new business. During the case collaboration project, for example, there were evidently other stakeholders such as the corporation hosting the venture company, the R&D funding agency, the third party brokerage service, and also all the complementary capabilities through venture company's strategic partnerships. In addition, the company had research partnerships with universities and laboratories ongoing at the same time with big science collaboration. However, collaboration with the big science center, due to the unique combination of all the above-mentioned assets and benefits that can be accrued from the joint collaboration, may trigger all the cumulated previous efforts and investments in the venture and transform them into a business breakthrough, as the previous efforts are complemented by the missing assets and the meaningful use. It is possible that without big science collaboration, the venture company might still struggle in a similar situation as had prevailed for years during periods before the collaboration started.

Finally, big science may provide the above business benefits without commercial sponsored research. Originally, at least from the CERN perspective, the case was simply about a potential new supplier company approaching CERN in order for the latter to validate new technology it was not familiar with but which provided a potential fit for its needs. CERN in general, as well as the people involved in the project, were not aware of their significant contribution to and role in the development of the venture company during the project, nor afterwards. Hence, it is important *not* to interpret this finding as a proof of CERN's excellence in its specific attempts to foster innovation. The positive outcome simply occurs through regular technology validation work, because of the fact that a company may use the "special application" (Hameri and Vuola, 1996) in such a way that it serves its strategic needs of business creation. On the other hand, as the benefits are produced unintentionally by the research center, its significant role does not require any additional efforts from the center compared to its normal operations. And it should not. CERN's mission is limited to basic research, after all.

6.4 Proactive procurement

In this paper, I take the lab perspective and use the model of 'mutually beneficial collaboration' (see Paper 2) as a basis for the development of a *procurement* model. The case data are analyzed with the focus now on procurement issues. These data are believed to be among the very first empirical data based on a long-term real-world practical experience on a systematic use of public procurement as an innovation tool. They might also be among the first to include pre-tender developments, as the cases were studied not only during the official purchasing process but also in real time since the very first contacts between the companies and the lab were established. Hence, the data are extremely interesting from the perspective of the concept of 'public technology procurement' or 'innovative public procurement' now vividly discussed and promoted specifically in Europe (EC, 2005; Fraunhofer Institute, 2005; Wilkinson et al., 2005).

The paper implies important guidelines to be considered in order to make innovative public technology procurement work in practice. It introduces the model of proactive procurement based on regular public purchasing procedures incorporated with two additional and new, yet essentially inherent, components of proaction to meet the challenge of managing cost and risk while also enabling innovation: first, *interdisciplinary technology*, which means active search and assimilation of new technology developed for alternative purposes and uses, and matching it with the needs of the lab. Thus the technology development work, as well as the related costs, will not be borne by the lab. Applying the new technology to the lab's needs potentially provides significant cost and performance advantages over conventional solutions, thus also radically changing the basis of competition; and second, p*re-tender collaboration*, which means thorough testing and piloting of technological options prior to tendering. The lab takes advantage of technologies that are at the prototype stage having not yet reached their breakthrough on the market. The company greatly benefits from the testing and piloting and provides the technology as test samples for validation. The lab thus does not need to buy technology or R&D at this point.

As the innovative use of interdisciplinary technology potentially changes the basis of competition, regular purchasing procedures and conventional price competition can be applied. Interdisciplinary technologies potentially provide substantial savings compared to the conventional solutions that labs would normally use. Furthermore, the proactive testing and piloting decreases the uncertainties typically involved in the purchase of new technology. Thorough testing and piloting of the technology, which in fact is part of the CERN culture since decades, familiarizes the lab with the technology already prior to tendering and contracting. What is new compared to the CERN normal practice, however, is the assimilation of interdisciplinary technology, for which the basic development has been driven by users and customers in other markets, and then applying the proactive testing and piloting of this technology in order to find out whether it is suitable for the lab's needs or not. This occurs simply through the lab's regular daily R&D and project work combined with regular purchasing procedures. No additional functions need to be neither created, nor new mission statements, nor additional budgets to cover the development costs. Proactive procurement is about mutually benefiting collaboration where the needs of both sides find a natural match.

Instead of using procedures and practices that favor the procurement of commodities and conventional technologies from established partners, big-science and other public organizations may apply the proactive procurement model providing them with new technologies so that all parties, the organization and its end users, the supplier, and the national innovation system, all win: The buyer organization and end users get more value for the money, due to the fact that new tech suppliers that are at an advanced development stage are motivated through benefits accrued

to their innovations and business. And national innovation systems benefit from both the successful commercialization of new technologies and the improved performance of public research and services.

6.5 Discussion

The above set of Research Papers deals with multiple new aspects in public research-industry collaboration. First, the overall concept of a *systematic use* of public research for industry-based technology and business development differs substantially from the mainstream technology transfer and science policy literature and discussion. Second, this is even more valid when taking into consideration that CERN is simultaneously both an intergovernmental *big-science* organization and a *basic research* lab, both types with which industrial collaboration have been relatively little studied. Third, the focus is on specific type of firms that are relatively *small, new* to the lab, and of *radical* nature. Fourth, the issue of 'public technology procurement' or 'innovative procurement' has become an increasingly important topic during the study, particularly in the EU seeking to stimulate and foster innovation through its massive public purchasing. It is also highly relevant outside the EU, for instance, to the SBIR program in the US, of which the evaluation is now ongoing. The procurement model developed in the fourth Paper (Vuola, 2006b) provides tentative answers to the key challenges of the new procurement policies under preparation in the EU, and also proposes implications for individual public research labs.

This research thus concerns rather unusual collaboration cases, in which the research lab was systematically approached with the intention to use its *needs* to foster new technology-based industrial innovation and business development. The study covers multiple pilot projects using this novel approach. During this longitudinal multiannual study, the cases then revealed that using big-science for business purposes is not actually possible without also big-science having prospects of 'using' the companies, i.e. that success is found in *mutually beneficial* collaboration based on the matching of strategic needs of both sides. Finally, the study then continued by taking the lab perspective and developing a model of how the lab can accrue the benefits of such win-win collaboration through what I have termed *proactive procurement.*

In the following Sections, I discuss the findings of this longitudinal multiannual study particularly in respect to the findings and conclusions of the first Paper that originally introduced the basic idea of the 'reverse' technology transfer, i.e. introducing new technology from industry to the lab. Then I revisit the main contribution of the study, i.e. the 'win-win' collaboration model, in light of all four Papers.

6.6 Reflections on using big-science collaboration along a technology trajectory

The first Research Paper introduces the basic idea of approaching the big science basic research lab with a new (industrial) technology to catalyze commercialization. The Paper proposes that big science basic research, if systematically used, can have a significant role in the technological trajectory and innovation process. Along the mechanism of new technology-based industrial product development, the appropriate phase for collaboration with a big science basic research lab is between 'technology development', which is typically preceded by multiple technological trajectories (Dosi, 1982), and the 'R&D application'. This collaboration phase is illustrated as the grey area between the two phases in Fig. 3. The first Paper proposes that once the initial prototypes of the new technological artefact have been developed, collaboration with external

parties becomes critical to further exploit the innovation. It is this phase, from the in-house development to R&D-based real-world implementations, during which mapping the application potentiality and collaboration with big science becomes viable. This step is crucial in the innovation process, as it usually is slow and time consuming. The first Paper argues that performing the technology mapping procedure that the Paper had developed may significantly catalyze the whole innovation process.

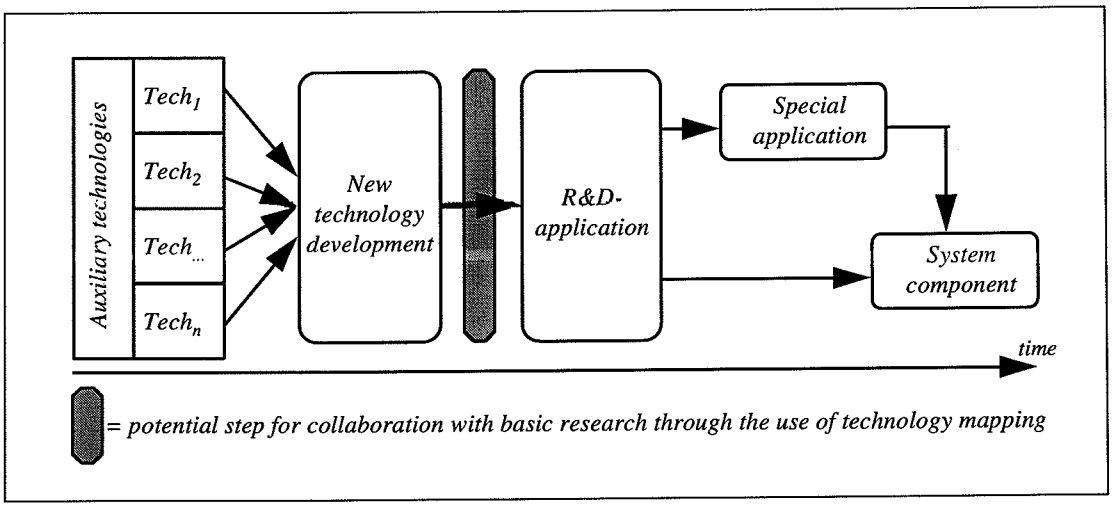


Figure 3. The evolution of new industrial technology. The grey area in the picture is where big-science application mapping may take place.

This 'grey area' together with the subsequent phases of joint 'R&D application' development, 'special application' development, and 'system component' development, are further studied in Papers 2 to 4 based on several years of research and experience on the actual R&D and business development processes over multiple years. The second Research Paper focuses particularly on the 'R&D application' phase. Using a basic industrial NPD process as the framework model, it develops a model of a joint innovation process between the lab and the company with two joint phases of 'Prototype development' and 'Testing and validation'. The key finding is that the collaboration has to be based on a match of needs of both parties, not on the traditional supply-demand setting. The lab aims at using the technology in its special application, yet the company's ultimate goal is in industrial system components in application areas completely other than those critical to the lab. While the strategic goals differ from each other, mutually beneficial collaboration is possible when there is a good match of practical needs.

This is an important finding. The goal, from the company's perspective, should not be the lab-specific 'Special application' per se. The case data show that, if focusing solely on lab/research-specific applications, the outcome may be nothing but satisfactory to both parties. The single-case study (Case 2, reported in the Research Paper 2) demonstrated that it would be better for both the company and the lab if company's goal were a 'system component' *outside the lab*. The Case 2 company had conducted R&D with the lab for multiple years, and, technically speaking, was also the best of all, yet the collaboration did not in the end provide the lab with the best possible know-how and technology available on the market, because the company was simply too expensive in the actual tendering competition. Lengthy R&D collaboration with the lab also made the small venture company with limited resources too lab-focused and lab-dependent. While the joint R&D

may take up to 5 years or even more, it may not, in the end, result in any business partnership. In this case, for instance, both parties were utterly disappointed in the end. Hence, the outcome of their multiannual joint cooperation was not perceived satisfactory by either of the partners. In this case, it became reality what Paper 1 feared, i.e. that "motivations to continue R&D may be scarce for a small innovating company, which is already exhausted by the development effort" (p. 536).

Hence, the statement of the first Paper that "the innovation potential [of the 'R&D applications'] is significantly higher than in other applications, yet, so are the related risks" (p. 536) requires further clarification. It is necessary to emphasize that companies should *not* focus on the 'Special application' per se. While 'R&D application' is the entering point for this new type of collaboration, firms should not start developing lab/research-specific technologies (i.e. those used e.g. only by CERN or the HEP community). Neither should the *lab* focus on lab-specific suppliers alone.

This is not to say that, in the R&D applications, there would not be any innovation potential that the scientific instrumentation-specific companies could not benefit from. However, the data indicate that the innovation potential for both the company and the lab is higher in cases where the company ultimately aims at generic 'system applications', using the lab's 'special application' as a *step* toward the ultimate goal of becoming a new innovative 'system application' in the common marketplace outside the lab. The lab's 'special application' acts as the necessary "meaningful use in social practice" (Tuomi, 2002) that a new technology needs on its way towards generic use of the innovation.

If one focuses on the lab- or big science-specific applications only, the market will remain relatively limited, and the lab, sooner or later, has to carry all the costs of the development of the technology. This might be the traditional way of doing cooperative R&D in the labs, yet the study proposes that it is neither the most cost-effective strategy for the lab, nor for the company. Instead, the lab should focus on companies that have a 'System component' application identified *outside* the lab, which is also the actual target market for the new technology. The company uses the lab collaboration in order to get there because it would be too big and disruptive a leap for the company to go there directly.

From the lab perspective, in each case, the specific big-science application in question was originally that of the category of 'R&D application'. The lab had conducted extensive R&D on that application for up to several years before the case technology was introduced to the lab. In several cases, the new technology seemed to provide a solution for the lab's specific R&D problem. After the validation, testing and piloting of this new candidate technology by the lab, the lab and the company could then move to the 'Special application' phase, as the company had already done most of the R&D. While the R&D had been conducted for purposes other than the lab, the lab could directly benefit from these past R&D efforts, and did not need to conduct any further R&D on this specific component.

So I retain that 'R&D applications' do have the highest innovation potential. Yet, they have to be viewed as an indication of *need*, and not as the solution. The 'R&D applications' hold innovation potential for new *industrial* technologies in terms of indicating that the technological choice for a future 'Special application' may still be open and mutually beneficial collaboration may be initiated. The 'R&D application' per se, for which the lab carries out its own lab-specific R&D, is too lab- or big science-specific technology lacking the perspective of more generic industrial use, and thus new technology companies are not recommended to spend their scarce R&D resources

on them. Instead, they should focus on their own technologies and investigate if the lab R&D *needs* could help them to get their technology commercialized. Furthermore, 'System component' applications at the lab (versus *outside* the lab, as emphasized earlier), on the other hand, are not the starting point in this mode of collaboration, because they typically entail no potential for further technological collaboration between the lab and industry.

The broader perspective of business development taken in Paper 3 (and later also in Vuola, 2006a) revealed that actually the lab's role in *prototype development* was only marginal compared to the company's overall efforts taken over several years or even decades. Unlike Paper 2 indicated, the lab had a meaningful role mainly in the 'testing and validation' phase "only". "Only" in quotes, as the lab's role, in the end, was actually surprisingly important. The point here simply is that, in real life, the lab did not do any actual engineering or development work for the prototype, but had a role, an important one, during testing and piloting, and in some cases also as the initial market for and the meaningful user of the technology.

As a conclusion, the evolution model of Fig. 3 is considered valid, yet the 'R&D application' box in it needs the above clarification. While this joint R&D phase is relatively long time-wise, up to several years, the lab's contribution to the actual prototype development is somewhat limited. For the lab, on the other hand, the prototype development phase is extremely important. While it is the company who developed the prototypes, the lab then tested and piloted them in order to know whether they could meet their high standards or not. However, this does not diminish the significance of the collaboration, quite the contrary. Paper 3 clearly demonstrates how big science, through its technology validation practice, may provide the necessary complementary resources and meaningful use for the small venture company. Hence, the practical outcome and consequences of the collaboration are actually even more important than the Paper 2 first indicated.

Finally, the last Research Paper (Paper 4), in addition to contributing to public procurement procedures, further elaborates the factors and conditions for successful execution of the win-win collaboration. These factors and contributions are summarized in the next section.

6.7 The win-win collaboration model

All of the Research Papers discuss a special mode of lab-industry collaboration: introduction of new industrial technology to the lab in such a way that the implementation of the technology in the lab context simultaneously serves both short-term needs of the lab and longer-term strategic plans and goals of the developer company. The collaboration is win-win, or mutually beneficial, because it is based on the needs of both parties, rather than being solely based on the needs of big science (conventional supply-demand B2B dyad, that is) or on the needs of the company (commercial research or traditional technology transfer, that is). The model is illustrated in Fig. 4.

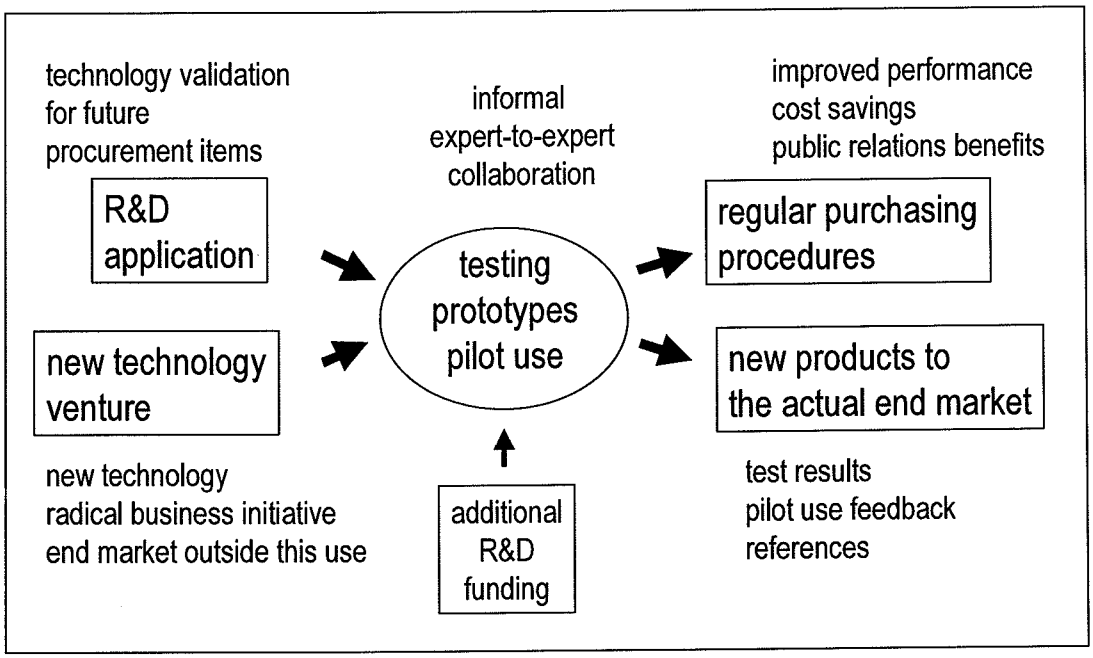


Figure 4. The win-win collaboration model.

In this model, the lab focuses on companies and their venture projects with unique technologies that are not known to the lab nor have the company any intention of making contact with the lab. The company or venture represents radical technology that was developed for purposes other than the discipline and applications of the lab. While the technology would not normally be available for the lab through the conventional buying orientation and reactive purchasing strategy, it potentially provides improved performance and novel cost-effective solutions for the lab.

The lab then proactively collaborates with the company by matching the innovation needs of both sides, and facilitates this informal expert-to-expert (E2E) collaboration prior to the commencement of the actual purchasing procedure. The lab aims at applying new technology to its specific needs, whereas the company's goal is to use the technology to generate growth and profit by launching new products in its main markets that are outside the lab. However, they both need the same technology, and their interests meet at the prototype development, testing and piloting stages. In practice, this means one should look at new technologies in industry that are at this stage only. On the other hand, the R&D on both sides should simultaneously be undergoing the same development phases in terms of timing, the perfect match being the right match of needs coupled with the right timing. Such networked (and often international) collaboration between industry and research is likely to get additional R&D funding from the government or other sources, which further motivates the company to collaborate.

The lab benefits from the cooperation through access to cutting-edge technologies, which would not normally be available for the lab, at reasonable cost, and through manufacturing prospects for the instrument design, all of which introduce an optimum performance to cost ratio into the lab's research projects. At the same time, the collaboration generates meaningful use in the social practice of the lab and its network, and input into industrial innovation and new business creation

in terms of test results, pilot use, feedback, learning benefits, and references, thus helping the company enter other markets outside the lab.

The model thus exploits the great potential labs hold in terms of catalyzing innovation in industry. This occurs simply through the lab's regular daily project and R&D work combined with regular purchasing procedures. No additional functions need to be neither created, nor new mission statements, nor additional budgets to cover the development costs. It is about mutually benefiting collaboration where the needs of both sides find a natural match.

The difference to traditional business-to-business (B2B) is that in regular B2B the company tries to sell products to the lab, treating the lab as a customer among others. The lab also treats the company as a mere supplier, often as a kind of compulsory element (to be tolerated) during the research instrument construction phase. This is the normal traditional supply-demand dyad, i.e. matching of company's offering to lab's needs, and *not* matching of the needs of both sides. As per comparison to the Fig. 4, the traditional supply-demand model would have only two boxes, i.e., "supplier" and the "regular purchasing procedures".

The new model also differs from regular modes of research lab-industry collaboration, such as contract research that is "performed by industry and paid by the lab", or sponsored research, which is "done by the lab and paid for by the company" (Roessner, 1993: 39). Typically, in case of contract research, the lower right box in Figure 4, "new products to main markets", is not present, leading to relatively expensive solutions for the lab, as it has to carry out all the costs related to the development of the end product. Typically also the box "regular R&D funding" would not be there, as big-science-specific R&D might not attract any additional funding from government sources. In case of sponsored research, the upper right box "regular purchasing procedures" would be missing, being an expensive choice for the company, as it has to pay to the lab for the development, testing and piloting work done there. In CERN's case the latter alternative does not normally occur at all, as CERN does not conduct research directly paid by industry, nor would any CERN staff normally be motivated or able to do it for free.

In Research Paper 4, which takes the lab procurement perspective, this model is termed *proactive procurement model*. It is emphasized that the model does not abandon the regular lab purchasing procedure but incorporates it with two additional and new, yet essentially inherent, components of proaction to meet the challenge of managing cost and risk while also enabling innovation:

- *Interdisciplinary technology*: Active search and assimilation of new technology developed for alternative purposes and uses, and matching it with the needs of the lab. Thus the technology development work, as well as the related costs, will not be borne by the lab. Applying the new technology to the lab's needs potentially provides significant cost and performance advantages over conventional solutions, thus also radically changing the basis of competition.
- *Pre-tender collaboration*: Thorough testing and piloting of technological options prior to tendering. The lab takes advantage of technologies that are at the prototype stage having not yet reached their breakthrough on the market. The company greatly benefits from the testing and piloting and provides the technology as test samples for validation. The lab thus does not need to buy technology or R&D at this point.

As the innovative use of interdisciplinary technology potentially changes the basis of competition, regular purchasing procedures and conventional price competition can be applied. The risk for

cost overruns, hence, is not an issue. In fact, interdisciplinary technologies potentially provide substantial savings compared to the conventional discipline-specific solutions labs normally use. Furthermore, proactive testing decreases the uncertainties typically involved in the purchase of new technology. Thorough testing and piloting of the technology, which in fact is part of the CERN culture since decades, familiarizes the lab with the technology already prior to tendering and contracting. What is new compared to the CERN normal practice, however, is the assimilation of interdisciplinary technology, for which the basic development has been driven by users and customers in other markets, and then applying the proactive testing and piloting of this technology in order to find out whether it is suitable for the lab's needs or not.

In summary, the prerequisites or success factors for such collaboration are the following:

1. *Unbundling of demand*: The lab should unbundle large instrument components into sub-components in order to reduce the application-specificity and thus increase the chance for more generic and interdisciplinary technologies to be considered to meet your needs.
2. *Functional specifications*: The lab should identify the outcomes from its requirements instead of preparing detailed locked-in technical specifications, i.e. to specify the end result to be achieved and prepare functional specifications that are open to several alternative technological trajectories.
3. *Active search for new technologies*: One should look for new technologies also from uses and applications other than those of the lab, and particularly those that, because of their radical nature, lack necessary resources and possibly even target wrong markets, and for that reason have not yet gained their commercial breakthrough.
4. *Timing*: One should focus on advanced prototype technologies that need demanding testing and piloting. Look at technologies that are at this stage only, not those in earlier development phases, nor those that are already launching the products on the market. R&D on both sides, the lab and the company, should simultaneously be undergoing similar development phases.
5. *Matching needs*: One should study and analyze the strategic needs of the company related to this specific new technology and the related new business development needs, and match them with the lab's procurement needs. A major strategic motivation for the company is essential in order for it to invest its time and resources into the collaboration without asking big money for it.
6. *Complementary assets*: One should check if the lab, its partner network or the research community can truly provide potential users, testing and piloting facilities and meaningful use for this particular emerging technology or business.
7. *Main application outside the lab*: The company should have also other motivations than a possible supply contract with the lab that should not be the end market for the new technology although it may act as an initial lead market for the technology.
8. *Additional R&D funding*: The company should try to get additional R&D funding from government or other sources for the technical collaboration phase. The very collaboration with the research organization and its large network usually enables the company get additional external funding, as it satisfies the criteria of networking and research collaboration typically set by governmental agencies.
9. *Informal collaboration*: The collaboration project should start with informal expert-to-expert interaction, testing, and piloting well in advance prior to the actual tendering. Then later, if the technology proves promising, the lab applies the formal purchasing procedures.

The model is applicable to both small and large companies. Determinant is not the size of the company but that the new product or business initiative radically differs from those found in the

mainstream business. Because of its radical nature, the initiative is in need of external resources, and typically the company is also open to try alternative ways and markets to commercialize its new technology.

7 IMPLICATIONS FOR THEORY

The theoretical frameworks in the Research Papers included those concerning technological innovation primarily from the perspectives of (1) technological trajectories, (2) NPD processes, (3) complementary assets, and (4) public procurement. Each of the Research Papers also discusses theoretical implications specific to these frameworks. Hence, those implications will not be repeated here, except partly for the last one, public procurement.

When viewed from the overall perspective (all four Papers within the technology transfer framework discussed in the literature review), this dissertation as a whole has important implications specifically for the technology transfer research.

The dissertation provides implications for theory in the four specific dimensions that the case of CERN provides as presented in the end of Chapter 2:

- specific to *lab*-industry interaction in general;
- specific to *basic research*-industry interaction in general;
- specific to *big science*-industry interaction in general; and
- specific to *public procurement* in general.

I will examine these dimensions in the above order, starting with the lab-industry interaction.

7.1 Lab-industry interaction

As was suggested by the literature review, the data demonstrates that similarities can be found between the mode of collaboration discussed here, and the lab-industry cooperative R&D of which there is much experience in the US, yet seemingly less known in the European lab environment.

First of all, while the lab contexts are different, many of the characteristics of the developed win-win collaboration model are largely supported by various earlier studies on lab-industry interaction. These include the following:

- Focusing on *R&D intensive companies* (Bozeman and Papadakis, 1995) and those with only *limited internal support* (Roessner, 1993). This is further supported by innovation and venture studies (e.g. Katila and Shane, 2005);
- Focusing on *projects for which the lab is an important customer and user.* Co-development projects in technologies for which laboratories are major users of the results (equipment, ideas, or services) are good candidates for collaborative R&D mechanisms (Ham and Mowery, 1998; Kingsley et al., 1996);
- Focus on such collaboration that fosters *knowledge and information exchange* and facilitates firm's *access to the expertise and unique resources of the lab* (Bozeman et al., 1995; Bozeman and Papadakis, 1995; Feller et al., 2002; Ham and Mowery, 1998; Roessner and Bean, 1990, 1991; Roessner, 1993; Rogers et al., 1998);
- These same studies also indicate that *leveraging firm's own R&D* is the main motivation for companies to interact with labs;

- Preference on *informal interaction* and avoiding administrative procedures when possible (Bozeman and Papadakis, 1995; Roessner and Bean, 1990; Roessner, 1993), also later supported by a CERN study (Byckling et al., 2000); and
- *Person-to-person contacts* between the lab and the firm are among the most important success factors (Roessner and Bean, 1990, 1991).

In the studied collaboration cases, whenever the above issues (together with the success factors enumerated in the previous Chapter) were followed, the collaboration provided successful outcomes. Hence, the experience with the studied cases of this dissertation fully supports the above earlier observations, and vice versa.

Second, as was proposed by the literature review (see Table 1), CERN as a public research lab can provide the companies with benefits similar to those provided by other public research labs. CERN's pre-tender R&D, supplier selection, and technology validation practices, in particular, generate a fertile environment for industrial companies to do cooperative R&D, similarly to any other large-scale research lab. Companies may accrue lab *expertise* and unique *resources, technical assistance*, and also use unique *lab facilities*, just like they tend to do with US federal labs and research centers (Bozeman and Papadakis, 1995; Feller et al., 2002; Ham and Mowery, 1998; Roessner and Bean, 1990, 1991; Roessner, 1993; Rogers et al., 1998).

Also, in line with the findings of Bozeman and Papadakis (1995) and others (Feller et al., 2002; Roessner and Bean, 1990, 1991), also in the studied CERN cases the lab *technology transfer staff* played only very minor role or no role at all.

Hence, in several ways the success factors, benefits and experience with the US federal labs and research centers seem to be applicable to CERN-industry collaboration. While the US lab-industry interaction is relatively well researched, previous studies on CERN-industry collaboration have not used this knowledge to understand and explain all the aspects of collaboration between CERN and industry. European research on lab-industry interaction is mainly centered on supplier studies, while, in the US, the focus seems to be more on cooperative R&D and the lab technology transfer activity. This dissertation is among the first attempts to view, explain, and also develop CERN-industry collaboration from the perspective of extensive technology transfer research and past experience on federal labs.

At the same time, this dissertation also provides knowledge and consequent implications that are new compared to earlier technology transfer literature on lab-industry collaboration. In particular the following issues are believed to be novel while also being generally applicable to all lab-industry interaction. First, this study introduces a new mode of lab-industry collaboration that does not directly fit e.g. the categorization of Roessner (1993) discussed in the literature review. This new mode is *not* about strategic *research* collaboration per se. Yet it is not about commercial/sponsored research either. In the cases, the lab and the company did not do research *cooperation* (i.e. joint research toward a shared research goal), but instead, *collaborated* in order to test, evaluate, and apply new, yet existing, technology (i.e. worked together in a joint effort to reach their own goals). Hence, there is at least one new way for industry and labs to collaborate, which has not been fully covered by earlier studies and categories, yet potentially provides promising outcome for both parties.

Second, companies may systematically, and almost free of charge, benefit from the lab resources and expertise by focusing on the lab *needs* (future procurements) rather than on the lab offering.

Similarly, labs may systematically, and often free of charge or at least at very competitive prices, benefit from industrial innovations by focusing on companies' R&D and business development *needs* rather than on their product offerings. Collaboration systematically based on critical needs of both parties is believed to be a new concept.

Third, while Ham and Mowery (1998), quite correctly, propose more focus on industry-lab co-development of technologies for which *the lab is a customer and user*, they, however, draw the conclusion that successful lab-industry collaboration should then draw on the historic missions and capabilities of the lab. This dissertation implies that corrections to this statement are necessary. For instance, collaborative research drawing on particle physics would certainly not attract many companies to the lab. More important, the development efforts do not need to be lab-specific, quite the contrary. In the CERN case, the data indicate that the development of HEP-specific solutions is an expensive alternative, and focusing fully on the lab mission is possible also without being limited to lab- or research-specific technologies or "drawing on the capabilities of the lab". User needs of the lab can be satisfied with technologies developed primarily for uses other than those of the lab. They can also be completely new to the capabilities of the lab. The use of such technologies is actually a cost effective alternative, as the development costs are not carried out by the lab.

Fourth, various studies have indicated that *large* companies and established partners tend to benefit from lab-industry collaborations the most (e.g. Autio et al., 2003; Rogers et al., 1998). As a consequence, labs may focus solely on large companies in order to be more successful in their interactions with industry. Few studies try to understand how SMEs could enter the lab and accrue such benefits. If survey data show that large companies have succeeded better in the past, it is a mistake to draw a conclusion that we should then give up with the SMEs. I believe that the actual problem lies with the collaboration modes and strategies used, not with the company type.

The above findings are of significant relevance to lab-industry interaction. There are several reasons for that. First, lab collaboration with industry in overall is increasing. For instance, *budget reductions* force labs "to rely more heavily on collaboration with private firms for the development and maintenance of technologies that are critical to their missions" (Ham and Mowery, 1998: 673). Second, policy-makers wish to see more *small* companies cooperate with labs, yet the reality often demonstrates the opposite (Rogers et al., 1998). And third, lab-industry interaction, so far, has had only limited impact to business and job creation in our societies. Bozeman (2000) summarizes his extensive technology transfer literature review by stating that "there is little direct evidence for federal laboratory-industry partnerships as a wellspring of jobs or new businesses" (p. 647). The win-win collaboration model being based on the needs of both parties provides an alternative that potentially overcomes each of these problems and challenges. Naturally, however, this is valid only for collaboration settings consistent with the prerequisites presented in the previous Chapter.

7.2 Basic research-industry collaboration

CERN conducting only basic research, the study has generic implications also for our knowledge on basic research-industry collaboration.

Extant literature on technology transfer indicate that, at the first sight, CERN as an European intergovernmental basic research lab may not be a fruitful or useful partner for private firms to develop non-HEP products: no systematic technology transfer activity (Hameri, 1996), no

industry-sponsored research (see Rahm et al., 1988), and no other missions than HEP, that is, being a single-mission lab (see Bozeman and Coker, 1992). In fact, David and colleagues (1988), drawing specifically from HEP research, argue that the outputs of basic research have rarely possessed any intrinsic economic value.

On the other hand, however, multiple studies on lab-industry interaction (Bozeman et al., 1995; Bozeman and Papadakis, 1995; Feller et al., 2002; Ham and Mowery, 1998; Roessner and Bean, 1990, 1991; Roessner, 1993; Rogers et al., 1998) indicate that a basic research lab may potentially provide companies with what they need. Sponsored research (together with employee exchange) are actually the least preferred forms of interaction with labs, while information dissemination, lab visits, workshops, and technical cooperation and consultation show the most promise of payoff for companies, being also the most frequent types of interactions. Past evidence also indicates that it is actually the lab technology transfer activity that provides neither much outcome nor great motivation for companies, and is actually the least reason for companies to start interaction with labs.

Hence, a basic research lab like CERN, in principle, should be able to provide companies with their preferred collaboration modes, and that the lack of opportunities for sponsored research or technology licensing with basic research should not be an obstacle for companies to systematically collaborate with a basic research lab. Based on these earlier contributions, I hypothesized in Chapter 3 that in the case of companies that are *not* former lab suppliers and do *not* produce lab-specific products, the basic research lab and companies could potentially be able to collaborate in such a manner that companies accrue multiple payoffs, in particular through such modes of interaction as information dissemination, lab visits, workshops, and technical cooperation and consultation. And this despite the fact that the lab's engineering and R&D functions exist solely for the purposes of basic research (HEP research in the case of CERN).

The evidence from this case study focusing specifically on CERN-industry interaction and cooperative R&D clearly supports the above theoretical framework. It is indeed possible to have collaboration that simultaneously serves both basic research and industrial innovation and new business. Each collaboration case also seemed to have modes of interaction such as "information dissemination, lab visits, workshops, and technical cooperation and consultation" (see Literature review).

Yet, these cases are not about cooperative research, which has typically been subject to the few extant basic research lab-industry studies (see e.g., Bozeman and Papadakis, 1995; Rogers and Bozeman, 1997). The cases here do not concern *research* collaboration per se. Instead, they are about business-driven collaboration between basic research and industry that directly serves certain development *needs* of both parties. This type of basic research-industry collaboration also provides concrete outcomes. According to the evidence, these outcomes include new technologies and solutions and cost savings for research, new products, new businesses, learning, income and profit for industry, and even new jobs in the society.

Hence, in such collaboration cases basic research indeed generates direct intrinsic value, including economic value, to firms and to the society. On the other hand, the reverse also applies, that is, product- and business-orientation contribute to basic research, that is, outputs of industry "possess intrinsic economic value" to basic research.

This is a significant finding, as it provides additional yet relatively rare evidence (Bozeman and Papadakis, 1995; Rogers and Bozeman, 1997) against linear concepts of innovation process, which tend to consider basic research as a source of innovation and fail to account for various feedback loops and stages (Kline and Rosenberg, 1986; Rosenberg and Nelson, 1994). The evidence indicates that a basic research lab may conduct product development for a firm that has done the underlying basic and applied research, in this upside down order. This occurs when lab-industry collaboration is based on strategic development needs of both the lab and the firm.

This type of collaboration can also be systematically initiated by matching technological development *needs* of basic research with the product and business development *needs* of the firm or venture. When the parties begin to collaborate, both the company and the research organization may see the collaboration as a sort of commonplace technology validation process, yet ultimately, when it advances and starts to produce various outcomes, it seems to become increasingly intense and an important source of mutual learning and complementary resources for both parties. The collaboration starts low profile and informal, yet becomes more formalized and strategic technology partnership when the collaboration advances.

Finally, two further yet minor contributions regarding the extant literature discussed in the literature review section: First, the earlier finding that lab-industry collaboration should serve the mission of the lab (Ham and Mowery, 1998), is partly supported by this study. To be successful and strategic, the collaboration indeed has to serve lab's mission, even a basic research-based mission, particle physics in this case. However, the company's development needs do *not* have to be related to basic research (e.g. particle physics). Still, and also for that very reason (see the model description), the company may effectively collaborate with the basic research organization, and also accrue innovation benefits from this collaboration. Second, while not the focus of this research, another finding in the literature also applies, i.e. that the firm should be "in command of most of the technical phases of product development while the lab is more narrowly focused to make a specific contribution to the project" (Rogers and Bozeman, 1997: 43). The studied collaboration cases support this finding, yet, as said, this was not specifically analyzed within this study, and the case selection does not include opposite cases.

7.3 Big-science studies

CERN being a major big-science organization, the study naturally has implications for our knowledge of big-science-industry interaction. Big science in general is increasingly gaining ground and importance (Carr, 2002; Galison and Hevly, 1992; Lambright, 2002, 2003; Wolfson, 2004). However, there are relatively few studies specifically on industrial collaboration with big-science. Due to the sheer size of its scientific instrumentation mega-projects, big-science has extensive procurement activity, and the few extant big-science studies tend to focus on CERN and its supplier contracts, supplier firms, and on the economic impact and secondary benefits of the procurement activity.

This study continues this tradition of big science-industry interaction studies, and thus also contributes specifically to our knowledge on big science-supplier dyads and earlier supplier studies. Previous research (Schmied, 1977, 1982, 1987; Streit-Bianchi et al., 1984; Nordberg, 1994; Autio et al., 1996; Autio et al., 2003) indicates that there are substantial economic and innovation benefits to big-science supplier companies. These earlier studies, however, have almost exclusively focused, quite naturally, on existing supply contracts and supplier companies, and thus have regarded the big-science lab primarily as a purchasing organization. It has not been

previously studied if the lab's significant engineering and R&D functions could be used specifically for the benefit of companies those are *not* earlier lab suppliers and are *not* active in its scientific instrumentation market at all. Second, it has not been previously studied what kind of collaboration mechanisms *prior* to these supplier contracts or even prior to tendering may occur - or what kind of new modes of collaboration may possibly be developed and managed. Third, it has not been actually studied how the lab could attract and benefit from new companies and cost-efficient technological innovations other than those provided by its established pool of industrial partners.

All the findings and implications discussed in this dissertation concern big science and naturally in particular CERN, which is the selected site for this case study. Hence, I do not repeat them here, yet they contribute in particular in the above-mentioned three-dimensional manner: first, using big-science engineering and R&D functions for the benefit of companies that are *not* earlier big-science suppliers and are *not* at all in the big-science instrumentation business (Research Papers 1, 2, and 3 discuss specifically this issue); Second, collaboration mechanisms *prior* to tendering and their management (Research Papers 2 and 3); And third, how the lab can attract, and benefit from, new companies and new innovations that normally are not at their reach, and in any case, not in their field (Research Paper 4).

For the reasons I discuss below, I feel it is highly necessary to analyze implications of these findings for the most recent supplier study by Autio and colleagues (2003) investigating CERN as a learning environment and a source of innovation benefits for its supplier companies. The study observed significant development of new businesses, products and services, boosted internationalization of sales and marketing operations, and improved quality among the suppliers. Compared to an average supplier, high technological learners had longer projects, had more previous experience in collaboration with the lab, were more dependent on the lab as a customer, interacted with the lab more frequently, kept promises less frequently, had a greater number of previous projects with the lab, and had more R&D intensive projects, among other things.

It is interesting, and somewhat alarming, to note that the companies that had more experience with the lab, and thus were better established at the lab, also accrued more benefits. More alarming, they were dependent on the lab as a customer. While these findings are not contested, this dissertation indicates that working with such companies might not, after all, be the best option for the lab itself. And furthermore, firms that are new to the lab and independent from the lab may also accrue great benefits from the lab if they collaborate systematically on a win-win basis. Also the policy recommendations of the survey study need a critical look. Its recommendations especially for CERN and its procurement policy include the following:

- CERN's current procurement policy, which selects the lowest bidder, is "probably close to optimal" (Autio et al., 2003: 51) for most of the procurements.
- For the technology-intensive procurements suppliers, "CERN can probably do much to enhance the creation of learning and innovation benefits, once the bidder has been selected" (p. 51).
- CERN to organize for and emphasize extensive and frequent interaction with its suppliers.
- In order to boost learning, CERN should allow readjustments of supplier projects' goals while projects are under way.
- Getting industry involved early on for the development of mission-critical technologies.
- CERN should consider developing long-term partnerships with selected high-value supplier companies in mission-critical technology areas.

- CERN should continue to produce the technological specifications itself and maintain sufficient engineering competence.

Based on new and detailed case evidence reported in this dissertation, I would modify and specify the above recommendations in the following way:

- CERN's current procurement procedures based on the price competition should be retained, yet they are not optimal without the use of *proactive* elements such as the active search and assimilation of new technology developed for alternative purposes and uses, and the thorough testing and piloting of technological options prior to tendering.
- For the technology-intensive suppliers, CERN can certainly do much to enhance the innovation benefits, yet it may not always be good use and management of its scarce resources, especially when the company is not able to absorb CERN's help. Furthermore, the learning and innovation outcomes may be better, if they collaborate more *prior to tendering*, not "once the bidder has been selected" (Autio et al., 2003: 51).
- Extensive and frequent interaction is important, however, it is costly for both CERN and the company, and also bad use of resources when it is used to solve problems that could be avoided by *proactively* collaborating to validate technology options.
- Readjustments of project goals during the project may boost learning, yet may also cause delays and cost overruns. The better option would be to act proactively and validate and test technology options *prior to* selection.
- Industry should be involved early on for the *design* of the components in order to take manufacturability and technology options better into account. However, companies should not get involved in the actual *development* activity too early, as it is costly, and can ultimately be exhaustive or even frustrating.
- CERN should consider proactively collaborating with companies that can provide new technologies, also with those new to CERN, in also other than mission-critical technology areas, and they should certainly *not* focus on mission-*specific* technologies. It is mportant to collaborate with companies that are not in HEP business.
- It is very important that CERN maintains and develops its engineering competence and continues to produce technical specifications itself, yet the specs should be *functional*, i.e. describing the wanted output performance, not detailed technical drawings etc. The engineering competence should be used specifically for validation, testing, and piloting of technology options prior to tendering.

While the above discussion was focused on CERN, it has generic implications for all big-science labs. Overall, learning and technology transfer are important; however, if focusing on them alone, other aspects such as the cost and risk are neglected. Maximizing the learning benefits probably does not improve cost-efficiency of the procurement activity. In fact, the promotion of post-tender learning, i.e. intense interaction once the bidder has been selected, easily leads to heavy exploitation of the lab's engineering force. Earlier studies (Nordberg, 1994, 1997) indicate that the lab often provides extensive consultancy (free of charge) to some of its supplier companies. This might also explain why (a limited minority of) firms experience such great benefits from the supply contracts as the above survey study indicates. Naturally, such studies together with the reported benefits are great publicity for the lab. Unfortunately, however, they do not question whether it makes any sense to spend basic research money in such a way. Even if this kind of free consultancy activity were argued for on the basis of its value as technology transfer from the lab to its member state industries, the evidence makes me doubt if this is the most effective mode of interaction with industry, or the most efficient way to use the lab's resources for the generation of

innovation, jobs and new businesses in the lab member states. Experience shows that the companies the lab has to consult the most with are usually the worst off (Nordberg, 1994). At the same time, earlier lab-industry interaction studies (e.g. Ham and Mowery, 1998) indicate that in order for lab to effectively cooperate and exchange knowledge with the partnering firm, the firm also has to be able to absorb and apply the outcomes of the cooperation, and have e.g. the necessary commitment and budgetary flexibility. It is very unlikely that the companies that are worst off have the necessary absorptive capacity to best benefit from the lab's precious technical consultancy. If this is the case, and the research indicates so, the use of the lab's post-tender consultancy for the benefit of its member state industries is far from being effective and efficient use of resources. *Proactive* use of these resources would be more effective and efficient for the lab as well as for the society in general.

7.4 Public procurement

While many of the procurement-specific findings are supported by extant literature on innovation and technology transfer, the study also has implications for the extant theories, guidelines and policy recommendations on public procurement.

First, earlier studies (Rothwell and Zegveld, 1981; Geroski, 1990) suggested that in many areas public procurement is a more efficient an instrument for innovation than the frequently used R&D subsidies. This study, however, came into a conclusion that the most efficient model is to combine public procurement and R&D subsidies to promote innovation. By combining these two, and making them an integral part of the proactive procurement and collaboration model, the innovation benefits could potentially become more significant than by using each of the instruments alone.

Second, Edquist and colleagues (2000), who developed the concept of 'public technology procurement' propose that "new informal rules" should be introduced, and propose the selection of a supplier be "based on its innovative capabilities and abilities to interact, rather than on the basis of a pure price competition" (p. 303). Furthermore, they claim that "borrowing rules from a fundamentally different kind of process [i.e., regular public procurement] and applying it to public technology procurement... advantages are lost" (pp. 302-3, brackets by myself). This study, however, found that regular purchasing procedures could be applied and yet foster innovation. This is true because, first, in the proactive procurement model developed in this study, technologies are transferred from outside applications and users, and thus the basic development and the related costs are carried out by other disciplines or by a wider array of users and buyers, and second, when these radical technologies compete with more traditional ones, they often are also the lowest bidders, simply because innovations tend to change the basis for competition.

Edquist and colleagues (2000) claim that public technology deals with "procurement under uncertainty", as "in practice, ... the final price and quality parameters of new and innovative technologies are unknown at the moment the contract is awarded. This changes the rules of the game" (p. 4). In the proactive model, however, these uncertainties are very much reduced, because the regular purchasing procedures can be followed, and the technology is already well advanced and developed in other disciplines. There is no more development to be done other than the testing and piloting of the technology at the lab, and the company conducting the required application development with the support of government R&D funding that has become available due to the joint collaboration.

The innovation process takes a long time, often up to several tens of years. It might be unrealistic to think that a radical new technology could be developed during a single public procurement process, even if the buyer could wait for several years, which is unlikely. A better strategy could be to use interdisciplinary technologies that are already at a relatively advanced stage but not yet on the market, i.e. at the stage where they also most need external resources and support to get commercialized.

8 MANAGERIAL AND POLICY IMPLICATIONS

The main stakeholders in a public research-industry collaboration project include the associated research organization, government, and industry. All of the stakeholders have different expectations from the collaboration, yet from the innovation point of view they all have something to gain. The collaboration model presented in this study with its focus on matching the research organization and industry needs seem to serve well the interests of all participating parties. The following Table 5 aims to sum the key implications of the research for each stakeholder. These outcomes are triangulated from the point of view of financial, organizational, technological and social facets.

	Research organization	*Government*	*Industry*
Financial	- Cost-efficiency through outperforming technological solutions - Increased manufacturing prospects - R&D costs may partially be shared with the industry	- Member states get multiple interest to their fees paid to the research organization - Possibility to fund well targeted networked projects	- Access to multiple financial sources to support the innovation process - Access to non-cost knowledge networks - Business breakthrough and long-term supply contracts
Organizational	- Informal collaboration needs to be initiated by active technological scanning, currently not in the agenda of the big-science labs - Cultural change is needed, industry is indispensable part of instrument building	- Direct cash flow based measures to assess industrial returns from big-science are not sufficient; cooperation levels, innovation output and other effects should also be measured - Technological liaison activity must be supported	- Enables corporate venturing instead of spinning out radical new businesses - R&D people get access to a wider social and knowledge network - Collaboration projects may take several years, which should taken into account
Technological	- Access to otherwise unknown new technologies - Better performance of or radically new solutions for scientific instruments	- Integrates member state with the technological networks of a wider economic area - National new technologies get additional and necessary development resources	- Access to unique and neutral testing and piloting environment for the innovation
Social	- Significantly increasing the chances of fostering innovation in member states - Enriches social network of the people at big-science lab	- Results in a cost-effective world-class research and catalyses national innovation simultaneously - Strengthens industrial competitiveness and networking	- At best enables innovation to happen and speeds up the innovation process - Companies report significant marketing, motivational and technological learning resulting from the collaboration

Table 5. The implications for the three main stakeholders.

In the following six sections, I discuss some of the managerial and policy implications in detail. I begin with three sections on *policy* implications, of which the first one stems directly from the data and the other two are based on my personal observations and experience along the 10-year-long study. The latter three sections then focus on *managerial* implications. The first two of them are directly based on the research data, while the last one is more experience-based. While all of these issues are highly relevant and closely related to this research, the experience-based ones were not in the focus area or among the chosen units of analysis of this research, and thus not subject to the actual data analysis of this research.

8.1 Implications for policies on procurement

As mentioned in the Introduction, the EU-15 expenditure on R&D in 2001 totaled €175b, of which 25% was devoted to basic research, and of which 10% to intergovernmental labs and projects like CERN and the LHC (EC, 2003b). In the past, most of the research instruments in public labs such as CERN could be developed or produced in-house. The scale and complexity of today's science and engineering projects render this approach unrealistic. Also budget reductions force labs to rely more on collaboration with firms for the development of technologies that are critical to their missions (Ham and Mowery, 1998). Many instrument components are needed in large quantities and new industrial technologies may provide increased performance compared to existing technologies. In general, industrial R&D has increased its importance over public R&D. In many technological areas industry is more advanced than labs in technological development trajectories, and particularly in production technologies.

Labs could benefit from these new technologies through technology procurement. However, experience shows that buying R&D from industry in order to build early prototype versions of the end products can become very costly for the lab. Contracting out for something unknown, yet to be developed, is risky and also expensive (see Paper 4). On the other hand, the incumbent partners are not always the most innovative ones, but just kind of good fellow partners helping lab engineers with their responsibilities for R&D and specification preparation. When applicable, the more economical way to cooperate would be to select partners from disciplines, applications and industries completely other than those familiar to the lab that have new technology, which has not yet reached the breakthrough in those applications and in the originally planned target markets.

Many of these new technological developments, however, are not at all available for labs. Leading companies are not necessarily interested in the lab business: the market is too small; they consider it too specific and narrow without economies-of-scale; and it is also relatively difficult for a newcomer to enter the market. Also the purchasing policies of public research organizations reduce the enthusiasm, as the direct value of supply contracts is not extremely encouraging due to the fact that contracts are normally adjudicated to the lowest bidders.

The small science-specific market, which is difficult to enter and highly competitive, is perceived as non-attractive to new and world-leading companies to contact the laboratory, still less to invest their time and resources in building a long-term relationship with it. Top-down directives and policy recommendations to public organizations do not help if most of the new technologies are eventually not at all available to the labs. And even if they were, buyers may resist their purchase because of the risks involved with new technologies. For example, the European Commission's recent directives (2004/17/EC, 2004/18/EC), as well as guidelines and handbooks in preparation (EC, 2005; Fraunhofer Institute, 2005; Wilkinson et al., 2005) are well-intended, but if the procurement process remains reactive (i.e., not proactive), the best potential partners and

innovations may remain out of reach, and furthermore, the risks and cost in the procurement will remain an issue.

Although there are no easy solutions, the evidence shows that proactively involving interdisciplinary technologies in industry and seeking collaboration with it could overcome these problems without the lab being obliged to change its purchasing procedures based on price competition. The proactive procurement model developed here assimilates industrial technologies of other disciplines, matches the innovation needs of both the company and the lab, validates the technology through pre-tender testing and piloting by the lab engineers and within its partner network, and applies the regular purchasing procedures and pure price competition. The pre-tender technical collaboration also attracts R&D funding from member state national technology agencies, which further encourages mutually beneficial collaboration. The research organization benefits from the cooperation through access to cutting-edge technologies at low cost and through manufacturing prospects, which together introduce an optimum performance to cost ratio into research projects. At the same time, the cooperation generates meaningful social practice and input into industrial innovation and new business creation. This model is particularly powerful for the advancement of radical innovations, which typically emerge at the interface of disciplines in social networks.

In this manner, a major part of the billions of dollars devoted annually to the labs and their procurement could directly be used to foster innovation and venturing, while at the same time the lab could use new technologies and increase its research instrument performance (i.e., improved performance per cost). Alternatively, significant amounts of money could be saved (i.e. lower cost for the same performance), while the lab continues to have a similar impact on industrial innovation. From the lab perspective, if we take the example of CERN, the first option in practice would mean more powerful and reliable accelerator machines and thus more scientific outcome and discoveries and more time for research, and the latter in practical terms would mean decreased levels of external bank loans needed for the construction of the LHC complex.

Member States and funding agencies should encourage labs to implement proactive interdisciplinary technology procurement practice in their labs. Procurement should be taken into consideration in strategic level science and technology policy-making. For example, countries developing their national big-science strategies (currently e.g. Canada, see Office of the National Science Advisor, 2005) may consider proactive procurement as an integral part of the overall big-science strategy in order to actively stimulate innovation that would benefit both the national innovation system and the lab. Based on the evidence reported in this dissertation, I propose the following detailed policy recommendations on proactive procurement:

- procurement procedures based on the price competition should be retained, yet only when combined with *proactive* elements such as the active search and assimilation of technologies developed for alternative purposes and uses, and the thorough testing and piloting of technological options prior to tendering.
- For the technology-intensive suppliers, the lab can generate significant innovation benefits, yet the learning and innovation outcomes may be better if the lab collaborates with the potential suppliers *prior to tendering*, not once the bidder has been selected. Proactive collaboration helps validate technology options and significantly reduces the need for post-tender technical consultancy from the lab.

- Readjustments of project goals during the project may cause delays and cost overruns. The better option would be to act proactively and validate and test the most potential technology options *prior to* selection.
- Industry should be involved early on for the *design* of the components in order to take manufacturability and technology options better into account. However, companies should not get involved in the actual *development* activity too early, as it is costly, and can ultimately be exhaustive or even frustrating for the firms, and in any case, does not guarantee success in tendering.
- The lab should consider proactively collaborating with companies that can provide new technologies, also with those new to the lab, in also other than mission-critical technology areas, and they should certainly *not* focus on mission-*specific* technologies. Important is to collaborate also with companies that have previously not been in big-science and scientific instrumentation market.
- It is very important that the lab maintains and develops its engineering competence and continues to produce technical specifications itself, yet the specs should be *functional*, i.e. describing the wanted output performance, not detailed technical design. The engineering competence should be used specifically for validation, testing, and piloting of technology options prior to tendering.

Overall, learning and technology transfer are important; however, if focusing on them alone, other aspects such as the cost and risk of technology development and procurement are neglected. Maximizing technology transfer benefits probably does not improve cost-efficiency of the procurement activity. In fact, intense interaction after the bidder has been selected easily leads to heavy exploitation of the lab's engineering force. While it may generate great publicity for the lab, it is certainly not good expenditure of research money. Even if it were argued for on the basis of its value as technology transfer from the lab, it may not be the most effective mode of interaction with industry, or the most efficient way to use the lab's resources for the generation of innovation, jobs and new businesses in the lab member states. Proactive use of these resources is more effective and efficient for the lab as well as for the firm and the member states.

8.2 Implications for policies on TTOs and other intermediary services

Bozeman and Papadakis (1995) argue that "perhaps much of the commercial relevant work of [federal] laboratories has not been captured with the term *technology transfer*" (p. 65, brackets added). Despite increasing policy interest in the 'one-way' technology transfer and associated pressure to show results from the technology transfer activity, labs and policy-makers may consider possible new uses of their scarce commercialization/promotional resources other than the traditional technology transfer alone. In most cases, the initiation and facilitation of strategic and informal expert-to-expert collaboration could be more fruitful for all parties of the 'Triple Helix' instead of investing resources into the traditional technology transfer activity that, according to Bozeman (2000), tends to be "as active in publicizing their technology transfer and economic development activities as in actually doing the transfer work" (p. 648).

Earlier research argues that "most industry-lab ties result from types of personal connections that cannot be orchestrated" (Bozeman and Papadakis, 1995: 71). However, the new mode of collaboration discussed in this dissertation can and should be initiated and orchestrated by a third party, as it, by default, concerns technologies and firms that are new to the lab. An independent business-oriented body within or outside the lab would do the job.

Policy-makers' interest in all technology transfer activity and the consequent pressures for quick outcomes may result in counterproductive actions. In the cases studied, the research lab 'stole' two of the case companies' ideas and started to develop them on their own. Technology similar to that developed in industry that was *not* critical to the lab was patented by the lab and then made publicly available for sale. Also extant research shows that intellectual property issues are among the most significant barriers to receiving benefits from research centers (Feller et al., 2002; Rogers et al., 1998). Policy-makers and labs should investigate the real benefits –as well as possible drawbacks- of the traditional technology transfer activity, and consider also other, possibly more productive forms of promotion work needed to advance collaborative and mutually beneficial forms of interaction, forms which also seem to better match industry motivations and needs (Bozeman and Papadakis, 1995; Feller et al., 2002).

Furthermore, in accordance with Roessner (1993), policy-makers, instead of pushing labs to develop products and trying to commercialize them, could make better use of such funding if they "fund industry directly to develop technologies that can eventually get commercialized faster through industry's own labs" (p. 40). The results of this dissertation are also in line with Roessner's other statement, i.e. that the most effective and most efficient posture a lab can take is to address its mission, and also make its work well known to industry, even if it has to spend tax payers' money for the latter. The cases show that mutually beneficial collaboration, promotion of industrial innovation, and effective and efficient procurement are possible if the lab simply focuses on its basic mission. No commercialization activities are necessarily needed. In CERN's case, any commercial activity does not even fit its mission and its values based on fundamental physics research of which the results are available to all.

On the other hand, Roessner's (1993) conclusion that if "labs and industry are to engage in mutually beneficial interactions, those interactions should be company-initiated" (p. 41) may be right in most cases of interaction and at least those he has studied. However, it seems that neither companies nor labs are able to initiate the specific form of collaboration discussed in this dissertation. More research is needed to further investigate and clarify the crucial third party role. Roessner also proposes that industry should participate in "setting priorities" of and "planning and conducting" the lab research. Again, this might be applicable to most of federal labs, but in the case of CERN and other basic research labs, it is not a good idea. While one of the implications of this dissertation also is that industry should participate in the scientific *instrument design* early enough in order to save costs for instance in manufacturing, industry should certainly not (neither is capable to) guide *basic research* e.g. in the field of fundamental physics.

In any case, the CERN Technology Transfer Office (TTO) was not generally involved in the studied cases. It did so only in one case, and this involvement was mainly negative in terms of IPR conflict discussed above. In general, many studies (e.g. Ham and Mowery, 1998; Rogers et al., 1998; Byckling et al., 2000) have reported that complicated administrative procedures and lengthy time periods to establish agreements, including IPR, are a major or even the primary obstacle in the initiation of interaction with research labs. Logically, this would be even more annoying or harmful for small companies and ventures. Thus, again, this unpurposely favors large companies over small ones. One of the findings of this study also was that administration is to be avoided when possible. The collaboration should start informally and directly between experts of both parties.

Research organizations and policy-makers may need to rethink the role of the TTOs. TTOs might be more vital in searching for new technologies and partners in industry than trying to

commercialize lab-based technologies. Earlier assessments of technology transfer activities and efforts support this. For instance, Harmon et al. (1997) did not provide "any evidence that the successfully completed technology transfers made any substantial contribution to either new business creation or the generation of new jobs" (p. 424). Bozeman (2000) also summarizes his review of the technology transfer literature by stating that "there is little direct evidence for federal laboratory-industry partnerships as a wellspring of jobs or new businesses" (p. 647). Harmon et al. (1997) conclude that public policy and efforts of technology transfer agencies may need to shift their emphasis from facilitating "search and shopping for a technology" (by organizing and/or paying for "publicity") to providing assistance in network building and relationship marketing efforts (p. 424). They also found that, in reality in university-industry collaboration, universities often play the role of assisting in refinement or testing of technologies initially developed by private companies.

Earlier studies (Ham and Mowery, 1998) show that despite extensive (and expensive) efforts to promote technology transfer from research to industry, the most successful forms of interaction may be those focusing on projects for which the research organization is a major *user*. In this role, research would be the 'recipient' rather than the 'agent'. These forms of interaction include, for instance, 'contract research', which is performed by industry and paid for by the lab, and the type of 'cooperative research' focusing on co-development of technologies for which the lab is a user.

8.3 Implications for policies on government R&D subsidies

New technology-based teams developing new businesses that radically depart from the mainstream businesses, face difficulties not only in start-ups or SMEs but also in large corporations. Commercialization of radical technologies and the development of radically new businesses is challenging even for large leading firms with skilled management and great resources. Public R&D funding and innovation support, which also played an important role in the studied cases, should not make a distinction between small and large companies but should focus on viable *radical* projects in all kinds of companies. Incremental product development usually does not need public support, as funding for such customer-driven development is easily found internally in the company. Radical projects, however, require external resources, irrespectively of the size of the company.

Using the evolution model presented by Paper 1 (see also Fig. 3 in Chapter 6), the Figure 5 below illustrates the evolution of a knowledge intensive new technology-based innovation with respect to potential partners and funding sources during the commercialization process. As said above, this is valid no matter what is the size and type of the company. Public funding is needed for new technology projects, no matter whether in small or large companies. Public R&D funding is also an essential part of the mutually beneficial collaboration model and the proactive procurement model.

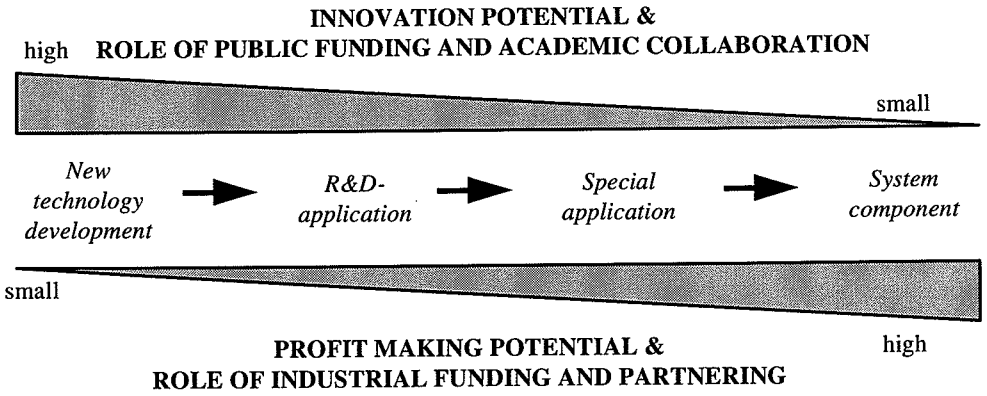


Figure 5. The evolution of a knowledge intensive new technology-based innovation with respect to potential partners and funding sources during the commercialization process.

8.4 Implications for lab management

Public research, including basic research, has a significant role in new technology-based industrial innovation and new business development. The lab's successful contribution to innovation and business creation in the economy has a positive impact to the lab in terms of visibility and public relations. More important, it also has a *direct effect in saving costs*. Innovations tend to solve technological problems in the most cost-effective way. Labs should thus be open to *new* partners and technologies and encourage and help them initiate partnerships with the lab.

In order to maximize cost savings, labs should focus on new-technology ventures with target markets outside the research lab so that the new technology is not primarily transferred to the lab in order to be commercialized but to help with the venture's trajectory to end markets. There is no need to change financial rules, official tendering procedures, or the mission of the organization. The only requirement for the research organization is to be flexible enough to be ready to replace some of the established partners with *new technology ventures* and emphasize *informal testing and piloting collaboration* prior to formal tendering and contracting.

The resulting practical recommendations for labs are the following:

- *Win-win projects*: Labs need to initiate and coordinate win-win collaboration projects with companies and their venture projects that develop promising radical technologies. Intergovernmental organizations should encourage cooperation with member states and their national innovation systems. Experienced technology and business broker services might be required to initiate and coordinate win-win projects.
- *Cultural change*: Lab management needs to drive cultural change within the lab to encourage informal collaboration with industry during R&D and to actively search for radically new technologies that are unfamiliar to the lab. "Not invented here" should be regarded positively among lab engineers and scientists.
- *Training*: The lab needs to organize training for key project engineers and buyers on the principles of win-win cooperation and proactive procurement, as well as on the practice of technology search, matching of needs, and on cross-functional teamwork for production aspects.

- *New metrics*: Lab management together with Member State delegates or other lab funding agencies should design and introduce new metrics for industrial return to motivate lab staff as well as Member States to use proactive procurement. This could be facilitated by the "indicator selection process" (Ojanen and Vuola, 2006), or similar, which is based on the mission and strategy of the lab, and considers all the relevant dimensions of performance measurement.
- *Public relations*: The lab should communicate its role in industrial innovations by organizing press conferences locally in Member States. This could result in significant indirect benefits to the lab in terms of public relations, visibility and sustainable funding, but especially to the partner companies commercializing their new technologies through increased visibility and valuable references.
- *In-house engineering*: Instead of outsourcing, labs should retain and further develop their project engineering and project management functions in-house. Labs should not use large prime contractors in R&D and instrument construction, but rather split the instrument design into sub-components, and then bundle all similar items across all sub-components and purchase them in larger quantities (unbundling and bundling). These are essential prerequisites for attracting interdisciplinary technologies from industry and thus also accruing all the benefits they can provide.

8.5 Implications for venture teams and R&D and business development managers

Ventures may consider actively seeking collaboration with public research centers and labs. The evidence indicates that, when well managed, collaboration with a research center may provide the company and its new business and product development with major elements needed for the new technology to become innovation and the new business initiative to become an established business: testing facilities, laboratory equipment, test procedures and results, pilot users, user feedback, and specialized technical expertise. In addition, the collaboration may indirectly attract additional public R&D funding, which, while not directly provided by the research organization, is attracted by the fact that the venture collaborates with public research. Third, research, especially in case of big science, may also provide an initial market and meaningful use for the technology and the first breakthrough contracts as well as references that are valuable in the general market place, in relations with strategic partners, and also internally within the parent company or corporation.

8.6 Implications for corporate management

Corporate management should allocate resources to radical initiatives even if they do not necessarily serve the existing customers of the mainstream business. New technology-based business development and venture projects should be provided with sufficient independence from the business models and practices of the surrounding mainstream microenvironment, and provide the venture with continuous basic funding. The funding does not need to be excessive, quite the contrary, as modest resources may drive the venture to seek external complementary resources and collaboration with public research, which then accrues multiple benefits to the venture, and may also lead to its breakthrough into profitable business. External complementary resources and collaboration with research is thus recommended, and surprisingly, especially toward the *end* of the innovation process and new business creation, and also with *basic research.*

9 CONCLUSIONS

As presented in the Introduction, the objective of this dissertation is to address the following research questions:

1. How could new technology companies and ventures *systematically approach and use* a big science lab for product and business development purposes?
2. How does the big-science lab operate as a *source of complementary outside resources* for new technology-based companies and emerging businesses?
3. What is the *collaboration mechanism* between the large research organization and a new supplier candidate from the very moment they start to interact?
4. How could public research organizations meet the challenge of *managing costs and risks of technology development and procurement* while also enabling industrial innovation?

As mentioned in the Introduction, the Research Papers discuss each of these questions from different perspectives. In the following, I synthesize their contribution to each of the questions. The aim is to be critical and constructive, reflect on the applicability of findings, and provide directions for future research.

9.1 Research question 1

The first question was addressed by Research Papers 1, 2, and 3. Paper 1 dealt with the approach issue, i.e., how to "introduce new technology to a complex research environment", while Papers 2 and 3 focused on the use of the large research center for the development of new products and new business, respectively. Earlier supplier surveys had indicated that there are multiple benefits to CERN supplier companies, and also have quantified these benefits, yet it was not known how to accrue them systematically. This study indicates that a systematic approach seems to be viable.

In this approach, it is essential to understand the possible applications and implications that the new technology shares when implemented to replace conventional solutions. The big science center as a potential user and customer of the new technology with the related technological domains is then systematically mapped to establish technological trajectories, which overlap with the possible applications. This mapping provides the framework for detailed application analysis with pointers to the right engineers, experts, and project managers responsible for the potential application area. The big science lab, however, cannot be "used" of "exploited" without serving the mission of the lab, i.e. particle physics in the case of CERN. Mutually beneficial collaboration is necessary, and it has to be based on the development needs of both sides. The starting point is the matching of these needs. This mutually beneficial collaboration may also generate significant innovation and cost benefits to both parties.

9.2 Research question 2

The second research question was addressed specifically by Paper 3. The study indicates that, through collaboration with a big-science center, a small venture company may grow into a new

business with the help of a set of complementary resources directly and indirectly accrued from business-oriented partnership with the research center, in particular when combined with the meaningful use within the practice of center's complex social network. These resources include testing facilities, laboratory equipment, neutral test results, specialized technical expertise, as well as long-term pilot use and valuable user feedback. Furthermore, the external resources may also include additional national R&D funding that, while not directly provided by the research organization, is indirectly attracted by the fact that the company collaborates with big science.

In addition, big science may also provide an initial market and breakthrough supply contracts, as well as references that are valuable on the marketplace and in relations with strategic partners and other big-science stakeholders, which can be explained by the concept of innovation as 'meaningful use in social practice': first, a 'social practice' in terms of users and testers of samples, prototypes, and end products at the big-science center and within its partner network; and second, this use is also 'meaningful' in terms of the high reference value, and also in terms of many leading engineers, scientists and partner laboratories that were involved in the project. This 'meaningful use' of the new technology in the big science setting is not merely about big science acting as a market or a customer as in a classical business-to-business (B2B) relationship, as big-science know-how, expertise, pilot use and laboratory facilities on the site and within its partner network, together with its reference value, are potentially unique compared to company's usual B2B customers.

This finding is important, because the evidence indicates that big science may provide ventures with the necessary step to overcome the difficulties related to commercialization. It is well known that commercialization of novel technology is challenging. Venture teams typically lack necessary support, competence and resources to achieve commercialization. Decreased or limited internal support drives companies to seek for and rely on external sources of complementary assets, including also public research labs. However, systematic use of big science, especially big-science basic research, to provide the venture with necessary resources has clearly been understudied.

The study in Paper 3 was limited to a single case. However, Paper 2 (and also Vuola, 2006a) preliminarily provided similar results based on a multiple-case study. Naturally, we do not know what would have occurred to the case company without its cooperation with CERN. If the resources it invested to the CERN collaboration project were used for other purposes, what the outcome would have been? The company itself regarded the CERN collaboration as very significant and ultimately as a breakthrough case for the new technology and the venture, yet we do not know other possible trajectories in case the collaboration would not have taken place. Future research could include comparative data on firms in similar development situation yet alternative trajectories and collaborations. However, each innovation is a unique case, and also a step change situation in the case of radically new technology, full understanding of the determinants would require real-time participation in the innovation process.

In any case, there are limitations to (or requirements for) the company to be able to fully benefit from the complementary assets and meaningful social practice that big science may provide for its partners. The company, naturally, has to be in a situation in which it actually needs outside resources and social context. Those that are most in need are companies, venture teams, business development teams, and such that have initiatives that are radical compared to mainstream business models and products. It is not so much about the size or type of the company or venture team, it is more about the radical nature of the initiative and the resulting internal resistance and

limited internal support that pushes it to seek for complementary resources and users outside its usual context. Hence, the results are limited to companies in such situations.

9.3 Research question 3

The third research question was addressed by Paper 2 and from a broader business development perspective by Paper 3. The main objective of this research question was to increase our knowledge of the pre-tender developments between a large research center and a supplier company. Earlier studies having focused on supply contracts and research center-supplier interaction "once the bidder has been selected" (Autio et al., 2003: 51), pre-tender collaboration had not been studied earlier. This study provides a model for a specific case of pre-tender collaboration mechanism based on the needs of both the "research organization" and the "supplier candidate".

While limited to these specific cases, the process that they use is the regular technology validation process the research center applies to all new technology. In this respect, the detailed longitudinal real-time data on these pre-tender mechanisms contributes to our knowledge on these mechanisms. There are naturally differences in preferences across individual engineering and project teams within the research center; however, they all follow a similar procedure to test the capabilities and characteristics of a proposed technology or firm that is new to them. In all of the studied cases, there were already other technology options existing and well advanced when the new technology was proposed to the lab engineers. Hence, initially, the procedure was a routine test procedure to verify the true potential of yet another option.

Equally important, however, is the development of a mutually beneficial joint innovation process between the parties. In cases that are based on the needs of both parties, the company new product development (NPD) process merges into the big-science development process during the phases of prototype development and testing and piloting. It is assumed that these phases are the most fruitful phases for such collaboration. This also means one should look at new technologies in the industry that are in the prototype phase or latest in the testing and validation phase. On the other hand, the big-science instrument development sub-project should simultaneously be undergoing the same phases. The perfect match is thus the right match of the needs, timing, and people. From a long-term perspective (Paper 3), the big-science center naturally is just one partner among others along the overall technological trajectory. Its role in the overall technology development effort may not be significant at all. However, from a product development perspective (Paper 2), such as the end of the overall innovation process, it may be significant, as discussed above.

While the study was limited to CERN, technology validation procedures conducted by engineers tend to be similar in various organizations, not only in research organizations. New application areas could include other large-scale projects that need new technologies, e.g. those in the aerospace industry, defense sector and energy production. Furthermore, with some modifications, the mutually beneficial collaboration model could possibly be applied to governmental and international humanitarian aid and development funds. Instead of mere "one-way" aid, they could provide new technologies through mutually beneficial collaboration so that national innovation systems in both developed and developing countries would "win": The developing nations would get more than before, due to the fact that Western industries would be motivated through benefits accrued to their innovations (see Vuola, 2006d, 2006e, for preliminary concepts). I recommend future research in these new application areas.

9.4 Research question 4

The fourth research question was the central theme of Paper 4. It has long been proposed that public procurement be used as a tool to stimulate and enable innovation. Earlier concepts imply the purchase of something yet-to-be-developed, which, however, by default increases the potential for risks and additional costs. So far, it has been unclear how innovation-boosting technology procurement should be managed in practice. The cases studied in this dissertation provide a rare set of long-term data on several experimental public procurement cases. Based on the above mutually beneficial collaboration model, the study develops a model called *proactive procurement* that deals particularly with the issues of risk and cost management of the purchase of new technology. This model applies regular public purchasing procedures incorporated with two additional and new, yet essentially inherent, components of proaction to meet the challenge of managing cost and risk while also enabling innovation: *Interdisciplinary technology*, i.e. active search and assimilation of new technology developed for alternative purposes and uses, and matching it with the needs of the lab; and *Pre-tender collaboration*, i.e. thorough testing and piloting of technological options prior to tendering. The lab takes advantage of new technologies that are at the prototype stage having not yet reached their breakthrough on the market. The company greatly benefits from the testing and piloting and provides the technology as test samples for validation. The lab does not need to buy technology or R&D at this point.

In addition, as the innovative use of interdisciplinary technology potentially changes the basis of competition, regular purchasing procedures and conventional price competition can be applied. Substantial savings may be generated compared to the conventional solutions that labs would normally use. Furthermore, the proactive testing and piloting decreases the uncertainties typically involved in the purchase of new technology. Thorough testing and piloting of the technology familiarizes the lab with the technology already prior to tendering and contracting. This occurs simply through the lab's regular daily R&D and project work procedures.

The applicability of this model might be limited mainly to research organizations alone, which is also the scope of the research question. However, other public organizations use similar purchasing procedures, and the model could be applicable to technology procurement in general (Vuola, 2005, 2006c). Essential is that the buying organization can meet the 'prerequisites' of the model (see Paper 4). I recommend future research in all possible new application areas.

9.5 Future research

The data collected for this study during several years and on several innovation processes have potential for multiple further case studies, even more so when combined with appropriate additional data sets. I would suggest, for instance, the following studies:

- Using the given data for a detailed comparative case study contrasting the successful and unsuccessful innovation and business development cases. This could potentially provide new knowledge in the areas of technological innovation processes, new technology commercialization, and corporate venture creation. Moreover, it could be highly useful especially for corporate venture teams and corporate management struggling with their new business initiatives and technologies that depart from their mainstream businesses.

- A study comparing various kinds of customer partners as testing and piloting platforms, for instance, a comparison between a big-science center (CERN) and an industrial company as

customers partners for new technology commercialization and new business creation. For instance, the former might be more suitable for radical projects, whereas the latter be better for more incremental projects. Such study could further provide strategic options to catalyze and manage radically new industrial innovation and business development.

- A conceptual study on new technology commercialization as a process of matching the user needs and the supplier needs (versus matching of supply and demand), as this dissertation also proposes. Such study could provide a new economic model for the specific case of new technology commercialization. Attempts to apply the dominant supply-demand model to such cases may be the reason why R&D and venture teams lack the support, competences, resources, or corporate culture, structure and processes necessary to achieve commercialization, as the Introduction indicated.

- A study on metrics based on the "indicator selection process" or similar that starts from the mission and strategy of the lab, and considers all the relevant "dimensions" of performance measurement (see Ojanen and Vuola, 2006). As proposed by Paper 4, labs need to introduce new metrics for the so-called 'industrial return' in order to motivate the lab staff as well as governments to implement mutually beneficial collaboration and proactive procurement. The proposed study may help find such metrics and facilitate their introduction.

Finally, any future implementation of the developed collaboration and procurement model to new application areas will provide a great opportunity to collect rich longitudinal case data on the implementation itself and the use of the model that can then be examined in real time and retrospectively. Such research will shed new light on the collaboration and procurement model, and provide necessary adjustments to them especially when applied to contexts other than that of a big-science basic research lab. Such research would hopefully also change practice and improve cost efficiency of public procurement while also enabling technological innovation in our industries. Both of these issues are of utmost importance within our societies at this very moment.

APPENDIX. LIST OF ALL PUBLICATIONS AND PRESENTATIONS

All of the papers published and presented during this research are listed below in chronological order.

1. Using basic research as a catalyst to exploit new technology based innovations -a case study. *Technovation* 16(1) 1996, pp. 531-539 (with Hameri, A-P.).
2. Categorizing the Measures and Evaluation Methods of R&D Performance –A State-of-the-art Review on R&D Performance Analysis. Working paper 16, 2003, *Telecom Business Research Center Publication Series*, Lappeenranta University of Technology, Lappeenranta (with Ojanen, V.).
3. *Managing disruptive technological change in large companies – the role of national and international innovation networks.* Working Paper, December 15, 2003, accepted for the IAMOT 2004 Conference.
4. Managing globally distributed expertise with new competence management solutions –a big-science collaboration as a pilot case. *The Proceedings of the ISPIM Conference*, June 2003, Manchester, UK (with Koivula, T., Livan, M., Nordberg, M., Salmia, T., Ferguson, J.).
5. Systematic use of big-science collaboration to catalyse industrial innovation –a case study. *The Proceedings of the ISPIM Conference*, June 2003, Manchester, UK.
6. A Framework of Industrial Knowledge Spillovers in Big-Science Collaborations, *Research Policy* 33 (2004), pp. 107-126 (with Autio, E. and Hameri, A-P).
7. *Win-win cooperation for innovation.* Report to CERN. Geneva, December 14, 2004.
8. *Challenging conventional technology transfer: New technology from industry to basic research to foster new business creation.* Technology Transfer Society Annual Conference, September 30, 2005, Kansas City.
9. *Innovation, New Business and Learning through Reverse Technology Transfer and Win-win Collaboration – the case of CERN.* Presentation, Research Value Mapping (RVM) Seminar, September 27, 2005, Georgia Tech School of Public Policy, Atlanta.
10. *Proactive interdisciplinary technology procurement.* Association for Public Policy Analysis and Management APPAM, the Fall Conference, November 3, 2005, Washington, D.C.
11. *Radical new business and public resources.* Working Paper, November 14, 2005.
12. Big science as a catalyst of new business development, in Elias G. Carayannis and Piero Formica, *Knowledge Matters: A Networks and Clusters Perspective from the US, Europe and Asia*, MacMillan Press, to be printed in Fall 2006.
13. *Collaboration for innovation that mutually benefits Western industries and Africa.* Working paper, accepted for a live panel presentation at the "Business as an Agent of World Benefit: Management Knowledge Leading Positive Change" Global Forum, Case Western Reserve University, October 22-25, 2006.
14. *Collaborative Ventures with Big Science: How Companies Use CERN for Business Development.* Oral presentation at the 2006 Annual Meeting of the Academy of Management "Knowledge, Action and the Public Concern", August, 2006.

15. Coping with the multiple dimensions of R&D performance analysis. *Int. J. Technology Management* 33 (2/3), 2006, pp. 279-290 (with Ojanen, V.).
16. *Developing an Implementable Policy for Innovative Procurement – CERN as a Pilot.* Accepted for the Atlanta Conference on Science and Technology Policy 2006 "US-EU Policies for Research and Innovation", May 18-20, 2006.
17. *How Science Can Foster Innovation by Saving Money.* Presentation at the 2006 Annual Meeting of the Academy of Management "Knowledge, Action and the Public Concern", August, 2006.
18. Mutually benefiting joint innovation process between industry and big-science. *Technovation* 26(1), 2006, pp. 3-12 (with Hameri, A-P.).
19. *Using the Birthplace of the World Wide Web for Technology Commercialization and Business Creation.* Working Paper, April 29, 2006.
20. *Western industries and developing countries as equal partners for radical innovation.* Working paper, accepted for presentation at the 2006 Technology Transfer Society Annual Conference "Next Generation Innovation: New Approaches and Policy Designs", September, 2006.

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