Mutually benefiting joint innovation process between industry and big-science

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Abstract

This longitudinal study is based on nine in-depth case studies carried out over the past nine years, entailing observation of and participation in the actual innovation processes taking place at the interface of big-science-industry cooperation. The resulting mutually benefiting innovation model integrates industrial and big-science R&D at moments when they best catalyse technological innovation processes by matching specific needs from both sides and facilitating their joint efforts during the cooperation. The big-science centre being CERN[*] with its multiple skills, diverse assets and technology validation practices generate, when needs from both sides are clearly defined and well coupled, a most fertile ground to enable and boost industrial innovation. The big-science centre benefits from the cooperation through access to cutting edge technologies at reasonable cost 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 and new business creation. 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 and people as well as timing. The research documented in this report complements previous research efforts by providing detailed recommendations to all parties present in big-science collaborations, namely the big-science centres, member state policy-makers and industry experts and managers.

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[*] CERN, the European Laboratory for Particle Physics, 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.

1. Introduction

Several studies have documented the important role universities and other academic institutions have on technological innovation (SAPPHO, 1971; Mansfield, 1991; Pavitt, 1991; Bozeman, 2000; Shane, 2002). Along this research tradition increased interest has been directed to study the impact of big-science centres on technological innovation, learning and other spill-over effects (Brendle et al., 1980; Bach et al., 1988; Schmied, 1977; Bianchi-Streit et al., 1984). Since these seminal studies, research on the use and usefulness of major experimental basic science laboratories as sources of innovation and means of catalysing industrial innovation have increased significantly (Hameri & Vuola, 1996; Nordberg, 1997; Autio et al., 2003, 2004). This present study contributes to this tradition by documenting participative research on how companies can catalyse new technology-based innovation processes through systematic big-science collaboration, while also providing the big-science laboratories with necessary means to achieve their technologically challenging instruments at reasonable cost.

In the past, most of the instruments in high-energy physics (HEP) laboratories such as CERN could be developed or even produced in-house. The scale and complexity of today's HEP projects render this approach unrealistic. Many instrument components are needed in large quantities and new industrial technologies may provide increased performance compared to existing technologies and thus are desperately needed for the never ending scientific quest for new discoveries. In this study the phrase "new industrial technology" refers to technologies that are new to the market, and they are being developed by the industry. They may have different origins (universities etc.) but are now hosted by industrial companies, thus they are also new to HEP.

These new technological developments, however, are not always available for HEP or other big-science. Technology companies are not necessarily interested in the big-science 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 big-science market. Also the purchasing policies of international research organisations may 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. This leads to a consequence that the small big-science-specific market, which is difficult to enter and highly competitive, clearly does not attract new and world-leading companies to contact the big-science centre, still less to invest their time and resources in building a long-term relationship with it. This situation leads to the following research questions:

- *How to attract* new technologies and best industrial partners?
- How to *motivate* them for a long-term and/or goal-oriented cooperation?
- How to work with them without increasing the *cost* of the scientific instrument?

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, 2003). According to the same statistics, about 25% of all R&D was directed into basic research, of which about 10% was channelled to intergovernmental research projects. This leaves about €4b for major big-science laboratories (the umbrella organisation for some of the big-science laboratories can be viewed at http://www.eiroforum.org/), which use on average some 25% of their budgets on purchases, making it a market equalling €1b. By using CERN as a benchmark, some 50% of the purchasing budget is used on technology intensive components and instruments (Autio et al., 2003). 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. But, 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 to achieve its goals. This leads to a conclusion that the above-stated research questions are highly relevant, especially as the literature survey will show that most of the radical industrial innovations tend to fail.

The rest of the paper is organized as follows. First, we briefly discuss the methodological issues and describe the sample used for the study. Then the literature review is presented leading to the development of a generic innovation model on how to link industrial innovation process with big-science activities. The model is then tested with case studies leading to detailed practical implications, guidelines and recommendations for big-science centres, policy-makers and industry managers. Conclusions and limitations of the study as well as the agenda for future research are discussed at the end of the article.

2. Sample and methodology

The underlying big-science centre in this study is CERN, the European Laboratory for Particle Physics. CERN is currently undertaking major engineering and construction effort to complete the Large Hadron Collider (LHC) project by the end of year 2007. Once ready this accelerator with 28 kilometres of circumference will be directing 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. The LHC project has been ongoing the past ten years and is currently well advanced to the implementation phase. The project is a manifestation of most diverse collaboration between academia, public authorities and industry. The technologies involved cover practically almost all fields of engineering and in many cases these technologies are stretched well beyond the conventional limits. CERN supplier base holds more than 10.000 companies that have supplied the organization. The cheer size and scale of CERN’s activities provide a unique environment to initiate and study the actual innovation processes taking place at the interface of big-science-industry cooperation.

This article is based on a longitudinal experience-based study on industrial innovation and CERN. Since 1995, nine CERN-industry cooperation projects have been studied using a combination of an in-depth case study method, participative experimentation and retrospective interviews (Yin, 1994; Toulmin and Gustavsen, 1996; Reason and Bradbury, 2001). Participative research experiments were conducted to find answers to the above-listed *how* questions. The experiments focused on companies or new businesses with unique technologies that were not known to CERN before their introduction, nor did the companies consider CERN as their possible partner to develop and commercialize their innovation. Without external intervention the projects would not have unfolded the way they did, which means that the model that will be presented after the literature survey was tested by actively intervening the innovation process. Thus, the focus is on establishing mutually benefiting cooperation through third-party match-making between industry and big-science. Further on, the aim is to document how to conduct this kind of matching activity, which differs from the traditional technology transfer activity associated with big-science laboratories with tender dissemination, licensing and general networking with outreach activities. The case companies and their projects with CERN cover a large spectrum of technologies:

- materials technology
    - production technology based on metallurgical processing;
    - production technology using composite materials;
- microelectronics
- efficient production technology for power electronic devices
- nanotechnology

- heavy-duty robotics
- instrumentation and measurement technology
- information technology

Companies involved with these technologies vary also in size and maturity. The sample holds large multinational companies, but also small companies with few years of operating history. For the sake of confidentiality company names and their basic information is not documented here. Also details of the concerned technologies are not disclosed, as their uniqueness may already reveal the case company. Yet, these omissions are not hindering the documentation of the essentials of the match-making and the resulting innovation processes. One of the authors worked over nine years with the projects as a third party expert and consultant. Detailed records, interview notes, emails and other business related correspondence on the projects have been stored to make in-depth longitudinal study possible. This article is part of a research work aiming to a doctoral dissertation.

3. Innovation process – literature review

At the conceptual level, new technology innovations are often divided into two categories (Rice et al., 1998; Garcia and Calantone, 2002):

- *Incremental* (continuous) innovations are product improvements or new products that are, when the R&D is correctly managed, based on recognised customer needs. Most of the industrial R&D falls in this category of innovations.
- *Discontinuous* ("radical" or "really new") innovations are new to the market and do not address any recognised customer demand. They may 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 organisation hosting and developing the technology (Freeman and Soete, 1997). Radical innovation is always based on new technology (Garcia and Calantone, 2002). In industrial companies, systematic processes are applied to get the most out of the R&D investments. These processes are called "stage-gate" or "new product development" (NPD) processes. They emerged 50 years ago and they've been highly popular ever since (Johnson and Jones, 1957; Cooper, 1988; Griffin, 1997). A typical NPD process based on the stage-gate approach is illustrated in Fig 1.

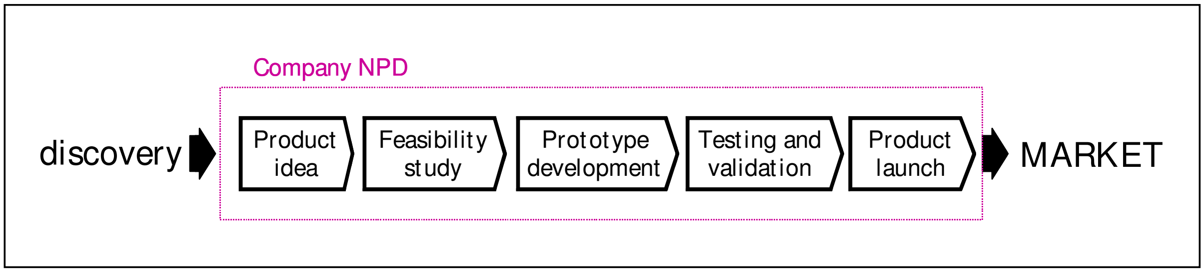


Figure 1. A typical new product development (NPD) management process.

The NPD process starts with an idea for a new product or business, which is then managed typically through five phases (stages) and decision points (gates) and is finally launched onto the market. It should be noted that the NPD process helps in *managing* R&D; it does not try to explain how innovations emerge. The starting point is a business idea or a new product idea. In the case of new technology and discontinuous innovation, several technology trajectories and many years of development and research typically precede NPD, i.e. before the product-oriented development starts (O'Connor et al., 2002; Veryzer, 1998; Hameri and Vuola, 1996; Dosi, 1982). Despite systematic NPD, industry often fails in its attempts to commercialise new technologies (Christensen, 1997; Garvin, 2004). In general, only 15% of new ideas succeed, and almost half of those making it up to the market fail (Griffin, 1997; Kirschoff and Phillips, 1989; Porter, 1987). Difficulties and problems are assumed to take place after the "Feasibility study" phase (Fig. 1) when the prototypes are to be developed and tested, and the new products validated and launched on the market.

Innovation is essentially a coupling process, and the crucial contribution of the entrepreneur is to link the novel ideas and the market (Freeman and Soete, 1997). To facilitate this, the importance of testing and piloting of prototypes at customers' premises has been raised (Cooper, 1988). Allen and Cohen (1969) emphasized the importance of communication and flow of information, while von Hippel (1978) highlighted the role of users in the process of innovation. Tuomi (2002) argues that innovations become innovations only when they are taken into meaningful use in social practice and that "the emergence of innovations depends to a large extent on resources that are available for potential users" (Tuomi, 2002: 11). 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). Bower and Christensen (1995) emphasize the importance of locating the initial market for disruptive technology: it might be better to enter a totally new and marginal market rather than the company's usual mainstream market.

In well-run companies, however, due to the systematic NPD process, the existing customers, and not the new markets or users, effectively control the patterns of resource allocation (Pfeffer and Salancik, 1978; Bower and Christensen, 1995). In addition, radical projects face internal resistance within the company's own culture, people and processes, and investors may consider radical product and business development as lack of focus (Christensen, 1997). This leads to the conclusion that new technologies with the potential to become radical innovations, face difficulties not only in start-ups, but also in SMEs and large corporations alike. Independently of the company size or type, a new technology at the prototype phase needs to be linked to external resources, potential users, testing and piloting facilities and an initial market that is preferably small, marginal and meaningful.

4. Building the framework model

Several studies have emphasized the role of the unique CERN environment and technical infrastructure in the birth of the World Wide Web (Hameri and Nordberg, 1998; Berners-Lee and Fischetti, 1999; Tuomi, 2002). Experience also shows that CERN may offer a fertile ground for development efforts, which may also result in spin-off companies (Byckling et al., 2000), as well as a unique user base and infrastructure for piloting and testing of industrial prototypes (Vuola et al., 2003). CERN may also act as a first customer (i.e. the "initial market") for new technologies, and can be "leveraged" for advancing development projects (Autio et al., 2004).

This is no surprise as CERN runs a multi-billion-euro multiannual project budgeted over periods of up to more than 10 years in advance and with set functional goals, although the technology to realize the project is not always known beforehand. As a consequence, many new technologies are needed, and some of them potentially in large quantities. CERN has a substantial in-house engineering force and R&D function, several specialized test laboratories, and a network of hundreds of institutes, universities and companies together with thousands of users around the world. From the innovation perspective, this is a somewhat unique environment. CERN potentially has what innovation needs: resources, potential users, testing and piloting facilities, and "meaningful use in social practice". However, CERN's resources are "hidden" resources, as they exist solely for the purposes of particle physics research, and *not* for industrial innovation (CERN convention).

However, CERN *procurement* yields positive economic impact and learning benefits for Member State industries (Schmied, 1982; Streit-Bianchi et al., 1984; Nordberg, 1997; Autio et al., 2003). Nevertheless, no model has been presented for a systematic use of the "hidden" resources of CERN for the benefit of industrial innovations, or on *how* industry could accrue benefits *systematically*. With a systematic approach and by maximizing the benefits, Member States might accrue more than just the statistical average indicated by the above-mentioned studies. Samples in previous studies are typically limited to supplier companies, i.e. those that have won contracts, and pre-tender cooperation as well as problems and failures have been less studied.

CERN project managers and experts have great freedom to conduct their tasks and responsibilities. They are "highly educated and intelligent 'customers'", who have the inclination and freedom to test novel technology (Byckling et al. 2000: 75). However, when final suppliers are chosen for large sub-projects, the freedom is strictly limited by CERN's administrative procedures. A project manager is bound to cooperate only with the lowest bidder(s) among all those complying with the technical requirements of the specification (CERN, 1999). In addition, political pressure may influence the decision-making process (Hameri and Nordberg, 1999). A summary of an in-depth case study is described below to illustrate pre-tender cooperation, the tendering process and their influence on the final outcome and satisfaction levels.

> *A corporate venture had already started cooperation with CERN several years before the LHC was even approved. CERN and HEP were one of the main raisons d'être for the company. It was also the best performer in many technical tests CERN conducted on samples and prototypes. Several years later, after more than five years of joint R&D, testing and piloting, an international tendering competition was organised and, as a result of a tough price competition, the company was left without a supply contract.*

After a thorough analyses, the following can be concluded:

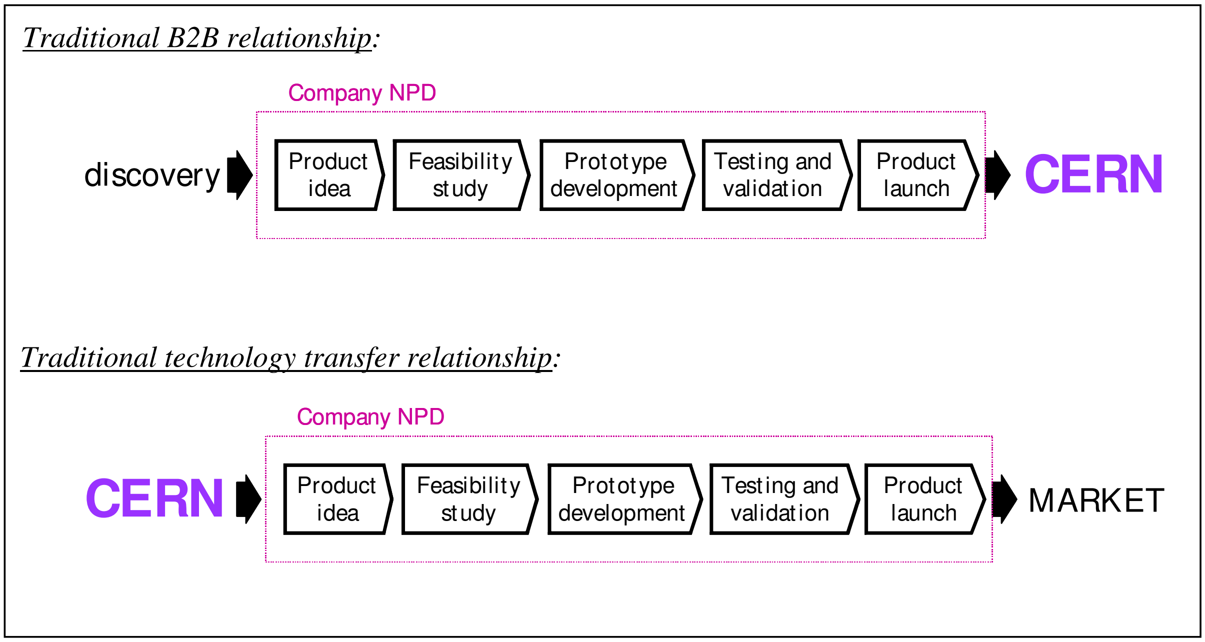
- *The best company does not necessarily win.* Although technically the best, the company did not win the contract. This was a great disappointment to the company, but also to CERN. Thus the cooperation did *not* in the end provide CERN and the LHC with the best possible know-how and technology available on the market.
- *Too dependent on CERN.* The company had invested a lot on 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, especially for a small venture. 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. But 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. This unfortunate outcome for the company, together with the disappointment of the Member State concerned, cannot have been good for CERN's reputation.

It can be assumed that the cooperation cannot be mutually benefiting or "win-win"[1], if it is not based on the needs, or more precisely, on the strategic needs in both CERN and the partner company. Win-win is realized only if the needs of both sides match. Two examples illustrate the CERN-industry dyads lacking the needs-based approach but typically present at CERN today:

1. *Traditional B2B (business-to-business) relationship. The company tries to sell products to CERN, treating CERN purely as a market and as a customer among others. CERN also treats the company as a mere supplier, often as a kind of compulsory element (to be tolerated) during the accelerator construction phase. This is the normal traditional supply-demand dyad, i.e. matching of company's offering to CERN's needs.*
2. *Traditional technology transfer. CERN tries to sell its technologies to industry. Here CERN is a sort of supplier putting a major effort into finding "demand" in the industry, i.e. companies willing to buy CERN's technologies. However, this again is based mainly on CERN's need, i.e. the need to sell technology. This effort is also called "technology push".*

Naturally both B2B and technology transfer (TT) are also needed. Technology transfer diffuses, and in some cases protects, CERN's technologies. On the other hand, CERN could not live up to its mission without the traditional B2B that is an obvious choice in most of the procurement cases. Figure 2 illustrates these two dyads by means of the NPD process chart presented earlier in Fig. 1.


Traditional B2B relationship:

Traditional technology transfer relationship:

Fig. 2. The traditional CERN-industry dyads illustrated by means of the industrial NPD process: In traditional B2B relationship, CERN is the market for industrial products, whereas in the TT relationship, a CERN technology acts as an input into industrial product development process.

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[1] By 'win-win' cooperation we refer to a mutually benefiting cooperation, i.e. that both of the parties gain through the cooperation, and furthermore, they both actually get more than they would without the cooperation.

Up to 90% of CERN's supplier companies are less technology-intensive (Autio et al., 2003) and traditional B2B could be applied to those cases. However, the remaining 10% of the companies, i.e. the technology-intensive ones, represent 50% of CERN's total procurement budget. The needs-based win-win principle could be applied to these cases. What are these needs then? Table 1 describes the generic needs on strategic level as well as the related needs on the practical level.

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 1. Generic strategic and practical needs of industry and CERN.

At the strategic level, both CERN and industry need innovation. They have a shared goal, so collaboration at strategic level is possible. At the practical level, needs are complementary, so motivation for win-win collaboration can be found.

The above-said altogether enable us to build a win-win cooperation model that can later be empirically tested (Eisenhardt, 1989). Using the NPD process chart (see Fig. 1.), the above principle of win-win match of needs, and the framework of systematic technology mapping and application analysis introduced by Hameri and Vuola (1996), a process model for CERN-company cooperation is proposed in Fig. 3. In this process, CERN's (sub-) project management process and the industrial NPD process merge into one common process at the prototype development phase, i.e. at the moment when both CERN and the company are assumed to need a joint effort to achieve their goals.

In the cooperation model, CERN's goal is to apply the new technology to the production of collider components, whereas the company's goal is to use the technology to generate growth and profit in main markets. However, they both 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 win-win 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. On the other hand, the CERN component sub-project should simultaneously be undergoing the same phases. The perfect match is thus not just the right match of the needs, but the right match of needs coupled with the right timing.

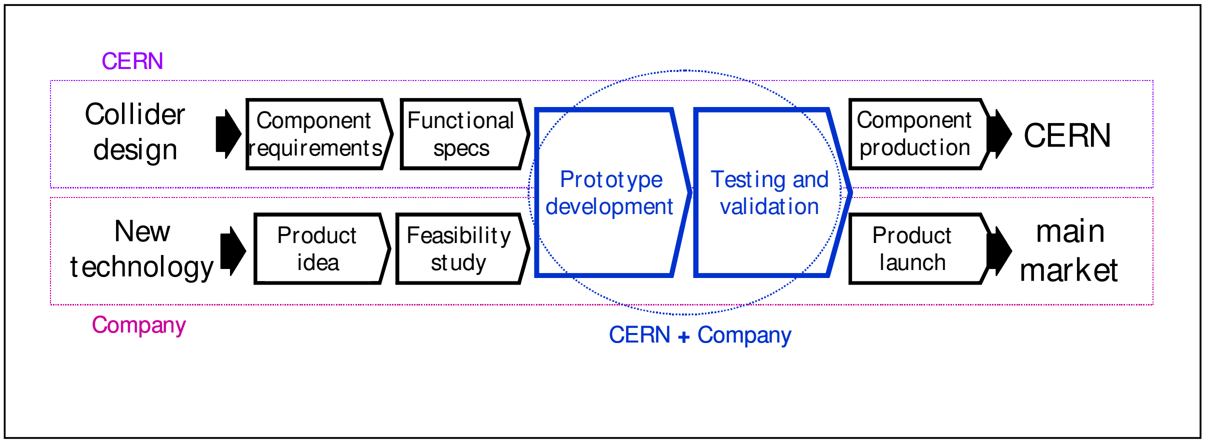

Fig. 3. A process model for new technology based CERN-company cooperation.

The key guidelines for the initiation of new technology based on win-win CERN-industry collaboration are listed below:

- *New tech prototypes*: Look solely for new industrial technologies that are in the prototype phase and before the new business has gained its breakthrough on the market place.
- *Matching needs*: Study and analyse the strategic needs of the company related to this specific new technology *and* the related new business development needs, and match them with the needs of CERN.
- *Resources*: Check if CERN can really provide potential users, testing and piloting facilities and a meaningful social practice for this particular technology.
- *The goal outside CERN*: Ensure that there are motivations other than a possible supply contract with CERN (if any). CERN should not be the end market for the new technology, although CERN may act as an initial market for it.
- *Timing*: The CERN sub-project and industrial product development (NPD) phases must match. “Don’t start too early, or too late”.
- *Start low profile*: Expert-to-expert interaction, informal joint development, testing and piloting. Then later, if the technology proves promising, apply the official CERN purchasing procedures.

This model provides a framework for practical experimentation with new technologies, companies and CERN. After the experimentation, conclusions will be drawn to refine the model, and to provide detailed practical implications.

5. Testing the model

The framework model was tested with several new technologies and industries during 1996 to 2003, including materials technology, electronics, nanotechnology, robotics, instrumentation and information technology, hosted by start-ups, SMEs as well as large corporations. Low-profile cooperation (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. Consequently, it should not be formalized by strict administrative rules. CERN is expected to provide an “equal opportunity” to all of its member states that may then also refer to this “obligation” and require equal treatment in all aspects. Innovations, however, are unique, not omnipresent.

Contacts between engineers/experts play the key role. There is a variation, however, in the open-mindedness and collaborative skills among engineers in both CERN and industry. It is thus essential to find the right match also at the personal level (not only needs and timing as stated earlier). Creative information exchange between experts did occur, especially during the pre-tender low-profile cooperation phase. This is a significant new finding, as earlier research has looked mainly at the learning benefits after the tendering phase. The cooperation projects provided the companies with expertise, testing facilities, users and piloting experience, and, in half the cases, breakthrough sales contracts and valuable references. In this sense, CERN truly provided meaningful social practice for the new technology, particularly meaningful actually in terms of references. In these cases, CERN thus became the small, new, marginal market needed for the initial commercialisation of the new technology.

The timing aspect had an even more important role than was thought beforehand. 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. Also the national innovation system may significantly support such new initiatives in terms of R&D funding for prototype development and testing. This motivation together with the availability of national R&D funding may significantly save CERN’s R&D costs. These companies, which have their end market outside CERN but need the CERN contract to get there, are very much motivated to engage in joint R&D with CERN even at their own cost (assuming part of the costs is covered by a funding agency).

The companies that participated in tendering were also the cheapest bidders in tough international competition, in spite of the fact that they were newcomers without previous experience of CERN tendering procedures and practices. One explanation could be that radical innovations change the basis for competition. There is, however, also another reason. Major external effort was needed to help the entrant firms. Without a third party’s spontaneous intervention, these cooperation cases might not even exist. Furthermore, third party coordination was needed to ensure the right strategic match, and to manage the project throughout the life cycle so that there was a win-win outcome.

The external efforts and help covered several tasks related to the entrepreneur’s role of linking novel ideas and the market (Freeman and Soete, 1997). These included, for instance, efforts to identify new markets and customers, efforts to build relationship and trust with the new customer and users, to focus the R&D on a specific application area, to find adequate testing facilities, to negotiate the first breakthrough sales contracts, and to exploit the valuable references to help marketing and sales to new customers.

In two cases among the sample CERN took the company’s product idea and started to develop it on its own. The companies concerned were not informed by CERN, nor asked for tenders for the products. It could be argued that this is one of the potential consequences of an informal (i.e. non-contractual) approach. However, these cases were the only ones where official CERN agreements and procedures were applied as early as during the testing and piloting phase and that did not lead to mutually benefiting situations.

The choice between different component technologies is often based on CERN’s experience on prototypes and thus production technology options are ignored in the design. The cooperation may then happen with the “wrong” companies (i.e. not “the best” to meet its needs): CERN *does* cooperate with companies during the R&D phase but in many cases with those specialized in HEP instrumentation or those with limited production capabilities even though ultimately CERN would need large quantities. This may lead to an expensive component design lacking the (mass-) production perspective, as the following case illustrates:

> *Long-term R&D for an LHC component had for some time been ongoing with several companies (we will call them companies A, B, C and D), most of which were well known to the HEP community. The manager responsible for the project was happy with his partners, not seriously willing to consider any other companies, nor technology choices other than those developed by his team. The section leader clearly had his preference, saying "Company A is just super" and that" it is very difficult for new entrant firms to get into it at this stage". CERN spent of the order of at least 1 MCHF on R&D with Company A over a 3-year period. A new company (Company E) was then introduced, several years later than A, B, C and D, with unique experience of mass production but no previous contacts with CERN. Informal low-profile prototype development was started at the company's own cost. Two years later the official tendering procedure revealed the Company E to be three times less expensive than Company A. Component production is now ongoing and relations between CERN and the company are good and direct.*

Without the introduction of Company E with strong mass-production experience, the component cost for CERN would have been several times higher than finally, and fortunately, proved to be the case. In addition, had this intervention happened earlier, CERN would have saved significantly during the component R&D. All these factors taken together represent substantial savings within one component sub-project alone.

6. Conclusions

The main stakeholders in a big-science project include the associated research organisation, member states and industry. All of them have different expectations from the collaboration, yet from the innovation point of view they all have something to gain. The innovation model presented above with its focus on matching big-science and industrial needs seem to serve well the interests of all participating parties. The following Table 2 aims to sum the key implications of the research for each stakeholder. These outcomes are triangulated from the point of view of financial, organisational, technological and social facets.

	Research organisation	*Member states*	*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 organisation – 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
Organisational	– 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 2. The implications for key stakeholders involved in big-science research.

This study recommends a basis for more systematic cooperation between big-science and industry, which would allow industry and new technology based new businesses to work with and benefit from big-science in a systematic manner, and big-science to get the latest technologies and capable industrial partners at low cost. Despite the fact that the study was limited solely to CERN, the other major experimental big-science laboratories in Europe do operate in principle the same way. The other big-science centres in Europe share similar member state structures and procurement policies, and as said the market is annually around €1b, which should be exploited to improve the innovative output of European industry. Furthermore, the model could possibly be applied to the following:

- other cooperation between basic research and industry;
- other large-scale projects that need new technologies, e.g. those in the aerospace industry, defence sector and energy production;
- with some modifications, governmental and international development aid as well as Third World development funds. Instead of mere "one-way" aid, they could provide new technologies to developing countries so that national innovation systems and the developing countries would both win. The Third World would get more than before, due to the fact that industry would be motivated through benefits accrued to their innovations (e.g. piloting ICT solutions in highly/poorly populated areas, etc.).

Further research on these issues is proposed, and the methodology of using both case studies and experiments is highly recommended.

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