



Knowledge transfer at CERN



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ABSTRACT

The transfer of knowledge and technology is an important part of the mission of most research organisations. At CERN, these activities are driven by a policy focusing on maximising the impact rather than revenue generation. To achieve this, CERN is employing many different modes of knowledge transfer, from licensing of intellectual property, making software and hardware available under open licences and engaging in and catalysing international collaboration. This paper summarises some of the modes CERN use to transfer its knowledge, the rationale for using them and provides some examples of the impact they are creating.

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1. Introduction

CERN, the European Organization for Nuclear Research, is the world's largest high-energy physics laboratory. Established in 1954, it has contributed significantly to our understanding of the world and the universe. The organization has a four-fold mission: to create new knowledge through conducting basic research, to develop new technologies for accelerators, detectors and Information and Communication Technologies (ICT), to train the scientists and engineers of the future and to unite people from all countries and cultures.

Commercialisation of research and exploitation of intellectual property has for a while received increased focus (Nowotny et al., 2003). This can be seen in many aspects, such as the increased emphasis that the Horizon 2020 EC framework programme puts on innovation and job creation compared to its predecessors. Research funding is also moving more towards result-based models (Bentley et al., 2015). Thus, showing that one is contributing to economic prosperity has become more important, even in basic research.

Many studies have been conducted to assess the impact of CERN on society. A recent cost–benefit analysis, evaluating the socioeconomic impact of CERN concluded that the Large Hadron Collider (LHC), had a net present value of 1.2 times the investment and 91% chance of a creating a positive return on investment over the projects lifetime (Florio et al., 2015). However, the long-term value of the pure basic research discoveries was not included in the analysis because of their unpredictable nature. Several studies have looked particularly at procurement activities at CERN, finding positive economic impact and learning benefits for suppliers (Autio et al., 2003; Bianchi-Streit et al., 1984; Schmied,

1982). Autio, Bianchi-Streit, and Hameri (2003) found that in most of the technology-intensive procurement contracts, the suppliers derived significant marketing reference benefits from CERN and in addition, 38% of the respondents developed new products or services as a direct result of the supplier project; 42% increased their international exposure, and 44% indicated significant technological learning. Studies have also looked at the creation of spin-off companies (Byckling et al., 2000) and impact from spinning-off human capital (Bruzzi and Anelli, 2014).

How an organisation transfers its knowledge and technology and in that way provides positive externalities is therefore interesting from a research perspective as well as from a policy perspective. This paper will describe the general policy and principles for knowledge and technology transfer at CERN. Following this brief introduction, Section 2 will present literature on knowledge and technology transfer. Section 3 provides the broad lines of these activities history at CERN. Section 4 will present modes of knowledge transfer employed by CERN today, their rationale and indications of their impact. In Section 5, we conclude and provide suggestions for future research.

2. Knowledge and technology transfer

Knowledge and technology transfer could be defined as “the movement of know-how, technical knowledge, or technology from one organisational setting to another” (Roessner, 2000). A distinction can be made between “diffusion”, defined as a spontaneous unplanned spread of new ideas, and “dissemination” for knowledge transfer that is directed and planned (Rogers, 2010).

Knowledge and technology transfer offices have been created in most universities and research centres to manage the dissemination process (Siegel and Wright, 2015). For some, the commercialisation of

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research is a way of obtaining extra income for the institute (Bray and Lee, 2000). However, more importantly, it is a way of strengthening the institutes attractiveness and role in society (Leitch and Harrison, 2005). One study found that only 16% of knowledge and technology transfer offices in the US were self-sustaining (Abrams et al., 2009). Revenue generation is only a part of the picture, and knowledge and technology transfer offices have been found to increase access to external funding, to promote innovation and entrepreneurship and to contribute to other public benefits (McDevitt et al., 2014).

Upstill and Symington (2002) argued that there are three basic modes for technology transfer from public research to the business sector:

- Non-commercial transfer; seminars, informal contacts, publications, secondments and staff exchange and training
- Commercial transfer; collaborative research, contract research, consulting, licensing and sale of intellectual property and technical services
- New company generation; direct spin-offs, indirect spin-offs and technology transfer companies

Non-commercial transfer such as publications, presentations and informal exchanges have been found to be among the most important ways information is diffused from public research to industry (Cohen et al., 2002). Even in universities known for their large patent output, such as MIT, publications outnumber patents as a mean of transferring knowledge (Agrawal and Henderson, 2002). To increasing the impact of their research and developments, organisations may also make their knowledge available free through Open Source licences and other open mechanisms (Sorensen and Chambers, 2008). Open models are not limited to software and there is a greater appearance and expansion of efforts also in the hardware domain, leading to new ways of sharing knowledge. New licences are being created to govern the process of identifying, reproducing and sharing hardware designs (Powell, 2012). Staff moving from research to the commercial sector has also been found to be of large contributor to economic benefits for society (Zellner, 2003).

Commercial transfer of knowledge and technology encompasses many different modes, where licensing and sale of patents have often been the key focus of technology transfer offices (Wright et al., 2004). Licensing is often considered advantageous as it allows researchers to continue working on their research, without needing to commit large amounts of time to commercial matters (Lockett et al., 2003). However, it is also found that the likelihood and degree of commercial success leading from licensing agreements increases with inventor engagement (Agrawal, 2006). Collaborative research allows industry to participate in frontier science. In addition, it is shown that the knowledge from public research organisations transferred to industry through collaborative research and consultancy contributes to suggesting new R&D projects, but even more so contributes to completing existing projects in industry (Cohen et al., 2002).

New company creation can be an effective way of transferring knowledge from research organisations to society. In cases where inventions are not protectable or the value of intellectual property is difficult to capture through licence agreements, spinning-out a company can be more advantageous (Franklin et al., 2001). These new companies can exploit the founders tacit knowledge, IP developed at the organisation or both, referred to as indirect spin-offs, technology transfer companies and direct spin-offs, respectively (Upstill and Symington, 2002). Although licensing to established companies often has been preferred in knowledge transfer offices, new company creation is increasingly seen as an important transfer mechanism, by practitioners as well as policy makers (Mustar et al., 2008; Wright et al., 2004).

Considering all the modes and possibilities for disseminating knowledge developed at an organisation, knowledge transfer activities are

many and varied. Thus, defining metrics for knowledge transfer activities have proven to be an area that poses many challenges (Rossi and Rosli, 2013). The core metrics recommended by the European Commission's Expert Group on Knowledge Transfer Metrics are research agreements, invention disclosures, patent applications, patent grants, licences executed, licence income earned and spin-offs established (European Commission, 2009). Albeit these indicators provide a good base for comparing the effort of the knowledge transfer offices, they are only focused on a limited set of the commercial modes. In particular, open modes of dissemination are not included in these metrics. A problematic part of this is that knowledge transfer activities might be shifted towards indicators that are measurable and easily comparable, such as revenue creation, despite producing a smaller total impact (Rossi and Rosli, 2013).

3. Knowledge and technology transfer at CERN

CERN started technology transfer activities in 1988, when the CERN Industry and Technology Liaison Office was founded to stimulate interaction with industry and to assist in issues related to CERN's intellectual property. The field and objectives of the activities have changed over the last years, as well as the general structure of CERN, and thus the knowledge and technology transfer office at CERN has gone through many iterations before reaching its current form as the CERN Knowledge Transfer Group.

An objective that was included in the inception of these activities at CERN was revenue creation, providing extra income. However, even though there is still an objective to gain a fair return on the transfer of knowledge, considerations such as contributing back to society and strengthening CERN's role in society have the priority. Today the mission of CERN's Knowledge Transfer Group is to "maximise the technological and knowledge return to the Member States and promote CERN's image as a centre of excellence for technology"; in addition, the CERN IP policy states that impact shall have priority over revenue creation as a steering principle for the activities (CERN, 2010).

The current policy at CERN, focusing on maximising impact, makes it clear that using only commercial modes of knowledge transfer, such as licensing and paid consultancy, is not the unique path to choose. A main part of the objective of the CERN Knowledge Transfer Group is therefore to evaluate different dissemination methods and select the appropriate mode to fulfil this mission. CERN is therefore increasingly sharing its knowledge through a variety of different commercial and non-commercial modes as well as new company creation.

4. Modes employed by CERN

The knowledge transfer from CERN's pure fundamental research to society usually occurs through diffusion in a non-commercial form; in particular, most basic research is disseminated through publications. The direct results of high-energy physics often do not create any immediate benefits for society, as they are focussed on pure knowledge creation rather than applied knowledge.

CERN's convention states "all scientific results shall be made openly available to the public" (CERN, 1953). Following on from the convention, most results from the pure physics mission of CERN are released as Open Access Publications, available to anyone with an Internet connection. CERN is a strong advocate for the Open Access regime and recommends that all results from the physics mission are published under Gold Access. In 2013, 60% of all CERN Physics results were published under this scheme (CERN, 2014). There is evidence that Open Access increases the impact of publications (Antelman, 2004) and that there is an overall positive impact trend for Open Access journals (Gumpenberger et al., 2012).

The active dissemination of CERN knowledge and technology is rather focusing on all of the collective knowledge and technology required to execute the high-energy physics research. To conduct

experiments at the scale of the LHC, significant technology developments in the field of magnets, radio frequency cavities, superconductivity, detectors and ICT among many other domains is required. These developments in contrast to the pure scientific results can often have a direct positive impact on society.

Intellectual property rights are closely connected to knowledge transfer activities, including software, hardware designs, know-how and patents. CERN currently manages a portfolio of 52 patent families. The strategic motivation for using patents as a tool for knowledge transfer is to enable transfers that require significant capital and/or time investment from industrial partners who would otherwise not invest in the industrialisation of the technology, such as technology leaps in accelerators or detectors. While not a motivation, a patent also inherently recognises CERN and the inventors being at the origin of such a new technology.

Whenever a new technology is disclosed, its patentability potential is evaluated, but much more important is whether a patent would add significant added value to facilitate its transfer. In 2014, 87 new internal opportunities were disclosed. In principle, many patents could have been applied for from these 87 disclosures. However, only 5 patent applications were made after evaluating them based on the criteria above. In the ProTon Europe Survey and the AUTM U.S. Licensing Activity Survey both for 2011,¹ the average number of invention disclosures were 22.4 and 117.5, and the average number of patent applications were 11.8 and 71.3, respectively (Piccaluga et al., 2012). Considering that these numbers averages from a large group of very different organisations – most of which are universities – a direct comparison of numbers as a metric of success is of limited value. However, they do indicate that CERN limits its patenting activity compared to the number of invention disclosures.

The licensing of patents and other forms of intellectual property is the most traditional form of technology transfer and one that CERN also uses. However, it is not the only way CERN shares its knowledge and technology with society, and compared to other modes, it only contributes a small part of the total impact created. The purpose of this paper is therefore to detail the most frequently employed modes of knowledge transfer, their rationale and indications of the impact they create, providing examples of their impact.

4.1. Licensing

Traditionally, the focus of technology transfer offices has been on licensing (Wright et al., 2004), which at the inception of CERN knowledge transfer activities was also the prioritised mode of dissemination. However, with the increasing emphasis of open models and other schemes for disseminating technology and knowledge, licences are today considered only one of many potentials tools to create positive externalities.

Fig. 1 shows that the number of licence agreements concluded has been growing over the last few years. R&D licences to academic partners are often granted for free, whereas commercial licences are granted against a fair return payment through up-front payments and royalties. These licences currently generate a return of between 1 and 2 million euros annually, inline with the objective of maximising dissemination rather than revenue. The licence revenues are in turn returned in part to the department and group where the invention originated and in part to an internal fund used to finance further development of technologies towards commercial or other impactful applications.

Licensing is often considered advantageous as it allows researchers to continue working on their research, without needing to commit large amounts of time to commercial matters (Lockett et al., 2003). However, for the case of technologies developed at CERN, a certain

¹ The survey conducted by ProTon Europe, collected data from 329 European knowledge transfer offices. The The Association of University Technology Managers (AUTM) U.S. Licensing Activity Study, surveyd 186 knowledge transfer offices from the U.S.

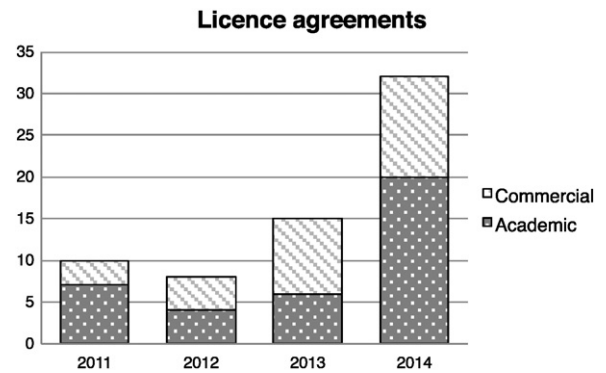


Fig. 1. Overview of new licence agreements signed 2011–2014.

amount of time is often required to transfer the know-how required for the licensee to properly exploit the technology, or for the technology to be taken to a stage where it is interesting for external partners to continue the development. Thus, a significant commitment from the inventor is usually required. Inline with Agrawal (2006), this shows that engaging the inventors is important for successfully transferring knowledge.

The Medipix project, CERN's most successful licensing case, is an example where the inventors have contributed a large effort in transferring the technology to practical applications. Medipix is an advanced hybrid pixel detector with the ability to count single photons, enabling it to produce x-ray images that are high resolution and noise-free. This makes it excellent for use in medical imaging and a broad range of applications involving radiation detection (Campbell, 2011). The first version was created in an informal collaboration of four institutes since then the number of Medipix chips and collaboration members has expanded to today's Medipix3 collaboration with more than 20 members (Medipix, 2015).

The Medipix chip has created significant impact with five start-up companies spinning-off from various members of the collaboration, all basing their business on various applications of the chip. Many licences to established companies and academic institutes have also been concluded. Applications of the Medipix chips range from industrial x-ray, radiography and computed tomography (CT) to monitoring of radiation exposure on the international space station (ISS) and educational tools for schools. The licensing revenues are currently used to fuel the collaborations, which then further develop the chip, with the new Medepix4 collaboration close on the horizon.

CERN has also recently tried to put certain technologies under *Easy access IP*, a scheme that involves making some of CERN's technologies available free of royalties, in exchange for the licensee demonstrating that they will create value for society and acknowledge the contribution of the originator (Easy Access IP, 2015). However, at the current time, CERN has only released a few technologies under this scheme, leading to a limited interest from commercial partners.

4.2. Collaborations, service and consultancy

The knowledge at CERN can also be used in collaboration with industry, or by providing services and consultancy. However, CERN has no mission to serve as a contract research entity, and the rationale for providing service and consultancy is always the transfer of CERN specific knowledge. If this knowledge is reasonably attainable elsewhere and particularly if it is commercially available, CERN will normally divert the request.

Fig. 2 shows the agreements signed each year for service, consultancy, collaboration and partnerships. However, it is important to mention that these are far from the only collaborative agreements that CERN

conclude each year. Many additional collaboration agreements are established every year with the hundreds of institutes around the world that CERN is collaborating with for the execution of its basic research mission. The numbers reflect only the specific agreement set out with the purpose of knowledge transfer from CERN to develop new products or services outside of the world of high-energy physics.

Collaborative agreements span a wide range from hadron therapy for cancer treatment and augmented reality, to research on photonic crystals and high-gradient structures for compact accelerators. The purpose of this collaborative research is to generate technological results with a potential for commercial exploitation.

Service and consultancy agreements are normally set up to provide service and assistance in relation to a CERN developed technology; this is often also included as part of a licence agreements. Thus, the dedicated service and consultancy agreements are often focused on providing services and assistance related to CERN developed Open Source Software or use of very specialised equipment at CERN for testing purposes. For service related to Open Source Software, two good examples are INVENIO, a software package developed to run the CERN library and document repository, and INDICO, which is developed to organise all of CERN's meetings and events, the room booking required and the uploading and archival of material related to the events. For the case of INVENIO, the requests for service reached a level where it was decided to establish a spin-off company to deal with the amount of requests. This spin-off company is today delivering INVENIO as a cloud-based service.

4.3. Open Source software

CERN is committed to an Open Source approach for its software and the IP Policy states: "For software developments that are owned in whole or in part by CERN, CERN favors the Open Source approach. Exceptions can be made where there is a good reason not to put the software development under Open Source conditions at a given time" (CERN, 2010).

The exceptions for not releasing software as Open Source are normally as follows:

- Significant development is needed to package the software for public release, and this effort exceeds the benefits of distributing the software.
- The software package does not have a level of quality that warrants distribution.
- Collaborative agreements or external constraints, such as those imposed by funding bodies, prevent open source licensing.
- Open Source is after a thorough analysis considered less effective than proprietary licensing for maximising the dissemination or impact.

A large fraction of the software packages developed at CERN are today licensed under different Free and Open Source Licences. A taskforce established by CERN recommended that software developed at CERN should be made available under widely used licences. A copyleft approach is seen inline with the spirit of open scientific collaboration, making sure that new modifications made to the software are available with the same freedom to the user. The GPLv3 (GNU General Public License) was recommended as the default licence for CERN developed software and should be proposed for software developed in collaboration with other partners. Other widely used licences such as LGPLv3 and Apache v2 are recommended for libraries or if there are external constraints (CERN, 2012).

A recent study that made a cost–benefit analysis of the LHC looked at ROOT (a framework for storing and analysing data) and GEANT4 (a software for simulating the passage of particles through matter), quantifying their benefit to society to be worth 5.4 billion Euro (Florio et al., 2015). Today ROOT in particular has found its way to applications reaching very far from high-energy physics and is used by telecom companies, in the aerospace industry, by finance institutions and by insurance companies to analyse fraud, in addition to many other applications involving large amounts of data.

The arguably most important contribution to society from CERN is the World Wide Web (WWW), developed by Sir Tim Berners Lee during his time at CERN. The first developments were released in the public domain with subsequent developments released Open Source. It is likely that the WWW would never be the defining standard nor create nearly as much impact as it did if it had been made proprietary.

Examples as the above show the power of Open Source and open standards and the significant impact that can be created. However, the efforts in tracking the dissemination and subsequently evaluating the impact of the large portfolio of Open Source Software at CERN are very limited. Thus, there are significant challenges in better measuring how the software is disseminated and subsequently understanding the impact that is created.

4.4. Open hardware

Open Hardware allows anyone to study, modify, use and produce a design. For CERN, Open Hardware began in 2009, when a group of electronics designers in CERN's Beams Department created the Open Hardware Repository. The purpose was to have an Open Source philosophy to hardware development. Later, the CERN Open Hardware Licence (CERN OHL) was created to provide a proper legal framework to distribute these designs. The licence governs the use, copying, modification and distribution of hardware design documentation and the manufacturing and distribution of products based thereon. The licence essentially gives anyone these rights with the condition that new developments are published under the same terms.

Many companies, research institutions and individuals have adopted the CERN OHL as a way for them to share their designs, and it is used by most of the projects in the Open Hardware Repository. However, it is not limited to projects related to high-energy physics. Companies and individuals use the licence on products ranging from electronic modules for do-it-yourself projects and music controllers to platforms for scientific instrumentation that was developed for quantum optics. Thus, the Open Hardware development at CERN creates an impact, through the licence itself as well as the hardware released under it.

The Open Hardware Repository currently hosts more than 100 projects, ranging from small projects with a few partners to bigger projects with multiple contributors from both industry and academia. A dozen companies are actively involved in projects in the Open Hardware Repository, and some produce the physical hardware for CERN and other customers. CERN plays an important part also as a pilot customer for the hardware, legitimising the quality, making it easier for companies to sell it to other customers at a later stage. The Open Hardware

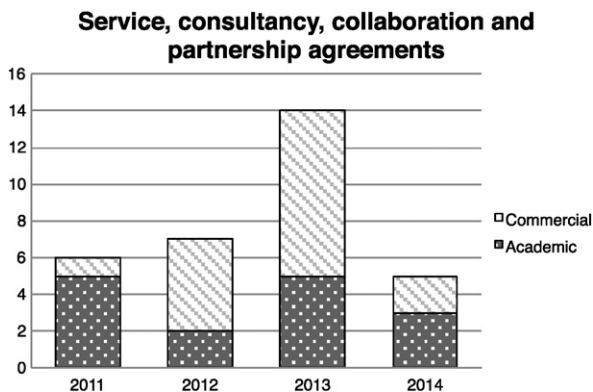


Fig. 2. Overview of service, consultancy, collaboration and partnership agreements from 2011 to 2014.

Repository has led to an unprecedented re-use of existing design among scientific collaborators and internally at CERN.

Currently, there are 17 companies involved in the Open Hardware Repository, which contribute to and benefit from different aspects. Table 1 shows an overview of which part of the hardware development the different companies are involved in and the number of projects in the open hardware repository they are involved in.

An internal overview made at the end of 2014 showed that of the eight CERN designs commercially available, more than 1200 units were produced for almost 100 different users. This indicates that Open Hardware can lead to the creation of commercially successful products and is a valid mode for dissemination of knowledge. However, as with Open Source Software, there are still significant challenges in tracking and measuring the dissemination and impact.

4.5. Spin-off and start-up companies

Spinning-out a company might be advantageous when an invention is difficult to protect or license out (Franklin et al., 2001). At CERN, very few companies have actively been spun-off. However, during the last 3 years, significant efforts have been put in place both internally and externally to facilitate the spin-off process. Internally, new policies are in development; trainings and activities have been put in place to teach CERN people entrepreneurial skills. These activities are mostly aimed at students, fellows and limited duration staff, which might choose entrepreneurship as a possible next career step after CERN. In addition to creating a positive impact on society through the creation of new products and services, new company creation can also serve as an alternative career path for all the researchers and engineers that choose to leave the field of high-energy physics. Externally, a network of network of business incubation centres (BICs) of CERN technology has been established (CERN, 2015a).

These very recent efforts have led to a slight increase in start-up activity at CERN. However, only two spin-off agreements were set out in 2014. It is foreseen that as the emphasis on new company creation continues, a higher number of spin-offs will follow. In universities, it have been found that spin-off companies are often started by former employees without any ties to the university, the so-called informal or indirect spin-offs (Howells and McKinlay, 1999). Some evidence shows that this is also true for the case of CERN and anecdotally one has seen companies in recent years being started by former CERN staff, students and fellows that no longer had any official link to CERN. Providing these people with the means and a certain amount of support to follow this alternative path and better tracking, their development should receive more emphasis.

One initiative that might do exactly this is the network of BICs. The first BIC of CERN technology was started at a pilot with the Science and Technology Facilities Council (STFC) in 2012. There are currently 8 BICs of CERN technology in CERN's member states, most of which have been established in the last one and a half year. See Fig. 3 for an overview of the locations and local partners. The BICs support the development and exploitation of innovative ideas in technical fields broadly related to CERN activities in high-energy physics, such as, detectors, cooling technology and high-performance computing. The BICs of CERN technology are managed by local partners, which were already managing existing BICs, thus avoiding the need to set up entirely new programmes, by rather introduce CERN technologies into existing incubation structures. The local partners offer office space, expertise, business support, access to local and national networks and support in accessing financing. Whereas CERN contributes with the transfer of technology and know-how through technical visits to CERN, support to the companies in the BIC and preferential-rate licensing of CERN intellectual property.

The STFC-CERN BIC that has been running the longest now house three young companies with additional companies in the pipeline. The companies in the BIC are in the domains of 3D manufacturing, heating elements and nanocoatings. These companies benefit from CERN's technology and expertise and, as important, if not more, the business support provided by the local partners.

4.6. EU projects

The Framework Programmes for Research and Technology Development are funding programmes established by the European Union for supporting research and innovation in the European research area. The programmes have been abbreviated FP1 to FP7 with the 8th and current phase being named Horizon 2020. These framework programmes have been important instruments for connecting CERN to external actors and funding research that is not part of CERN's core mission.

In a knowledge transfer context, it is interesting to have a look at the recently finished FP7 that lasted from 2007 to 2013. CERN was part of a total of 87 projects, coordinating 36 of them. These projects spanned from R&D for accelerator upgrades, particle therapy for cancer treatment, to developing new research grids and smart cities. The funding allowed CERN to partake and share its knowledge in many fields CERN typically does not engage in. Some examples are the 4 projects focusing on novel treatment of cancer, a project using CERN software to build a solution for archiving blogs and Citizen Cyberscience, bringing the general public into research through open platforms.

Table 1

Overview of the 17 companies active using the Open Hardware Repository to develop or produce hardware, software and drivers. Showing the country they are from, which areas and number of projects they are active in.

Company	Country	Hardware development	Hardware commercialisation	Firmware development (e.g. VHDL)	Software development	Projects
1	France	X	X	X	X	1
2	France			X		1
3	Germany		X	X	X	2
4	Italy				X	18
5	Poland	X	X	X	X	32
6	Slovenia	X		X	X	2
7	Spain	X	X	X	X	3
8	Spain				X	2
9	Spain			X	X	2
10	Spain	X	X	X	X	18
11	Spain				X	1
12	Sweden	X				1
13	Switzerland	X				1
14	Switzerland	X				2
15	The Netherlands	X	X		X	5
16	UK			X	X	1
17	USA		X			1



Fig. 3. Map showing the current location of BICs of CERN technologies and the partner organisations.

The total budget for all FP7 projects CERN took part in was 692 million euros, 404 million came from the European Commission and 288 million was matched by the partners. From all of these projects, CERN received in total 111 million euros and provided matching funds of 93 million euros. Perhaps more interesting than the funding itself is the number of partners CERN collaborated with, in total 526. Of these many were universities and other research organisations, but also 73 small and medium size companies and 53 larger companies, indicating that EU projects serve as a useful contact surface between CERN and the private sector.

FP7 was also a very important funding mechanism for training young researcher, and slightly more than 550 researchers have been trained through the Marie Curie projects CERN took part in under FP7, with more than half of those hosted at CERN. The different Marie Curie actions provided funding for both early stage researchers (ESR) and experienced researchers (ER),² where the most common funding instruments for CERN were the Initial Training Network and COFUND. COFUND differs slightly in that it is not a fully funded fellowship but, as the name hints, an additional financial support to existing programmes. Table 2 shows the distribution of fellows trained at CERN and in partner institutes for the Marie Curie projects CERN took part in.

EC-funded projects have as shown been very important for both working with industry on a large range of different topics and contributing to training new researchers. FP7 was a very successful programme

for CERN, allowing for collaboration, knowledge sharing and training of young researcher, much of which would not have taken place without this additional funding.

4.7. Human capital

A part of CERN's mission is training the next generation of scientists and engineers. Many students, recent graduates and also professionals come to CERN to spend between 1 and 5 years on different contracts. In big science centres, limited spin-off of human capital due to low staff turnover is often seen as an impeding factor for knowledge transfer (Beise and Stahl, 1999). This is often justified by the fact the big science centres work with long-term project and require steady employment. CERN does maintain a rather large base of permanent staff, and per 2014, 70% of the CERN staff held indefinite contracts, whereas 30% held limited duration contracts (CERN, 2015b). Around 40% of the limited duration contracts are in term converted to indefinite contracts. However, in addition to the around 2500 staff, there are also other contract types that are spinning-off more human capital, such as the various student and fellow programmes.

Table 2

Overview of fellows trained at CERN and in partner organisations in FP7-funded projects CERN took part in.

	ESR	ER	COFUND
CERN	96	40	185
Partners	202	33	

² Early Stage Researchers are defined as those who are in the 4 first year of their research career. Experience Researchers need to be in possession of a PhD or have at least 4 years of experience.

A recent study looked at the fellowship programme as a source of spinning of human capital (Bruzzi and Anelli, 2014). The CERN fellowship programme is targeting recent graduates and candidates with maximum 10 years experience and offers the possibility to stay at CERN for up to 3 years, working in a large range of disciplines such as applied sciences, computing and engineering. In the period 2007–2012, 831 fellows finished their fellowship at CERN, of these, 288 or 35% had left CERN completely. Of the fellows that left CERN,

- 85% found a new position, 5% had started their own company, 2% returned to their old employer in a new position and 2% returned to their old position and 5% were unemployed since they ended their fellowship;
- of the ones currently employed, 41% were in industry/services, 26% in other research organisations, 30% in universities and 3% in other;
- 73% gave a positive response to the importance of the fellowship for being able to secure their current position;
- 55% reported that they had a position in a different country than the country where they received their last diploma, and albeit 15% of these staid in Switzerland, it still indicates that CERN is a strong contributor to international mobility.

In addition to the fellowship programme and the Marie Curie actions, there are many other student programmes. The summer student programme trains nearly 300 students from 70 different countries every year, in a programme combining theoretical lecture and practical work integrated into research teams as CERN. In addition, CERN has a programme for technical students, PhD students and administrative students, as well as various other schemes for teaching and training engineers, scientists and other professionals. These programmes all contribute to knowledge transfer by spinning-off of human capital from CERN.

CERN also contributes actively to education through teaching and training engineers and scientists in its many topical schools, spanning the key domains, accelerators, and detectors and computing. A special programme has been established to train high-school teachers, providing them with an understanding of high-energy physics, so they again can teach their students. In addition, CERN engages heavily in outreach activities, welcoming some 100.000 visitors to CERN every year to see the laboratory get a basic introduction to particle physics and the mission and research of CERN. Many of these visitors are high-school students, hopefully inspiring them to pursue further scientific studies.

4.8. International collaboration for medicine

Physics has spurred significant advances in medical field, all the way back from Ancient Egypt to today (Keevil, 2012). CERN has a long tradition for contributing to the medical field and is currently doing it by developing new concepts for medical accelerators, better detectors from beam control and medical imaging, producing new exotic radioisotopes and through its expertise in large-scale computing. This is done through many of the different modes already discussed. However, CERN also plays an interesting role as a catalyser for collaboration in the field, bringing the multidisciplinary community of medical physics together.

One of the most prominent fields where CERN catalyse collaboration is the field of hadron therapy. By treating patients with protons and carbon ions, instead of x-rays used in conventional radiotherapy, hadron therapy allows for treatment of deep-seated tumours with good accuracy and minimal dose to surrounding tissue (Scharadt et al., 2010). CERN contributed to the field through the Proton-Ion Medical Machine Study (PIMMS) that was coordinated by Philip Bryant CERN in collaboration with Austria (Meinhard Reigler) and TERA, Italy (Ugo Amaldi), from 1996 to 2000 (Bryant et al., 1999, 2000). The dual-ion centres CNAO in

Italy and MedAustron ebg in Austria are results of the PIMMS study (Dosanjh et al., 2014).

Today CERN is still actively contributing to the field in a catalysing role through the coordination of the European Network for Light Ion Hadron Therapy (ENLIGHT). ENLIGHT was established in 2002 to coordinate the European efforts in hadron therapy. It was funded by the European Commission for the first 3 years, and despite the funding finishing in 2005, it is still thriving, and today the network exceeds 400 participants from more than 20 European countries (Dosanjh et al., 2014). One of the major strengths of the network is that it has been able to attract participants from all relevant fields, such as clinicians, physicist, biologists and engineers and uniting them towards a common goal. The network also promotes knowledge sharing between all the participants coming from different backgrounds, fostering the development of new concepts and technologies while making sure they are inline with the requirement of the clinical practitioners needs.

Under the banner of ENLIGHT, four very successful EC-funded projects have significantly contributed to the development of the field in Europe. Two were large research and development projects and two were Marie Curie training projects, training a total of 44 researchers, most of which actively contributes to the further development of the field today in institutes around the world. The projects were also important as they served as a larger platform for collaboration between many of the important stakeholders in Europe.

In line with the catalysing role, CERN is also part of organising the International Conference on Translational Research in Radio-Oncology–Physics for Health in Europe (ICTR-PHE). A conference arranged every other year, bringing together some 400 stakeholders from the medical as well as the physics community working on research towards improving the current state of cancer treatment.

5. Conclusions

The overview presented shows how CERN actively disseminates its knowledge with the purpose of creating a positive impact on society. This is done through conscious choice between open and closed models for dissemination of knowledge, as well as the diffusion of knowledge that naturally takes place in an open scientific environment. The steering principle for all these activities is always to maximise the benefit for society.

The overview has also showed that all of the modes have been able to make a significant impact on society in different ways and that CERN has over a long period contributed to the economy as well as increasing health and quality of life, by transferring its knowledge and technologies and by catalysing collaboration. Some technologies have made a significant impact licensed to a few partners, others have reached thousands of users around the world through open models.

Some of the modes described in this paper have limited metrics describing their impact. The main reason for this is the lack of data, as well the lack of appropriate indicators to track. The non-commercial modes for dissemination in particular have very limited metrics put in place for tracking the impact. Indications show that in particular Open Source Software has created large impacts, although quantifying the actual impact of contributions from CERN is limited because of the lack of tracking of the dissemination and impact.

Steering the active dissemination after impact rather than economic return does give rise to certain challenges, such as the difficulty of choosing between different modes. A challenge is therefore evaluating and putting in place measures on how to manage, measure and stimulate this diffusion of knowledge. New research should focus on creating metrics for evaluating and comparing the impact of all of these different modes. In addition, a large challenge is to have a better understanding of criteria for selecting different modes of knowledge transfer, ex-ante, to achieve the desired objectives of the organisation, in CERN's case socio-economic impact.

CERN is first and foremost a laboratory set out to push the boundaries knowledge in the field of high-energy physics. However, it is clear that there are significant side effects from these activities, which are transferred to industry and society in a variety of different ways.

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Giovanni Anelli—Head of Knowledge Transfer Group

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