Case Study on the Knowledge Transfer and Innovation Structure at CERN

Bruno Silva de Sousa
Supervisors: Alberto Di Meglio CERN & Gianluigi Viscusi EPFL

Strategic & Innovative Project ▪ EPFL EMBA
Geneva October 2019

Executive Summary

Innovation and technological spillovers from public research organizations to society became a high-priority on many political agendas with the introduction of the Triple Helix in the early 1990s. Consequently, organizations such as public universities or public research laboratories developed knowledge and technology transfer units to manage their innovation value chain – from the intellectual property management to, in many cases, the conversion of technology into innovations with economic or social value with access to incubation structures, industry networks, science parks, or venture capital.

The ability and effectiveness necessary to capture and convert intellectual property assets into innovations are influenced by organizational dynamics that characterize the research organization. For example, at the inventor level, financial incentives play a crucial role in supporting technology disclosure. At a later stage, if that same technology is commercially exploited by a private company, for example in exchange for royalties, the long-term cooperation of the original author may be essential to support the technology appropriability by the private firm, and hence enable the technology development to higher stages of maturity or readiness.

Many times, the organizational flexibility necessary to implement the optimal conditions that maximize the innovation throughput is difficult to achieve, or even conflicting with specific organizational dynamics. Indeed, such is the case at CERN – one of the world's largest and most respected centres for scientific research – where, for example, the fact that the research programme is financed by 23 Member States brings significant complexity to the question of fairly distributing the innovation spillovers across all countries.

Through the case study methodology and interviews with four senior managers at CERN, positioned at different levels of the innovation pipeline, we identify and characterize the internal dynamics that are impacting the innovation potential at CERN and thus limiting the potential returns to society. We identify weaknesses that deserve open discussion within the Organization and propose a set of mitigation recommendations. Namely, the spin-off of the knowledge and technology transfer organizational unit to an independent non-profit entity to obtain the necessary autonomy to extend the innovation value chain. Additionally, we discuss the competency gap and cultural aspects entrenched in the Organization that would ask for the development of an entrepreneurial spirit, which demonstrated possible in other research institutions with the development of ambidexterity capability.

Table of Contents

1. Introduction

1.1. Background

Scientific research organizations, through their curiosity-driven activities, ultimately aim to expand human knowledge. Such is the case for CERN, where the quest to discover the origins of the universe develops unique and cutting-edge technology (CERN, The CERN History Study, 2019). As a publicly funded organization, the laboratory must ensure that its technology delivers tangible benefits to society (CERN, CERN Knowledge Transfer, 2017).

There are multiple examples of technologies from CERN that found their way to become innovations with economic or social value. The World Wide Web is a flagship example that is part of our everyday life that revolutionized the way we access information and consume services. Yet, other technologies with potential on different scales, rely on serendipity and other uncontrollable factors to make their way back to society. To manage and improve this process, CERN and most of the public research organizations put in place knowledge transfer units with the objective to foster innovation, promote entrepreneurial activity, and maximize the impact of public research in society.

To this end, CERN drives its knowledge transfer activities with policies that focus on maximizing the impact of new technologies rather than generating economic value – by positioning on knowledge dissemination. However, measuring the economic and social impact of technology transfer through knowledge diffusion is far from trivial (Vetle & Anelli, 2016). Additionally, how many technologies from public research environments with innovative potential stay inside the lab because of knowledge-gaps or insufficient technological maturity levels, caused by the distance between business and the public research?

Upstill & Symington (2002) present three distinct modes for the transfer of technology from public research agencies to the business sector:

- Non-commercial transfer: seminars, informal contacts, publications, secondments, and staff exchanges and training.
- Commercial transfer: collaborative research, consulting, licensing and sale of IP, technical services
- New company generation: direct spin-offs, indirect spin-offs, and technology transfer technologies.

CERN currently exploit most of these mechanisms. As a publicly funded organization, it must engage in knowledge transfer and demonstrate its economic and societal value back to its Member States. However, the way public research organizations were originally designed may influence their knowledge transfer potential. For example, mission's statement, funding models, governance, policies, processes or culture may not align with second order objectives – such as maximizing the economic or social impact of technological spillovers resulting from research.

For example, licensing technology in exchange of equity in a start-up company became an effective way to support entrepreneurs who will assume the risks of starting a new venture. Through this mechanism, the entrepreneur will avoid paying royalties in a phase when cash is a scarce resource, and still allow the parent organization to capture value if the venture is successful. Licensing for equity send a strong signal of commitment from the parent organization to the spin-off, and in addition supports the development of the licensed technology.

This mechanism is not allowed at CERN from the Organization's obligation to not engage in commercial activity (CERN, 2010), conflicting with a licensing model with demonstrated results. Licensing for equity plays now a major role in the creation of new start-ups in universities, science parks, incubators, and other institutions – with consequent impact on local employment and economic development (Clarysse, Wright, Lockett, Velde, & Vohora).

Starting from CERN openlab – a public-private partnership with leading ICT companies and research organizations, and a player in the innovation and knowledge transfer arena (CERN Knowledge Transfer, 2019) – we aim at understanding the innovation and technological ecosystem at CERN, extending the analysis to the multiple dynamics in the Organization that impact the knowledge transfer and innovation potential. Then, based on the case study methodology supported by academic literature on research policy, knowledge transfer, and entrepreneurship, complemented with the result of qualitative interviews and the review of internal policies, propose a set of recommendations that can contribute to higher throughput.

1.2. Structure of the Document

This document is divided into five sections. Following the introduction, we explore the context at CERN – the European Organization for Nuclear Research – where we review part of the history, achievements, ongoing activities, and future challenges, with focus on the IT Department and CERN openlab. We continue with an in-depth review of the processes, organizational policies, and activities developed by the Knowledge Transfer group at CERN.

In the second section, we propose the research methodology selected for this project – the case study strategy – and define the case study design according to its principles.

The third section dedicates to the academic literature. It focuses on the evolution from the Triple Helix to the Quadruple and Quintuple Helix in the European context, the evolution of knowledge transfer activities since the Bayh-Dole Act – which made possible for US universities to exploit intellectual property protection and commercialization – the fundamentals of the Smart Specialization strategy – which was key for regional innovation strategies in the European context – and finally review the literature on best practices and strategies for technology transfer offices, innovating from big science institutes and the technology competence leveraging methodology.

The fourth section develops the findings from the research activities, including the result from qualitative interviews with senior managers at CERN – Alberto Di Meglio sponsor of the project and Head of CERN openlab, Giovanni Anelli Head of the Knowledge Transfer Group, Markus Nordberg Head of the Resources Development Unit, and Johannes Gutleber from the FCC Management Office at CERN. It completes with a review of internal policies at CERN that influence the knowledge transfer potential.

Based on the case study analysis, the document finalizes with a set of recommendations, grounded on fundamental assumptions, that can contribute to maximize the knowledge transfer throughput and innovation potential of the Organization.

1.3. About CERN

CERN is one of the largest scientific research facilities in the world. Physicists and engineers at CERN develop and operate some of the most complex scientific instruments to study fundamental particles to uncover what the universe is made of and how it works (CERN, CERN Mission, 2019).

Since its operation in 1954, the Organization accomplished significant breakthroughs. Among them, the experimental confirmation of the Higgs boson in 2012 – an elementary particle of the Standard Model theorized in 1964. The development and operation of the Large Hadron Collider, the world's largest and most powerful particle accelerator that consists of a 27-kilometer ring of superconducting magnets. The invention of the World Wide Web in 1989, initially as a method to exchange information between scientists that revolutionized communications worldwide.

More recently, the development of the Antiproton Decelerator – a complex apparatus to produce low-energy antiprotons for the study of antimatter. Forward looking, the High-Luminosity LHC, an on-going project that aims to increase the number of collisions by a factor of 10 to study matter in more detail by 2026, and the Future Circular Collider – a conceptual design report for a more powerful collider for the post-LHC era (CERN, Key achievements, 2019).

CERN's origins are traced to the 1940s during the Second World War when a group of visionary scientists identified the need for a world-class physics research facility in Europe. The objective was, both, limit the drain of scientists to America and provide an invigorating force for unity after the war in Europe. It followed with the establishment of a European Council for Nuclear Research at an intergovernmental meeting of the UNESCO in Paris in 1951. Two years later the final version of the CERN Convention was agreed and ratified by twelve Member States. The convention defined the ways the Member States would contribute to CERN's budget, organization and initial ethos – the development of science for peace on fundamental physics (CERN, Our history, 2019).

CERN'S MISSION STATEMENT

- *Provide a unique range of particle accelerator facilities that enable research at the forefront of human knowledge.*
- *Perform world-class research in fundamental physics.*
- *Unite people from all over the world to push the frontiers of science and technology, for the benefit of all.*

Today, twenty-three Members States are contributing to the capital and operating cost of the Organization through their representation in the Council, where all important decisions about CERN and respective scientific programmes are taken (CERN, Member States, 2019). The annual budget is around 1 BCHF (CERN, 2019 Annual Contributions to CERN budget, 2019).

CERN plays a vital role advancing the frontiers of technology. For example, through the collaboration of more than 1300 contributors to the FCC Conceptual Design – a possible

100 km superconducting proton accelerator ring with an energy up to 100 TeV named Future Circular Collider – CERN is introducing the challenge to develop new technologies for a sustainable deployment and efficient operation for a new scientific instrument. This project shows potential to improve our knowledge of fundamental physics and advancing technologies with a broad impact on society, as stated by Fabiola Gianotti CERN Director-General (CERN, FCC publishes concept design for a post-LHC future circular collider at CERN, 2019).

Through the development and operation of its accelerators complex, CERN developed unique expertise on a range of fields. From materials, to superconductivity, detectors, computing, industrial controls or cryogenics, among many others, the experimental research environment demands ultimate performance making the laboratory a unique place to develop and test technologies that may be relevant for the industry.

In addition to the invention of the World Wide Web, CERN was at the origin of many other technologies that impact our everyday life. For example, back in the 1970s, Bent Stumpe invented the capacitive touchscreen and the trackball to replace thousands of buttons, knobs, switches or oscilloscopes needed to operate the SPS accelerator. The industry adopted the technology immediately and was introduced many years later on the smartphone industry (CERN, 2010). Similarly, the particle accelerators and detectors developed at CERN find today multiple applications on medical field for diagnosis and therapy of cancers (CERN, Our research, 2019).

1.4. CERN IT Department

The CERN IT Department provides the information technology required for the fulfilment of CERN’s mission in an efficient and effective manner. It includes data processing, storage, networks and general-purpose IT services for the laboratory’s users and staff. Moreover, it provides the ground for advanced research and the development of IT technologies with other research institutions and industry, namely through the CERN openlab framework (CERN, Information Technology Department, 2019).

It operates the CERN Data Centre to power the entire scientific, administrative and computing infrastructure. It is located in the CERN main site and extends to a remote location at Wigner Budapest for higher computing power and redundancy purposes. More than 15000 servers provide 230000 processor cores and 90000 disks for 280PB of data capacity. Long-term storage is done with tape cartridge technology operating 30000 units which provide 400PB of capacity (CERN, Data Centre, 2019).

The LHC largest detectors – ATLAS, CMS, ALICE and LHCb – are compared with digital cameras with 100 million electronic channels capable of capturing 40 million pictures per second – representing 1PB of data per second. Existing computing systems are incapable of writing such volumes, hence the experiments are filtering the data to capture the most relevant events, on average at 1PB per day (CERN, Processing: What to record? , 2019).

The LHC data is aggregated in the data centre, where there is an initial data reconstruction and a copy for long-term archival on data tape storage. A second copy is sent to large-scale data centres worldwide members of the WLCG – global collaboration linking grid infrastructures and computer centres worldwide – that will then redistribute the data to perform computations. The WLCG is distributed across 172 data centres in 42 countries developing 900000 cores – 20% are from CERN. More than 10000 physicists access the LHC data and more than 300000 jobs run concurrently on the grid (WLCG, 2019).

The continuing physics programme is entering to the post-LHC era with the High-Luminosity LHC, which should start by 2026. The new version of the LHC should increase the collisions rate by a factor of 10 which will significantly stress the demands on ICT (CERN, Key achievements, 2019). The total computing capacity required by the experiments is expected to grow 50 to 100 times and the storage capacity to the exabytes range. The computing, software challenges, and roadmap for the high-energy physics is documented in a whitepaper detailing a complete programme of work including physics generators, detectors simulation, event reconstruction, data analysis, machine learning, distributed computing, data and software preservation, among many others (Foundation, 2017).

In parallel, the IT Department collaborates with industrial partners to develop new knowledge in ICT. Through CERN openlab it evaluates advanced solutions and makes joint research available to the worldwide community of scientists working for the LHC. We review now the CERN openlab framework to understand how CERN works as a testbed for the development of novel technology.

1.5. CERN openlab

CERN openlab is a public-private partnership with leading ICT companies and other research organizations or universities through which CERN accelerates the development of cutting-edge solutions. The complexity of the scientific instruments makes the facility an ideal environment for joint R&D projects. By granting access to its complex ICT infrastructure and engineering experience, CERN allows industry partners to test their state-of-the-art solutions and upcoming technologies in a unique environment and receive valuable feedback on their products. In exchange, CERN can assess new technologies at early stages of development for future use and develop new ideas and technologies (CERN openlab, 2017).

CERN openlab has been running for 19 years through three-year phases, each with around 20 projects in a wide range of IT topics. The collaborating companies usually engage with a combination of cash and in-kind contributions to hire young ICT engineers who will work on joint R&D projects. For example, Intel and Oracle have spent over 15 years collaborating with CERN openlab, demonstrating the long-term and strategic relationship between organizations.

During the first phase between 2003 and 2005, CERN openlab focused on the development of an advanced computing-cluster prototype named "*opencluster*". It expanded to a wider range of domains during the second phase resulting on valuable innovations on energy-efficient computing, grid interoperability and network security. During the third phase between 2009 and 2011, it focused on virtualization of industrial-control systems and 64-bit computing architecture. With the fourth phase, it addressed crucial topics for CERN's scientific programme, such as cloud computing, business analytics, next-generation hardware, and security aspects for the growing number of networked devices in prediction of the Internet of Things. The fifth phase, between 2015 and 2017, focused in domains such as data acquisition, computing platforms, data storage architectures, compute provisioning, network communications, and data analytics (CERN openlab, 2018).

By the end of 2017, CERN openlab published a whitepaper (CERN openlab, 2017), opening the way for the sixth phase with 16 key challenges divided in four R&D topics, including *(i)* data-centre technologies and infrastructure; *(ii)* computing performance and software; *(iii)* machine-learning and data analytics; and *(iv)* the application of the framework to disciplines beyond high-energy physics, including smart platforms for science, machine learning for large-scale systems, and computer simulation on complex biological systems (CERN openlab, 2019).

Additionally, CERN openlab contributes to the education of young scientists and engineers with a summer-student programme. Students worldwide come to the laboratory to receive technical courses given by experts on CERN-related topics, which extends with specific development projects related to ICT at CERN.

Today the industry partners include Siemens, Intel, Oracle, Micron, T-Systems, Google, IBM, Extreme, E4 Computer Engineering, Comtrade, Open Systems, but also renowned universities and academic institutes like INFN, Newcastle University, Fermilab, EMBL-EBI, King's College London, the Innovation Value Institute, the European Society for Preventive Medicine, the University of Eindhoven, and the SCimPulse Foundation.

1.6. Opportunity for Innovation and Technology Commercialization

Alberto Di Meglio Head of CERN openlab, exposes a global challenge that public research organizations, with similar characteristics to CERN, face to maximize the innovation potential from their technology spillovers, in return to the disposition from their funding agencies.

Big science research organizations, usually funded by multiple countries have specific mandates to perform fundamental and basic research, and commonly enjoy from privileges and immunities that facilitate the development of technological breakthroughs to achieve their missions. Significant efforts are put in place to make sure that those technologies make their way back to society – namely through knowledge transfer offices. However, these research organizations also have organizational constraints that create barriers to the flow of knowledge transfer. Managing multiple stakeholders, avoiding conflict of interest, complex administrative processes, and slow decision-making are examples of structural dynamics that are limiting the innovation potential.

In order to support the development of new ventures from CERN's ecosystem, members of the senior management discussed in the past the creation of an innovation park. However, such structure on CERN's premises was considered to favour the Member States hosting the laboratory – Switzerland and France. Such decision led to the development of a network of business incubators – BICs – distributed throughout the Member States, with the purpose of assisting entrepreneurs and businesses in taking CERN technologies and expertise to the market (Transfer K. , BIC Network, 2019).

However, according to Alberto Di Meglio the physical distance between the laboratory and the business incubators strongly impacts the effectiveness and potential. The laboratory produces high-technology, also known as frontier technology, where the collaboration with the scientists and engineers developing the knowledge is critical. There are knowledge gaps between the technology and entrepreneurs which creates barriers for the development of spin-off activity. Additionally, the physical distance and associated risk does not justify the opportunity cost for the entrepreneurs reaching the incubators.

Based on different approaches from research institutes with similar characteristics to CERN – such as EMBL – there is the willingness to explore alternative models, with the final impetus to bridge the gap between CERN's technology and society. Such can happen through a separate legal entity that could "*go over*" the current "*boundaries*", and with sufficient autonomy maximize the knowledge transfer efforts and innovation potential.

Moreover, such structure with the autonomy to commercialize products or services could channel researchers ending their affiliation with CERN to work on projects with innovative potential. Commercialization efforts could generate financial revenues that could revert back to the laboratory and contribute to research activities funding.

1.7. Knowledge Transfer at CERN

Since its creation in 1954, CERN was mainly transferring technology through procurement contracts and collaboration agreements. The knowledge transfer activities started in 1988 with the creation of the CERN Industry and Technology Liaison Office to stimulate the relationship with the industry and assist CERN on intellectual property aspects. In 1997, the activity was reinforced with the establishment of an internal policy and a dedicated team (CERN, CERN Knowledge Transfer, 2017).

CERN is employing multiple modes of technology transfer – from licensing intellectual property, to developing software and hardware with open-source models or engaging on international collaborations with research organizations or industrial partners. These activities are ruled by internal policies that we review in the fourth section.

More than twenty years later, 26 start-up companies around the world are using CERN technology. CERN established a network of Business Incubation Centres – BIC's – in nine Member States to boost entrepreneurship activity with CERN's technology. This is the result of CERN's embodied motivation to develop opportunities and bridge the gap between science and society (CERN, CERN Knowledge Transfer, 2017).

The Knowledge Transfer group identified 18 technology domains of CERN expertise with application on fields ranging from medical & biomedical technologies, aerospace, safety, industry 4.0, cultural heritage and emerging technologies. Based on the work of Nilsen and Anelli (Vetle & Anelli, 2016), we review the principal modes of knowledge dissemination exploited by CERN.

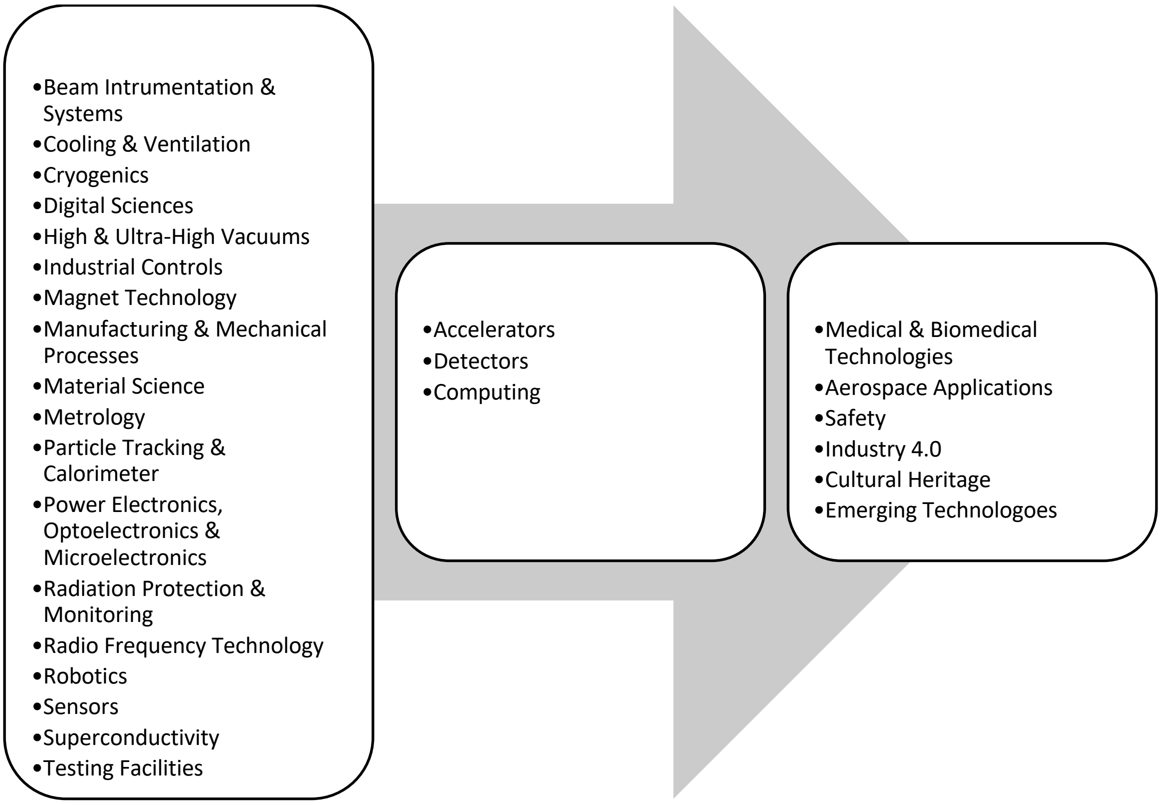

Figure 1 – CERN technology domains and field of application. Adapted from https://home.cern/about/what-we-do/our-impact

1.7.1. Publications

Most fundamental research is disseminated through active publication – as driven by the Organization's motivation to expand knowledge. A significant part is published via Open Access – an online method, free of cost with an additional open license that removes most restrictions for reuse (SPARC, 2019). In 2014, CERN in collaboration with international partners launched the SCOAP3 initiative, converting most journals in the particle physics field to Gold Open Access at no cost for authors – meaning peer-reviewed articles available to readers free of charge (CERN, Open Access Policy for CERN Publications, 2017).

1.7.2. Patents and Licensing

Upon the internal disclosure of new technologies there is an evaluation of the patentability. The motivation for patents is to support the case when industrial partners need significant resources, in time or capital, to commercialize the technology. In 2007 more than 60 percent of the patent portfolio was licensed generating around 1.5 MCHF (Jewell, 2008). CERN uses WIPO's Patent Cooperation Treaty (PCT) to fill its patents globally more efficiently (Marks, 2010). It also benefits from an agreement with WIPO for support in the case of patent disputes. The portfolio includes now around 300 patents over 50 families (Vetle & Anelli, 2016).

By definition, patenting is not essential for open science environments, however with the development of industrial applications of CERN's technology, it became essential to bring technology to higher maturity stages – by ensuring exclusivity to protect capital investments. Such paradigm change asked for the development of intellectual property (IP) awareness among the scientific and engineering community. The internal knowledge transfer unit expanded its activities with patent portfolio managers available to undertake prior art searches, grant inputs to R&D efforts, support for decisions, and patent submission. IP that is not licensed is accessible through the Easy Access IP initiative where inventions are available for free under a one-page agreement (CERN, CERN adopts new intellectual-property access scheme, 2012).

The licensing policy at CERN rules that royalty revenues returns in part to the department and group where the invention originated, as an incentive for the community to seek for patentability.

1.7.3. Collaborations, Service and Consultancy

It is beyond CERN's mandate to respond to contract research requests, however the Organization provides consultancy services for the transfer of CERN's specific knowledge. The form of collaboration agreements for R&D projects is developing on a wide range of fields from hadron therapy, to augmented reality, compact accelerators or collaboration and events management software.

For example, in the aerospace field and in collaboration with leading institutes like CNES, ASI and ESA, CERN's irradiation facilities hosted several test campaigns for the aerospace community – leading to the development of the CELESTA technology and selected by ESA in the "*Fly your Satellite*" programme (CERN, CERN Knowledge Transfer, 2017). On the Cultural Heritage side, in collaboration with INFN, CERN developed a reduced version of an accelerator that can be transported to museums and businesses to study the history and authenticity or artworks (Transfer C. K., 2019) – demonstrating the wide range of application of CERN's technology and openness to reuse its facilities.

1.7.4. Open Source Software and Hardware

Most of the software developed at CERN is released under free and open source licences – except under specific conditions such as when the application field is specialized and there is expressed interest from a commercial partner. Hence, technologies are developed with open access in mind to maximize the dissemination and impact. For example, the case of Invenio, an open-source library management system developed with contributions from multiple institutes worldwide. It serves as the foundation for other software packages distributed by CERN, such as Indico or Zenodo – a free repository to store data, software and research artefacts (CERN, Open source for open science, 2019). Similarly, the ROOT data analysis framework has application on multiple fields. Originally developed for particle physics data analysis it is now used in astronomy, data mining, telecom, finance, aerospace and the insurance industry (CERN, Root Data Analysis Framework, 2019).

Back to 2009, hardware engineers from the Beams Department inspired by the open software philosophy created an open repository for hardware design. It followed with the CERN Open Hardware License, providing the legal ground for the study, modification, distribution, make and sell of hardware design artefacts. Today 23 companies are involved with the initiative either through hardware development or commercialisation (OHWR, 2019). Its impact reached the developing world, in particular Asia and Africa, where the open-science model is enabling multiple *do-it-yourself* initiatives and developing student's confidence (Brazil, 2018).

1.7.5. Spin-off and Start-up Companies

CERN currently counts with 26 spin-off companies. Efforts to support this way of dissemination started in 2013 with the creation of a policy – reviewed in the fourth section – internal training, and activities to develop the entrepreneurial mind-set within the organization. This mechanism can serve as an alternative career path for staff, students of fellows with limited term contracts (Vetle & Anelli, 2016). The Knowledge Transfer group organizes weekly meet-ups to debate topics related to innovation and entrepreneurship with invited guests (Transfer K. , Entrepreneurship Meet-Ups, 2019).

Through the Business Incubation Centres (BICs), CERN assists entrepreneurs and small businesses to take CERN technologies and expertise to the market (Transfer K. , BIC Network, 2019). CERN supports the knowledge transfer activity with the mechanisms described so far, combined with the local incubator, which provides office space, business expertise, support, local networking and access to finance. In 2017 five start-up companies were accepted in the BIC's – InnoGex in France, Technopolis in Greece, STFC-CERN in the UK and the Finnish BIC.

1.7.6. EU-Funded Research Projects

The participation of CERN on EU-funded research projects facilitates the knowledge dissemination for projects that CERN would not necessarily join, but can contribute with technical expertise. Between 2007 and 2013 under the FP7 programme CERN participated in 86 projects and coordinated 36 – ranging from R&D on accelerators upgrades, particle therapy for cancer treatment, to new research for grids and smart cities, or knowledge preservation with CERN software (Vetle & Anelli, 2016). Today, CERN participates with research projects under the H2020 framework.

1.7.7. Human Capital

CERN actively contributes to the training of the engineers and scientists of tomorrow – as education is a pillar of the Organization's mission. CERN developed a series of student and apprenticeship programmes covering multiple topics and levels of education. It includes the CERN Teacher Programmes, S'Cool Lab, High-School Students Internship Programme, Beamline for Schools, and other opportunities for students from interns to doctoral students (CERN, 2019).

For example, the Summer Student programme gives the opportunity to around 300 students worldwide to benefit from lectures on physics, engineering and computing topics for 8 to 13 weeks during the summer. So far more than 6000 young students benefitted from this experience, featuring a high-quality programme combined with visits and workshops inside CERN's technical environment. Or the Technical Students programme, which gives the opportunity to around 200 students to develop their bachelor/master thesis at CERN during 4 to 14 months. It is complemented with the Doctoral Student's programme with 60 positions a year. Last, the Fellowship programme with approximately 220 positions a year for recent graduates, which contribute to the development of the scientific programme.

2. Methodology

Yin (1994) suggest that, in general, case studies are the preferred strategy when: *(a)* "how" or "why" questions are the focus of the research; *(b)* when the researcher has little or no control over the events in the context of the analysis; *(c)* the contextual conditions are covered because they are relevant to the phenomenon under study; or *(d)* the boundaries between the phenomenon and context are not clear. Additionally, over the last few years, case studies demonstrate being popular in innovation research because of their exploration and understanding of complex social changes associated with emerging technologies (Engels, Wentland, & Pfotenhauer, 2019).

From a philosophical standpoint, Yin grounds his approach on a constructivist paradigm. Constructivists argue that truth is relative and dependent on one's perspective (Baxter & Jack, 2008) . The paradigm recognizes the importance of the subjective human creation of meaning, but doesn't reject some notion of objectivity (Crabtree & Miller, 2008). Hence, constructivism is built upon the premise of a social construction of reality (Searle, 1995). The collaboration between the researcher and participants happen through stories, that allow participants to share their views of reality, enabling the researcher to understand the participant's actions (Lather, 1992).

2.1. Case Study Design

Yin (1994), proposes five components for research design: *(1)* study questions; *(2)* propositions; *(3)* units of analysis; *(4)* logic linking the data to the propositions; and *(5)* the criteria for interpreting the findings. The research design consists of the logic that links the data to be collected and the study questions. To maximize the design quality, the following aspects of quality control are taken into account: *(a)* construct validity; *(b)* internal validity; *(c)* external validity; and *(d)* reliability.

The research process started as an "*Opportunity for Innovation and Technology Commercialization*" described in the section 1.6, which geared towards an in-depth "*Case Study About the Knowledge Transfer at CERN*" – understood as the organizational entity with the capabilities to materialize innovation. Consequently, the unit of analysis proposed by the Case Study strategy narrowed down into *the organizational dynamics at CERN that influence the knowledge transfer potential* – that is the fundamental problem we are exploring in this analysis.

The research work started with extensive review of the academic literature and internal documents analysis to provide sufficient ground to start with the second phase with the qualitative interviews. Four senior managers at CERN were interviewed during the summer of 2019. The participants were selected taking into account their experience and exposure to knowledge transfer and innovation activities. All demonstrated openness – as part of CERN's spirit – in sharing their knowledge, views, opinions, and demonstrated willingness in following up the development of the report. The participants are:

- Alberto Di Meglio sponsor and supervisor of this project is currently the head of CERN openlab in the IT Department of CERN. He is an Aerospace Engineer (M.S.) and Electronics Engineer (Ph.D.) with extensive experience in the design, development and deployment of distributed computing infrastructures and software services. Joined CERN in 1998, then co-founded a start-up company developing monitoring systems and distributed computing networks. In 2004 joined CERN again to take part in the early stages of development of grid computing for research, becoming later the director of the European Middleware Initiative (EMI) (CERN openlab, 2019).
- Giovanni Anelli is the head of the Knowledge Transfer group since 2011. He is an Electronics Engineer (M.S., Ph.D.) and holds an EMBA from HEC in Paris. He worked 10 years in CERN's Microelectronics Group, where he designed several low-noise low-power analog and mixed signal VLSI circuits for High-Energy Physics applications. His research work focused on techniques to design radiation tolerant integrated circuits in deep submicron CMOS technologies, becoming an approach which is now employed by the large majority of integrated circuits of the LHC at CERN (CERN Knowledge Transfer, 2019).
- Dr. Markus Nordberg is the Head of Resources Development of the Development and Innovation Unit at CERN. He holds a degree both in Physics and Business Administration. He coordinates multi-disciplinary innovation projects at IdeaSquare at CERN and the EU-funded sensor and imagining R&D&I called ATTRACT aimed at scientific and societal impact of disruptive co-innovation. Prior he served 12 years as the Resources Coordinator of the ATLAS project at CERN and as Visiting Senior Research Fellow at the Centrum voor Bedrijfseconomie, Faculty ESP-Solvay Business School,

University of Brussels, and as a member of the Academy of Management, Strategic Management Society and the Association of Finnish Parliament Members and Scientists, TUTKAS (ATTRACT, 2019).

- Dr. Johannes Gutleber is a senior staff member of CERN. He obtained Diploma-Ingenieur and Doctoral Degrees in informatics from the Technical University Vienna, Austria in 1997 and 1999. From 1997 to 2008 he designed, implemented and commissioned the CMS experiment's on-line data acquisition software system at CERN's Large Hadron Collider. From 2009 onwards, Dr. Gutleber was in charge of the control systems and ICT infrastructures of the MedAustron ion particle accelerator project for cancer treatment at CERN. Since 2014 he is in charge of international collaborations in the Future Circular Collider study. In this role, he focuses on EU innovation and training actions, socio-economic impact studies and concepts to generate regional benefits in a global research infrastructure project. Since 2016, Dr. Gutleber is chairing working groups with representatives of French and Swiss authorities to develop a strategy and actions for a long-term sustainable development of CERN's future research infrastructure in the region.

The interviews followed a semi-structured, narrative-generating approach (Flick, 2010). Taking into account the organizational dimension of the case, Galbraith's STAR model (2011) was used to develop and categorize the questions. Galbraith (2011), identifies five elements within the STAR: *(i)* strategy; *(ii)* structure; *(iii)* processes; *(iv)* rewards; and *(v)* human resources. These elements provide a comprehensive map to define the data collection activities and research questions. The guiding questions for the interviews are listed in the table below.

ELEMENT OF THE STAR MODEL	***QUESTION***
STRATEGY	• *From a mission perspective what is the role of CERN in relation to knowledge transfer?* • *How do you rate the priority level of knowledge transfer for CERN?*

	• *What are the strong/weak points CERN has for the creation of technology? And Innovation?* • *How do you compare the case of CERN with other public research organizations?* • *How would you maximize the potential from a governance perspective?*
STRUCTURE	• *What processes or organizational entities are impacting knowledge transfer?* • *What are the implications of potential changes?*
PROCESSES	• *What is the effectiveness of the existing knowledge transfer processes?* • *What internal policies are impacting technology transfer?* • *Is there sufficient/motivation support for staff's to spin-off CERN's technology?*
REWARDS	• *What is your view about direct incentives for inventors at CERN?* • *How much direct incentives, could diverge the focus on the research activities?*
HUMAN RESOURCES	• *Is/should intellectual property management part of the mind set of scientists and engineers at CERN?* • *Do/should we have the necessary competence to create innovation?* • *Does our culture embrace commercialization?*

Table 1 – Guiding questions for semi-structured interviews categorized using the STAR model (Galbraith, 2011).

The insights obtained during the interviews were generalized and described in the fourth section, organized by topics. Occasionally, the discussions moved to topics beyond the scope of the case study. The most common, was about whether shall CERN or its Member States should adjust the Organization's mission statement to give stronger emphasis on the maximization of its innovation potential? Or shall CERN review its identity as a laboratory and focus on fields beyond high energy physics?

These are clear boundaries going beyond the purpose of this work. While discussions around these topics was necessary to understand the context, going further and developing an opinion was considered unnecessary. Those are boundaries that define the fundamental assumption for this case study, that is – *knowledge transfer and the maximization of its innovation potential becomes a strategic priority*. The focus is then given to understanding what, and how to support the development of that main assumption.

The generalization of the qualitative interviews was triangulated with supporting documentation – namely through internal policies at CERN and documents publicly available, all referenced at the end of the document.

3. Literature Review

Through an analysis of the current dynamics on knowledge transfer in research and academia in general, we can obtain valuable lessons, frameworks, policies and theories to ground the development of recommendations for this case study. We start by developing an understanding of the role of publicly funded research organizations towards innovation and spillovers to society.

3.1. Context from the Triple Helix Perspective

The transfer of scientific and technological innovation into economic value became a high-priority on many political agendas. It is recognized that the economic performance, in terms of innovation and productivity, is strongly influenced by the character and intensity of the interactions and processes between producers, users, suppliers and public authorities (Foray D. , 1995).

The Triple Helix model developed the literature on technology policy during the 1990s. It defined the interaction between industry, academia, and government, through innovation and entrepreneurship in an evolving knowledge-based society (Etzkowitz & Leydesdorff, 2000). It is a universal innovation model assisting students, researchers, managers, entrepreneurs, and policy makers to understand the roles of university, industry and government in forming and developing "*innovative regions*" (Etzkowitz & Zhou, 2017).

Subsequently, there has been a continuous transformation of the economic players within each of the components of the helix. The university has transformed from a teaching institution into one which combines teaching with research. Most countries are reshaping their innovation environment based on the Triple Helix principles. The common objective is to create an innovative environment composed by university spin-off firms, tri-lateral initiatives for the development of knowledge-based economic value, and strategic alliances among firms, government laboratories and academic research groups (Etzkowitz & Leydesdorff, 2000). These dynamics are encouraged, but not controlled, by the government – an example is the Bayh-Dole Act in the US which gave the right to universities to license inventions from federal research funds (Nelson, 2001).

The Triple Helix has been used as policy making tool, that according to the authors, inspired governmental policies that tied together different initiatives at different scales to consequently increase the overall efficiency (Etzkowitz, University-Industry-Government:

The Triple Helix Model of Innovation, 2007). It developed innovation by blurring the boundaries between the university, industry, and government – for example, universities started taking a relevant role on patenting and licensing, moving beyond from basic research (Etzkowitz, 2003).

Technology transfer organizations (TTO) emerged in universities and research institutes to bridge the gap between the industry and science. The OECD (2011), identifies the following roles for TTO's:

- Establish relationships with firms and community actors;
- Generate new funding support from sponsored research or consulting opportunities;
- Provide assistance on all areas related to entrepreneurship and intellectual property (IP);
- Facilitate the formation of university-connected companies utilizing public research organization's technology (start-up) and/or university people (spin-off) to enhance prospects of further development; and
- Generate net royalties for the public research organizations and collaborating partners.

Despite the maturity of the knowledge transfer activity in Europe, there is still a gap comparing with the U.S. For example, the Community Innovation Survey shows that only 10% of the innovative firms in the EU have cooperative agreements with universities (Debackjere & Veugelers, 2005). In 1995, the "*European Paradox*" was coined on the European Commission Green Paper. It argues about Europe playing a major role in scientific excellence – measured by the number of publications – but lacking the entrepreneurial activity to transform this performance into innovation, growth, and jobs. Since then, multiple authors focused on this paradox, questioning its validity (Dosi, Llerena, & Labini, 2006), or announcing its end (Herranz & Ruiz-Castillo, 2012). Hence, the "*European Paradox*" provided significant substance for academics to explore the missing link between science and the industry (Dedrick & Kraemer, 2015).

The case of the discovery of the giant magneto-resistance (GMR) by French and German scientists and its development and commercialization by U.S. and Japanese manufacturers is a classic example of the paradox (Dedrick & Kraemer, 2015). While the scientists and labs received the Nobel Prize and approximately $10M in royalties, IBM and other players from the hard-disk-drive industry obtained several billions from the invention. Dedrick and Kraemer (2015), point to the importance of the absorptive capacity at the firm and national levels to capture benefits from innovation. The absorptive capacity consists of a range of learning and problem-solving skills needed to address tacit components of external knowledge to create value through modifications (Mowery & Oxley, 1995). Absorptive capability can be a source of competitive advantage when it enables superior performance with external knowledge (Escribano, Fosfuri, & A.Tribó, 2009).

Additionally, the appropriability regime in the industry plays a determining role – i.e. the environmental factors, excluding the firm, that govern the ability to capture profits (Teece, Profiting from technological innovation: implications for integration, collaboration, licensing and public polict, 1986). The appropriability level on innovations will determine the firm's level of investment in absorptive capacity. In the case of low appropriability, the capacity to capture value will be low and consequently the incentive to invest in the absorptive capacity will be lower (Cohen & Levinthal, 1990). Scholars argue that over time, as the industry matures the absorptive capability will converge across firms, making it harder to sustain it as a competitive advantage. The appropriability regime within an industry can vary across countries – as local policies, for example on the value of patents, will affect how companies can capture value (Schacht, 2005).

Through the GMR case, Dedrick and Kraemer (2015) argue that countries can help their firms and industries by creating an environment that supports the development of the absorptive capability – for example through research structures that capture external knowledge and disseminates to firms. As an example, France created the Spintec Research Institute – which monitors scientific and engineering developments in spintronics that might convert into opportunities for firms in the sector.

The Quadruple and Quintuple Innovation Helix developed along the ideas of the Triple Helix by including new components on the economic model – namely, the civil society and users. Similarly, the competence bloc theory (Eliasson & Eliasson, 1996), identifies seven actors that are indispensable to bring innovations to the market: competent and active customers, innovators, entrepreneurs, skilled labor, venture capitalists, exit markets and industrialists.

3.2. Technology Transfer from the University/Science Perspective

Based on the work of Debackere & Veugelers (2005), we identify the typical types of interactions between the industry and science that aim at improving the exchange of knowledge and technology:

- Technology oriented start-ups generated at research institutes;
- Joint R&D between firms and research institutes;
- Contract research based on consulting commissioned by the industry;
- Management and development of intellectual property portfolio;
- Activities related to advanced education, training, research staff exchange between companies and research institutes.

In publicly funded research organizations with applied or fundamental research mission, such as the case of CERN, the network links with the industry develops almost organically – namely through the ongoing work to develop and operate complex scientific instruments. Debackere & Veugelers (2005), argue that in many cases, the intensity and frequency of these links are seen as a performance indicator. Making the comparison with university research, science-based innovations have a multidisciplinary character, are people-centred, and built on knowledge difficult to codify. On the other hand, university-based systems, which benefit from a broader education mission enjoy a competitive advantage when comparing with research institutions (OECD, 2001).

One problem with technology transfer that affects both universities and research organizations, is the asymmetric information between the industry and science on the value of innovations. Firms typically cannot evaluate the quality of inventions before their commercialization, while researchers may have difficulty to assess the commercial profitability of their inventions. Additionally, the lack of understanding of each partner's culture can translate to conflicting objectives – for example, knowledge dissemination versus commercial appropriability of innovations. Additionally, general-purpose technologies, with multiple applications, are more likely to be exploited by technology entrepreneurs, while more specific technologies increase the barriers to entry (Debackjere & Veugelers, 2005).

Siegel, Waldman, & Link (1999), based on interviews at five major U.S. research universities identify critical organizational factors that impact university technology transfer. The most important ones are: faculty tenure – i.e. the grant of a permanent job contract in academia after a probation period, promotion policies, royalty's distribution, and the right combination mix between scientists, lawyers and managers within the knowledge transfer office – combined with the gatekeeping role acting as a bridge between science and industry. While these insights were obtained from a university context, we will look to understand whether they apply to research organizations through this project.

Another study focused on the European context (Polt, 2001), argues about the scale of most companies being below the necessary critical mass to stimulate the industry-science link. The same study prompts for combining basic and applied research within research teams and processes to align with changes in economy and society. Additionally, a direct transfer between researchers and the industry – i.e. avoiding intermediaries – and a day-to-day proximity to the researchers. Completed with complementary assets for effective technology transfer, access to venture capital and attractive incentives to reward transfer activities.

Again, based on the work of Debackjere & Veugelers (2005), the K.U Leven Research & Development stimulated the exploitation of the university's research through mechanisms that promoted entrepreneurial behaviour within research divisions. From an organizational perspective, the university developed a context of autonomy where researchers belonging to different departments or faculties could join efforts to integrate commercial-industrial components of their knowledge portfolio. Hence creating an interdisciplinary matrix structure within the university.

Additionally, close tights were ensured between research groups and the knowledge transfer structure through innovation coordinators. Coordinators were partially paid by the knowledge transfer unit to act as a liaison officer between the research and the knowledge transfer units. The rest of the time they acted as researchers within one division. From an incentive's perspective, the university rewards researchers with up to 30% of the generated income from licensing or royalties – after expenses are paid – and in the case of spin-off researchers can receive up to 40% of the intellectual property shares. The matrix structure along with the right incentives mechanisms creates a system where research excellence prevails, and the entrepreneurial/industrial activity is rewarded – requiring the right balance in mechanisms to coordinate research and innovation guaranteeing sufficient autonomy to engage in entrepreneurial activities.

In order to assist entrepreneurs, the university created its own venture capital fund in partnership with banks to fund start-up companies. Funding complements with access to an innovation and incubation centre located in the university campus – highlighting the importance of physical proximity with researchers and laboratories. It complements the seed development phase with access to close science parks that can house spin-off companies and other research institutions.

To complete the circle, the Leuven University founded the Leuven MindGate to act as a network organization to connect the elements from the Triple Helix model – research groups, entrepreneurial start-ups, established industry firms, and supporting services such as consulting and venture capital. This structure highlights its difference by consolidating the region's position by improving interdisciplinary relations, cross-pollinating a unique ecosystem for companies, entrepreneurs, investors and international talent (MindGate, 2019).

3.3. Challenges Managing the Quadruple Helix Integration

The Quadruple Helix Model emerged to reflect a shift from the Triple Helix (government, university and industry) to include end-users and key stakeholders from the regional ecosystems (Leydesdorff, 2011). With the implementation of the framework, scholars focused on determining the challenges faced by universities when managing the stakeholder's integration within the commercialization process. These insights are relevant for the development of this project. McAdam, Miller & McAdam (2018), contribute to the literature with an analysis of the Helix on a micro-level through a lens on the interactions between stakeholders.

Perkman, et al. (2013), argue that multiple factors may influence the commercialization process with the stakeholders. These include technology transfer support, formal incentives, research environment quality, climate, discipline, organizational culture, public policy and regulation, and organizational strategic agendas which can all impact the individual motivation to collaborate with stakeholders.

McAdam, Miller, & McAdam (2018), discuss about conflicting demands between academics and the industry leading to disharmony and divergence in strategic decisions during the commercialization processes – increasing the pressure on scarce resources. The tensions are observed both at the organizational and personal level. Some universities are developing an ambidexterity role by developing career paths for teaching, research, enterprise and technology commercialization (Ambos, Makela, Birkinshaw, & D'este, 2008). It is accepted that the engagement of the Quadruple Helix stakeholders in commercialization processes requires significant resources.

Consequently, institutions need to create a supportive environment where academic entrepreneurs can make their own informed judgments to allocate their time to meet the needs for the alignment of the commercialization process (Gibson & Birkenshaw, 2004). On the micro-level, organizational challenges centre on culture, expectations, norms and mind-sets, impacting the level universities can fully engage with the Quadruple Helix stakeholders and align their technology commercialization (McAdam, Miller, & McAdam, 2018). Similarly, contextual influences have a prevailing impact when promoting the relationships. McAdam, Miller & McAdam (2018) argue that the academic entrepreneur perceived power, legitimacy and urgency – with respect to the technology commercialisation – was critical in determining the industry and end-user's engagement. Hence TTO's managers play a critical orchestrating role to maximise the effectiveness of Quadruple Helix stakeholder's relationships for technology commercialisation.

Further, a systematic literature review on university technology transfer from a Quadruple Helix perspective by Miller, McAdam, & McAdam (2018), shed light upon the elements favouring the transition from the Triple to Quadruple Helix. From a "*Mode 2*", knowledge production approach to commercialization, to a "*Mode 3*" knowledge system (Gibbons, et al., 1994), universities evolved into units of technology transfer that in addition to the classical technology transfer mechanisms – IP, licensing, patenting, and spin-out companies – introduced incubators and other technology bridge foundations on intermediaries which support the codification and commercialisation of knowledge in university context.

The inclusion of the fourth helix, introduces societal based innovation users in a co-creational manner, rather than being passive recipients. It switches from an innovation-push to innovation-pull where stakeholders reflect their commitment, influence and participation throughout the technology transfer project. The user involvement suggests an open innovation environment approach where knowledge from stakeholders are exchanged, rather than the more closed approach of the Triple Helix (Miller, McAdam, & McAdam, 2018). Equally, the closed innovation approach from technology transfer to commercialisation is becoming prohibitively expensive, hence the involvement of the end-users stakeholders becomes more attractive as it leads to potentially short development cycles (Prajapati, Tripathy, & and Dureja, 2013).

Miller, McAdam, & McAdam (2018), suggest an agenda for future research on the transition to the Quadruple Helix. Again, the tension between basic research and commercialisation is an emergent key where questions such as what mechanisms (e.g.

incentives, training) can help to balance basic research and co-creational technology commercialisation with the industry and societal based users? The development of stakeholder's relationships is another area of further research. For e.g. how "*softer*" infrastructures and social integration mechanisms can enhance relationship building and how contextual factors influence and level of engagement? Another area of research is the technology transfer organisational structure. Core to this project, what type of intermediaries, at the core of technology transfer, are needed to increase quadruple helix stakeholder engagement?

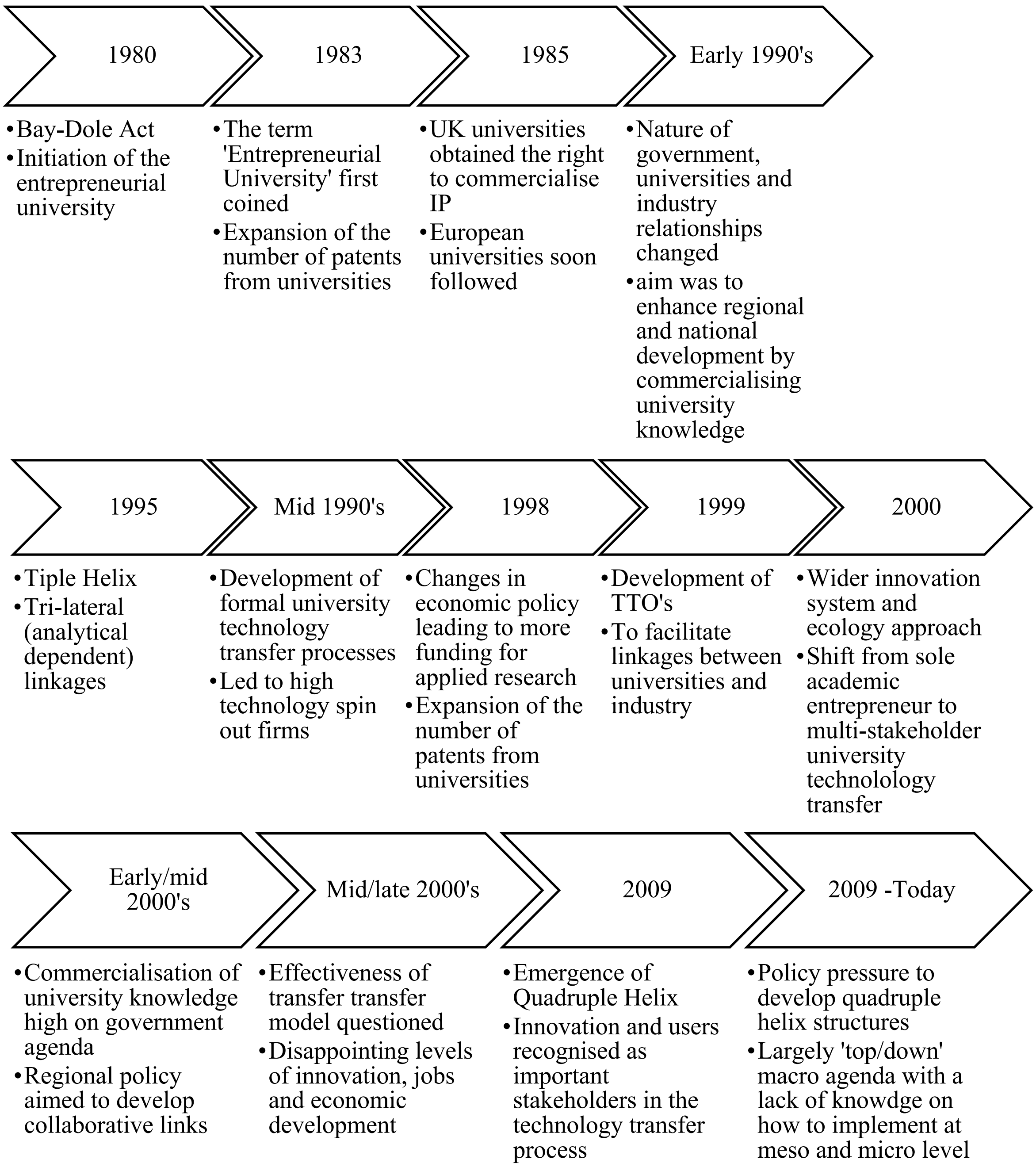

Figure 2 – Trajectory of entrepreneurial university and technology transfer stakeholder relationship. Adapted from Miller, McAdam, & McAdam (2018).

Scholars conclude that the exploration of the Quadruple Helix challenges is still in its early days and dominantly at a macro level. It reflects the need for micro-level focus to fully understand its complexity (Wright, Academic entrepreneurship, technology transfer and society: where next?, 2014).

3.4. Principles of the Smart Specialization Strategy

The concept of Smart Specialisation Strategy has emerged as a key element for regional-based innovation policies in the European Union. It consists of the national and regional innovation strategies which set priorities to build competitive advantage by developing and matching research and innovation strengths to business needs. It emphasises addressing emerging opportunities and market developments in a coherent manner, while avoiding duplication and fragmentation of effort. (Commission, National/Regional Innovation Strategies for Smart Specialisation (RIS3), 2014).

According to Carayannis (2001), The "*Mode 3*" knowledge system and Quadruple Helix models can serve as the foundation for smart specialization strategies as they emphasise focus on openness and cooperation in the innovation process. It aims at achieving innovation networks and knowledge clusters based on co-opetition (competition-cooperation), co-specialization and co-evolution on resource generation, allocation and appropriation through the actors of the model – government, academia, industry and civil society (Carayannis & Grigoroudis, 2016). Smart specialization focuses on a more vertical and non-neutral logic of intervention. It consists of a process of identification and selection of desirable areas for intervention, requiring technologies, fields and sub-systems within the framework of a regional policy.

Accordingly, Foray & Goenaga (2013) defined the following five principles of Smart Specialization:

1. *Granularity* – the level at which priorities are defined should not be too high – to avoid sectoral prioritisation – neither at a micro-level. The support should happen at the level of *activities.* As defined by the authors, the purpose:

   "*[…] is not to favour one particular firm but to support the development of collective action and experience aiming at exploring, experimenting and discovering new opportunities*".

By supporting activities, it improves the general performance of the sector and build capabilities while expanding the knowledge base towards new fields.

2. *Entrepreneurial discovery* – new activities should be generated from the entrepreneurial discovery process. Sources of entrepreneurship – innovative firms, research leaders. Independent inventors and innovators – are best positioned to discover the domains of R&D and allow innovation to happen locally. Consequently, policy makers should be able to differentiate between simple innovations and discoveries that have potential to generate new areas of specialization.
3. *Specialized diversification* – this principle emerges from the fact that after four or five years "*new activities*" are no longer new, as such, should no longer be part of the specialization strategy – whether they have failed or successfully reached maturity. Thus, new priorities can be funded and consequently achieve diversification.
4. *Inclusive strategy* – Within a regional economy, different sectors perform differently, and consequently it is easy to look only and the most dynamic part of the economy. This principle argues that through the entrepreneurship discovery process each sector should have the chance to be present in the strategy through a good project.
5. *Experimental nature* – the policy requires clear benchmarks and criteria for success and failure are needed. Because of the experimental nature of the policy – through entrepreneurial discovery – not all investments on activities will pay off. Hence, evaluation is central to that the support of particular lines of capability are not discontinued too early nor continued too long.

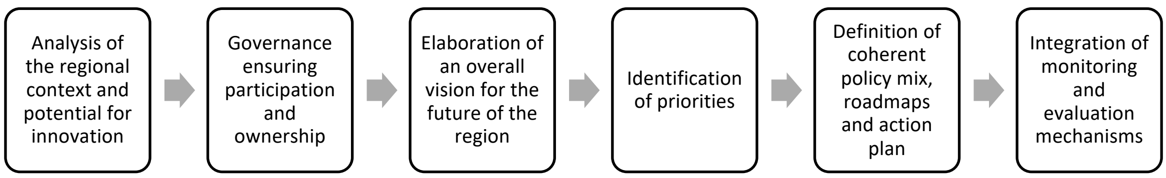

Figure 3 – Steps to Smart Specialization Strategy implementation. Adapted from European Commission (2012).

Throughout the goals of Smart Specialization, Foray & Goenaga (2013) highlight the importance of large R&D sectors in close proximity to maximize the gains from specialization through the ability to capture knowledge spillovers. Moreover, it is crucial to particularise by developing distinctive and original areas of specialization and concentrate resources in a few domains to generate size and critical mass effects – the authors underline the risk of doing a little of everything.

The Smart Specialization Strategy was adopted by the European Commission for its Cohesion Policy 2014-2020 as a policy platform to support investments on key national/regional priorities for knowledge-based development (Commission, National/Regional Innovation Strategies for Smart Specialisation (RIS3), 2014). It mentions the importance of support through human resources and knowledge infrastructure to reach the aimed critical mass, i.e. sufficient momentum to become self-sustaining. Moreover, the authors argue that the most promising way to promote knowledge spillover is to diversify into technologies, products, and services that are closely related to existing dominant technologies and regional skills – meaning that knowledge spillover is more successful within related industries. Concluding that specialized technological diversification in emerging economic activities should have relevance over diversification.

According to the RIS3 Innovation Strategies, the European Commission required the EU Member States a smart specialization strategy that:

- Is based on a SWOT or similar analysis to concentrate resources on a limited set of research and innovation priorities;
- Defines measures to stimulate private research, technology and development;
- Includes review and monitoring systems;
- Includes a framework outlining available budgetary resources for research and innovation with a multi-annual plan for budgeting and prioritization of investments;

As defined in the same report, ultimately, smart specialization is about:

"*[…] identifying unique characteristics and assets of each country and region, highlighting each region's competitive advantages, and rallying regional stakeholders and resources around excellence-driven vision of their future*".

3.5. Modes of Research and Technology Commercialization

Markman, Siegel, & Wright (2008), group modes of technology commercialization into three different approaches: internal, quasi-internal and external. For the internal approach, the analysis focus on the university and firms which are connected through the TTO office. Technology transfer officers act as the bridge between the entrepreneurs/firms and the academic/research environment who operate in distinctly different environments with different norms, standards and values. TTO's are classified according to their autonomy level – traditional structure, non-profit research foundation, and a for-profit private extension. Different structures are associated with different variations in technology transfer performance in their output and ability to manage licensing, sponsored research activities and alignment of incentives.

Quasi-internal approaches rely on external activities to stimulate the technology commercialization. Business incubators are a key facilitator to accelerate growth and success of entrepreneurial activities. Business incubators have four main objectives: 1) economic development, 2) technology commercialization, 3) real estate development and 4) entrepreneurship. There is evidence pointing that incubators perform best where is a complementary innovation system at the university – that is an entrepreneurial university. Such innovation system includes incubators, science parks, angel networks, academic entrepreneurs, entrepreneurs and students. Moreover, the performance is enhanced with the presence of venture capitalists or other individuals, with strong ties with the industry, when involved in designing and operating the incubator.

One alternative to business incubators is to rely on intermediaries by outsourcing the commercialization to specialists. For example hybrid public-private companies that undertake long-term and even exclusive contracts with universities to commercialize their IP. Such entities can bridge the knowledge gap to identify IP with commercial potential, access early stage finance and develop strategic partnerships to accelerate the venture development. In this context Clarysse et al. (2015), determined that university incubators that focus on a small number of high value spin-offs frequently establish their own venture capital funds or develop access to established corporate venture capital.

The external mode of research and technology commercialization involves university research parks, regional cluster, academic spin-offs and start-ups, licensing, contract research and consultancy, joint-venture spin-offs, collaborations, corporate venture capital and open science and innovation. We briefly review each of these modes:

- *University research parks:* typically large-scale projects that host a range of entities including corporate units, government labs and medium and small firms whose aim is to accelerate business through knowledge agglomeration and resources sharing. There is some debate about whether science parks and incubators enhance the performance of the businesses located on them (Siegel, Westhead, & Wright, 2008).
- *Regional clusters:* facilitate de creation of critical mass for TTO and improve scale economy of research areas. These involve development agencies, public research labs, intermediary organizations, local corporations and venture capital funds.
- *Academic spin-offs and start-ups:* these are new ventures that are dependent on a licensing agreement upon IP for initiation. The owner of the IP might own equity in the spin-off in exchange for patent rights. The organizational context determines whether the institution can take equity in the firm. It is noted that the creation of the start-up is not a straightforward process, but in many cases built on tacit knowledge from the academic or corporate environment. Also, most of the spin-offs are unlikely to serve national markets, however taken as a whole they have significant relevance in terms of local employment creation and revenue generation (Clarysse, Wright, Lockett, Velde, & Vohora). Important for the success of new ventures are the strong ties between TTO's, venture capitalists, business angels, IP specialists and entrepreneurs.
- *Licensing:* firms engage in licensing strategies to increase the speed, scope, odds and impact of their innovation. Siegel, Veugelers, & Wright (2007), conclude that returns on licensing are generally low and skewed towards a small number of licenses in small number of universities. The technology commercialization through licensing is mostly impacted by organizational matters – discording cultures between firms and universities; lack of incentives; and inappropriate staffing of the TTO units.
- *Joint venture spin-offs, alliances and collaborations:* these are new ventures where technology is granted to a company which is jointly owned by a public research institution. This model allows scientists to have a stake on the

company's equity which in order to accelerate the development of the technology into a product. On the other hand, the industrial partner can accelerate the development of the venture through their organizational processes, resources, talent, and business partners.

- *Contract research and consultancy:* for corporations, contract research can provide access to new knowledge, enhance its R&D and have access to talent. These activities may generate significant revenues but their measurement in problematic (Wright, Clarysse, Lockett, & Knockaert, 2008). However, as with other technology commercialization mechanisms it is unclear how consultancy activities can count towards promotion. There is evidence of effective transfer when universities have developed centres of research excellence.
- *Open science and innovation:* an innovation mode where different parties, including customers and end-users, co-innovate and co-create. Open innovation firms seek to co-create and co-commercialize research and technology regardless of its origin. The development of social capital in such projects plays a key role in attracting scientists, consultants, universities and industry players. Further research looking for evidence on the commercialization of open science – through the dissemination of open-source innovation – concludes that it is important for star researchers to be involved to commercialize their own research and bridge basic and applied research (West, 2008).

3.6. Creation of Spin-Off Firms at Public Research Institutions

Lockett, Siegel, Wright, & Ensley, followed an approach which focuses on "*knowledge gaps*" to understand the development of spin-offs from public research organizations. They argue that knowledge gaps occur on different levels including: the public research organization, spin-off, team, individual, incubator, and at different stages of the spin-off development.

While licensing has been the traditional route for public research technology commercialization, there is an increasing potential with spin-off companies. Policy makers increasingly see the technology transfer from public research institutions with a significant role for new venture creation, growth of firms and new job creation (Siegel, Waldman, & Link, 2003). Consequently, the exploitation of inventions from a non-commercial environment raises new entrepreneurial challenges. The development of spin-offs from a public research environment is affected by the difference on its natural knowledge and the knowledge needed to succeed – at the different levels of aggregation. For example, an individual researcher or entrepreneur may be important at the early stages of the venture, but over time the team becomes more central.

The authors identified the following key process issues: opportunity recognition, the decision to commercialize and due diligence, the choice between licensing and spinning-off, the time-period over with TTO's are involved and access to resources and knowledge. For example, there appears to be significant reliance on academics to identify opportunities for a spin-off, while evidence shows that engaged entrepreneurs are better at this task (Franklin, Wright, & Lockett, 2001). Or further research (Binks, Wright, Lockett, & Vohora, 2004) suggest that universities could improve their ventures to be "*investor ready*" by streamlining and improve transparency in their decision-making processes related to venture capital investments. Moreover, universities may need to invest on identifying the appropriate venture capital investor for their science technology base – suggesting as such more knowledge gaps that need to be closed.

A distinction should be made between academics, scientists and engineers who are willing to develop a spin-off and those capable of developing a successful one. New born entrepreneurs need to acquire the right business and commercial skills to create new ventures, or develop the understanding that they may need to step aside to take a technical role and bring entrepreneurs or managers that will bring the right human capital. Consequently, public research organizations need to develop the right mix of human capital skills and networks of entrepreneurship contacts.

Lockett, Siegel, Wright, & Ensley, concluded that start-up creation at public research institutions can be stimulated through the development of capabilities that fill the different knowledge gaps. They highlight first the importance of developing and appropriate culture and infrastructure that support academic entrepreneurship and technology commercialization. Moreover, it is crucial to develop active partnerships with the industry, government funding agencies and secure financial support from these organizations. Last, at the public research institute level they highlight the importance of recruiting, retain and develop star scientists.

At the public research institutes and incubators level, Clarysse et al., conclude that organizational learning is crucial for success, requiring more than just an investment. It requires time for the resources to be deployed and for the knowledge to be generated and internalized into the incubator. At the TTO level, there is a strong need to recruit and retain technology transfer officers with a large base of commercial skills or entrepreneurial experience. However, if public research institutes are restrained to remunerate knowledge transfer officers in line with the other elements of the university, they may be unable to attract the right individuals with the skills needed to make successful spin-offs. Still at the TTO level, there is also the need to increase the innovation speed with more rapid disclosures.

Moray & Clarysse, on a study at the Inter University Micro Electronics Centre (IMEC) identified three generations of companies displaying the organizational changes related to technology transfer policy:

- From 1986-1995, companies received insufficient funding and lack of experience from IMEC in evaluating capital needs. These companies had working prototypes but did not involve formal knowledge transfer mechanisms.
- From 1996 to 1998, IMEC began bringing IP into firms through license agreements. Some spin-off's evolved with technology and start capital from the university, and started attracting capital fund after 12 to 18 months – in the form of seed capital fund, business angels, and venture capitalists after working prototypes were demonstrated.
- From 1999 to 2002, a third generation with almost all spin-offs starting with less mature technology reflecting a policy change towards a push model by IMEC. IMEC introduced IP in the new companies in exchange of equity.

The authors finalize by suggesting that public research institutes may take different approaches to spinning-out new ventures: low selective, supportive and incubator.

With respect to location issues, Audretsch (2002), argues that the geographical proximity of the public research institute plays a significant role for the venture location. This conditioning relates to the type of knowledge and mechanisms to access that knowledge – in particular tacit knowledge to flow to the spin-off company. The authors conclude that the greater the distance between the public research institute and the science park then the less likely the spin-offs will be located there.

3.7. Role of Technology Transfer Office

Technology Transfer Offices (TTO's) are commonly defined as an "*intermediary*" between suppliers of innovations and those who can potentially commercialize them – i.e. firms, entrepreneurs and venture capitalists (Siegel, Veugelers, & Wright, 2007). TTO's facilitate commercial knowledge transfer of intellectual property resulting from research activities through licensing to existing firms or start-up companies. Consequently, TTO's activities have important economic and policy implications since licensing agreements can result in additional revenue.

According to Siegel, Veugelers, & Wright (2007), from the university perspective, there are typically three agents in the commercialization process: inventors or researchers, technology transfer/licensing officers or administrators and corporate managers and/or entrepreneurs who commercialize the university technologies.

These stakeholders have significant differences in culture and objectives. Firms and entrepreneurs aim to commercialize technology for profit. Moreover, when the innovation is a key source of competitive advantage it becomes crucial to maintain the control over the technology. Consequently, firms aim at securing exclusive rights in a context where speed is a major concern since firms often aim at establishing a "*first-mover*" advantage.

On the other hand, TTO administrators are perceived as the guardians of the IP portfolio which can potentially generate revenue. Consequently, they are motivated to market their technologies to companies and entrepreneurs but with the intent of maximizing their revenue – since they don't want to be seen as "*giving away*" lucrative technologies funded by taxpayers, or they want to safeguard the inventors from their researcher environment. Consequently, this dominant logic tends to slow down the commercialization process.

The commercialization process of university IP needs to surmount several hurdles. Again Siegel, Veugelers, & Wright (2007), argue whether researchers have sufficient incentives to disclose their inventions and prompt how to induce researchers into cooperation to bring their IP to the market, and how to overcome asymmetric-information problems. Firms cannot assess the quality of an invention *ex ante,* while researchers may find difficult to assess the commercial profitability of their inventions. It becomes the TTO responsibility to alleviate the asymmetric-information issue. Macho-Stadler, Pérez-Castrillo, & Veugelers (2007), suggest that TTO's may have incentives to put aside some project in order to build reputation for delivering valuable projects. Their analysis raises the importance of having a critical size for TTO's to be successful. In the end, the authors predict that the establishment of a TTO may result in fewer license agreements but higher revenues.

The same authors argue that on the effectiveness side, there is consistent evidence that incentives, cultural, and organizational practices are important to explain performance. Universities allocating higher percentage of royalty payments to faculty members tend to be more effective on technology transfer. On the organizational side, a decentralized management style was another critical factor, which allows the TTO to be much more sensitive to the needs of the stakeholders.

For the creation of new start-up's Lockett, Wright, & Franklin (2003), found that equity ownership was more present among the more successful universities. The ability for the university or inventors to take a part in the start-up equity, instead of licensing royalty fees, is a determining factor that will impact the number of new companies.

Summarizing Siegel, Veugelers, & Wright (2007), underscore the importance of identifying interests and incentives of those who manage the technology transfer process and the importance of human capital (TTO's staff, scientists and entrepreneurial teams) with the research environment culture. The authors develop a set of challenges and policy recommendations for successful TTO's in generating additional revenue:

- Adopt a strategic approach to the commercialization of IP and consequently consider the key formulation issues involving choices related to institutional goals and priorities for consequent resource allocation.
- Drive resources allocation by recognizing the different modes of commercialization the university wishes to emphasize – licensing, start-up's sponsored research, consulting, incubators or science parks.
- Make strategic choices regarding the technological field of emphasis.
- Formulate IP and patent strategies to ensure IP is well defined and protected before raising commercial interest.
- Adapt promotion and remuneration levels so that commercialization activities are valued.

Last, the same author highlights the problem with attracting and remunerating TTO personnel with the appropriate human capital skills to support the commercialization strategy, since the development of new start-ups requires a base skill level from legalistic skills in protecting IP to requirements, to opportunity recognition, and other commercialization skills.

3.8. Technology Transfer Office Value Chain

We review now aspects related to technology transfer organizations from a conceptual knowledge value chain and business model perspective. Landry et al. (2013), argue that types of TTO's tend to specialize in the provisioning of services at different stages of the value chain to benefit from complementary effects. They conclude that TTO managers can improve their business models by increasing the value they provide to customers by improving the level of service customization of the solutions provided. This can potentially increase the revenue for TTO's and consequently reduce the exposure to government funding.

By making the distinction between university, public research institute and semi-private non-profit technology knowledge transfer organizations, the authors concluded that non-profit are more likely than public research institutes to provide customized solutions for single client firms. Moreover, they have well-defined segments and more likely to implement well defined market strategies. On the revenue side they seem to generate less than university knowledge transfer units, hence they appear to rely more on government subsidies and more exposed to government innovation policies. Managers of such non-profit units tend to attempt reducing the dependency on subsidies by deriving more financial benefits.

On the other hand, public research institutes can rely more on technical resources and human capital with engineering and business background than other types of organizations. They are also very likely to implement well defined strategies regarding the promotion of their services. However, by comparison with the other types they are less involved in the provision of the services at the stages of the knowledge transfer value chain, less likely to target small firms and less likely to generate revenue from sales of services. Consequently, the authors conclude that public research organizations have a weaker business model, in part because their activities are embedded in larger organizations and have to answer to the strategy of corporate management. Thus, this type of organization is more likely to earn revenue by licensing intellectual property rather than selling technical and business services.

Landry et al. (2013), identify three primary stages in the value chain:

- *Exploration of knowledge based opportunities:* consisting of services helping firms to specify research and technological needs, and access to in-house technology, knowledge, equipment or patents.
- *Technical validation of knowledge based opportunities:* consisting of services at helping firms with prototypes, scaling up, patenting and certification.

- *Exploitation of knowledge-based opportunities:* consisting of services at helping firms with legal aspects, access to capital and commercialization.

The authors highlight the fact that such conceptual representation of the value chain is a simplified representation of innovation process in the real world, however it is very useful to analyse the crucial activities of the value chain.

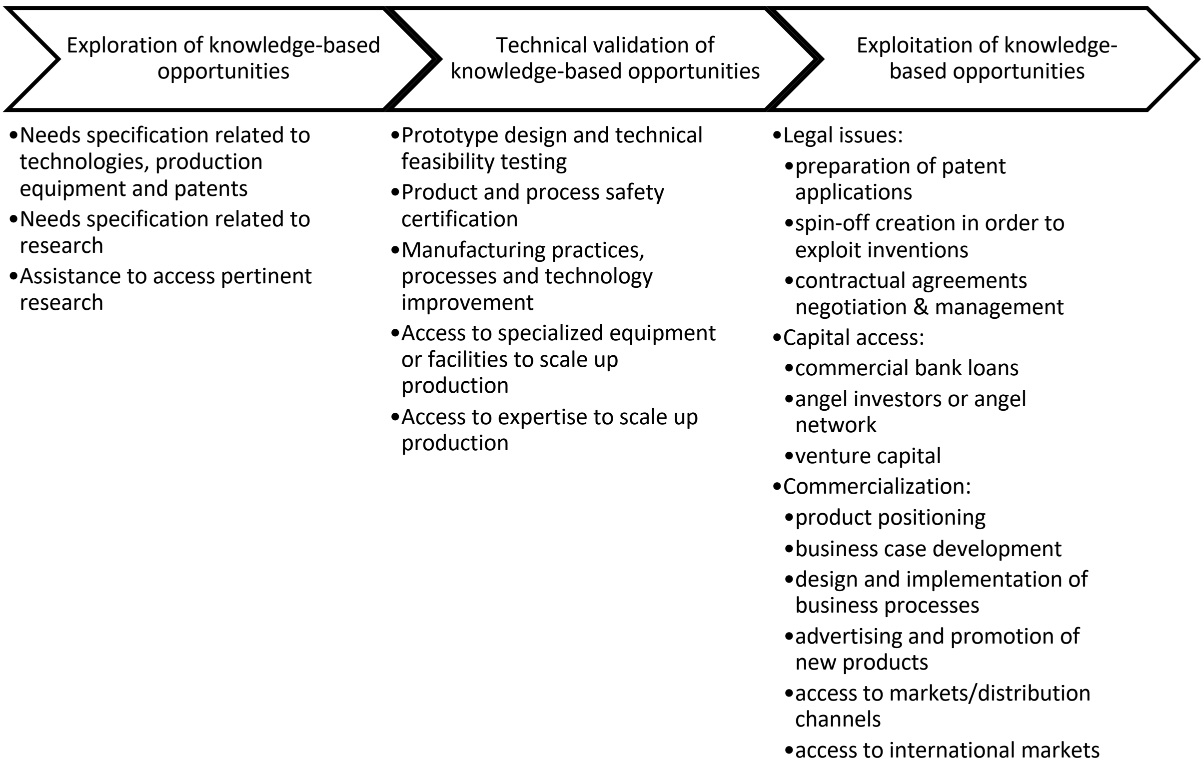

Figure 4 – Knowledge and technology transfer value chain. Adapted from Landry et al. (2013).

From an organizational perspective Campbell (2007), discusses about the importance to align the TTO mission with the institutional mission, and consequently the TTO activities should support and add value to the institution. There should be an agreement of what is added value for the parent organization – beyond financial returns there are long-term benefits such as sustained partnerships, cultural change, job creation and societal well-being. Consequently there should be the decision whether the TTO should undertake a pure commercialization strategy or broader knowledge transfer.

Support for establishing such units demands active support from the senior management. There needs to be an understanding of the relevance of knowledge transfer activities among managers throughout the organization. Not only that, but also an understanding of the technology transfer lifecycle to encourage academics, researchers and scientists to participate in technology transfer. Moreover, it should be clear for all stakeholders that while knowledge transfer may generate revenue, it should not be relied to become significant for organizational planning. The inception of TTO's should be aligned with national and regional policies and frameworks as a guide to set priorities. Such can support local funding and develop partnerships with interest for the local region.

From a culture perspective, there is the need of a message of support and encouragement to engage on knowledge transfer. TTO staff must work with researchers at all levels to raise the level of education in entrepreneurial behaviours, how to engage with business, and how to identify partnership or licensing opportunities. Moreover, there is the need to raise the awareness on IP management processes such as disclosure, confidentiality, and protection.

Campbell (2007) determines three key factors for success in technology transfer: removing cultural barriers, staffing the TTO and the reward system – being people the core element. Managers need to understand the potential of their technology and be flexible, while technology transfer managers need to be able to engage with researchers and business. TTO staff must spend time with researchers to better understand what can be offered to business, and on the other hand, they must engage with business to understand the potential market fit and gain agility in matching business opportunities.

From a business model standpoint, TTO's are usually a department or unit within the institution or a subsidiary entity. Acting as a subsidiary, may develop a positive perception of technology transfer and demonstrate a signal of seriousness with which it is viewed by the parent institution. Moreover, it will gain operational flexibility and the ability to define its human capital and remuneration packages. On the governing side, the TTO must be accountable to the parent institution and produce annual reports of activity. A group of advisors should be part of the organization to bring new experience and act as champions, both internally and externally. Similarly, a governing board should be formed with non-executive directors including senior members of the parent organization. Another option consists of outsourcing the technology transfer to an independent third party company – such approach will minimize investments but equally reduce potential gains both financial and in terms of social impact.

As a conclusion note Campbell (2007), suggests about the importance of defining clarity of purpose and defining the right foundation for planning the operations of the TTO.

Moreover, while knowledge transfer activities should have financial returns there are other ways how technology transfer creates value: by facilitating innovation for the public good and acting as a broker of knowledge transfer between the business and the public sector for society's benefit. In addition, transferring knowledge across a variety of disciplines such as humanities or social science are as relevant as transferring across applied sciences. Consequently, TTO's should have enough flexibility and multi-disciplinary human capital to achieve broad knowledge transfer.

3.9. Technology Transfer Office Strategies

Markman et al. (2005), through 128 interviews of university TTO directors developed a framework to understand the relationship between TTO structures and strategies, new venture formation and business incubators. From their study, 62% of the universities are establishing business incubators and research parks as ways to encourage technology-based new ventures and economic development.

The authors identified three archetypes: *(i)* traditional university structure, *(ii)* non-profit research foundations, and *(iii)* for-profit private venture. Each of the structures will grant different levels of autonomy to the TTO managers seeking for technology commercialization opportunities.

Under the traditional structure, the TTO act as an integral department of the university, usually reporting to the top management of the organization. These are characterized by a direct and often strong supervision from the institute's administration which often limits the autonomy on matters of decision making, licensing strategies and incentive systems. As reported by some of the interviewees of the study, strategic decisions – such as the implementation of an incubator – may take multiple months compromising the development of entrepreneurial activity.

On the other hand, many universities or multisystem research institutes create a non-profit research foundation to grant greater autonomy to undertake research and licensing activities. These represent 41% of the study sample. Such structure grants stronger legal protection against lawsuits coming from the licensing activities, and will benefit from a separate budget, combined with greater autonomy to choose licensing strategies, hold equity, recruit human capital and exploit the licensed technology. The study demonstrated that in general the president of the parent organization is the chairman of the governing board.

For-profit private entities – 7% in the study – are distinctively focused on economic development and start-ups creation. These include an independent CEO and board with personnel with significant experience in areas such as IP management, companies and business management, and venture capital. Private entities benefit from an even greater degree of autonomy to raise capital from different sources, engage in development programs, conduct negotiations with licensees and act entrepreneurially to start new ventures.

From an exploitation perspective, patent-protected technology is commercialized through one of the licensing strategies: *(i)* licensing in exchange of sponsored research, *(ii)* licensing for equity in the company, and *(iii)* licensing for cash. The study pointed that the strategic choice for licensing is strongly influenced by the maturity stage of the technology: early-stage invention, proof of concept, reduction to practice, and prototyping. Each are described below.

Technology stage	*Description*
Early-stage	May be an idea that might work should the idea be reduced to practice.
Proof of concept	Idea or technology that has been developed to the point that it shows signs of having the proposed effect.
Reduction to practice	An experiment of the idea has been replicated multiple times and the intended results have been reliably and repeatedly reproduced.
Prototyping	The new technology can now be constructed as a reliable method of producing the giver results and/or if it can be predictably manipulated to produce desired results.

Table 2 – Technology stages. Adapted from Markman et al. (2005).

Licensing strategies are partly driven by the technology in itself, within the proposed technology stages. TTO directors conceptualized these technology stages along two continuums of uncertainty: ambiguity regarding market application and ambiguity regarding of the robustness of the legal protection over the IP.

Licensing for sponsored research is usually paired with early-stage technology, being the predominant strategy for 11% of the universities of the study. While there are multiple benefits on sponsored research with corporations, both parties are cautious with subsequent dispute over research direction and ownership of future IP. Additionally, technology in early-stage of development require additional R&D capital, and firms are usually reluctant to invest or lock into licensing agreements without the certainty that the technology will have economic value. Because of such uncertainty, TTO directors feel the obligation to give significant monetary discounts as incentives for their licensees, which might ultimately impact the goals of maximizing licensing technology and income.

Licensing for equity is usually matched with proof of concept or reduced to practice technologies. It is the predominant strategy for 17% of the institutes. According to the research, this mechanism provides the financial flexibility necessary to take new technologies to the market. Large corporations are usually less interested in technologies at such stages because they usually require higher internal rate-of-return for R&D investments. Moreover, combined with a lower success rate and limited commercial impact, makes the bureaucratic process of engaging in a relationship with the university economically unfavourable.

Consequently, with a stake on the equity, the research institution invests on what is a private partnership to further develop the technology. As defined by Markman et al. (2005), the objective becomes supporting the new venture and potentiate the energy, aspiration and motivation of the venture's technology scientists and founders to create commercial application of the IP. Hence, the technology institute either leverage the venture with endowed resources or create their own incubators. Some TTO's will even encourage their licensees to join their incubation structure as a way to legitimize the firm and the technology – 62% of the entities in the study devoted significant resources into building business incubators to accelerate the technology commercialization efforts. In case the commercialization attempt fails, the licensing agreement is terminated, which releases the technology back to the research institution – and hopefully re-licensed in the future at a more advanced maturity stage.

Licensing for equity presents several advantages. Respondents of the same study explain that security equity positions makes sense when the technology is unresolved, its economic value uncertain and the opportunity costs of licensing for royalties is low. Equity is equally preferred as it confers to the research institution the opportunity for future financial gains as licensees develop the technology. Additionally, an equity position in a company ensures long-term incentives to align the objective of the research institute to commercialize the technology – such alignment might mitigate uncertainty on IP-related litigations between the licensor and licensee (Jensen & Thursby). Moreover, an equity position in start-ups sends a signal on the research institute confidence in the technology and team to potential stakeholders – increasing the probability to secure additional funding or access to distribution channels.

As licensing strategies are driven by the degree of technology maturity and future economic returns scenarios, licensing for cash correlates with technologies at the prototype stage where a market has been identified. This strategy is the primary choice for 72% of the TTO's of the study. As most of the TTO's purpose is to generate rents from the scientific discoveries, the higher is the financial outcome predictability the most likely the TTO will choose licensing for cash. This strategy is also frequently used for technologies where the commercialization can span across different industries. As the commercialization of a prototype technology is clearer and licenses for cash can be exclusive for the licensor, these become more attractive to large companies. In addition, licensing for cash can develop strong ties with industry partners in anticipation for future collaboration and potentially generate knowledge spillovers that the research institute is free to exploit.

The study demonstrated an apparent conflict between making immediate income through licensing for cash and making long-term cash flows through licensing for equity. While research has shown that taking equity in start-ups produces greater financial returns in the long run, TTO's administration share that they are unlikely to succeed unless they recover their R&D and administration costs. Consequently, they are looking at technology commercialization as a source of recurring revenue. On the other hand, the study demonstrate that the presence of incubators in 62% of the research institutes, demonstrates as reported by university administrators, the willingness for these institutes to become a source of local economic development through the creation technology-based ventures. It becomes apparent, that TTO's motivation to maximize cash flows and minimize legal risks often leads to a strategy that does not support new venture creation.

3.10. Innovating from Big Science Institutes

Large-scale big-science installations provide a fertile ground for technological innovation – as discussed in the second section. However, active industry partners are necessary to start the innovation process to convert scientific artifacts into commercial products. To this end, based on the example of CERN, Hameri (1997) developed a comprehensive framework for a systematic approach to establish joint R&D efforts.

From an industry perspective, it prompts for an internal definition of the technological competencies, a development strategy for each technology, and then systematically search for opportunities embedded in big science research. In parallel, the industry should target research centers to establish a technological network of contacts and scan for technological opportunities.

A technology breakdown (Figure 6 – Technology breakdown from big-science. Adapted from is combined with a mapping of technological trajectories that overlap with core competencies. Dedicated technology liaison offices may help to process the technology spectrum. Moreover, public documentation such as annual reports are a valuable source of information. Yet, Hameri highlights the value of developing a contacts network inside scientific organizations. Additionally, companies that actively extend their technology networks with partners that hold a diverse range of technical competence, may develop an advantage on future challenges.

The success of an industrial big-science project strongly depends on its management process. Many joint efforts have been in vain due to poor management – many times projects are left to survive by themselves after their approval. To exploit fundamental research, as a catalyst for in-house product and process development, it requires to focus on the particularities prevailing in big-science projects. Hameri provides the following recommendations for an industry/big-science joint R&D project:

- Confirm that individuals involved really understand the objectives of the partnership and the resources at hand.
- Define and clarify who is the customer of the project.
- Control firmly the project progress – experimental projects tend to change their schedule, but one should make efforts to stick to the original objectives. Credible project management and reporting routines are highly recommended.
- Exploit all information available and know-how – joint projects are a unique opportunity to exploit technical know-how usually below the market-price.
- Benefit from additional financial sources to fund further R&D.

Throughout this process, hesitation can become a limiting factor. In such context, it is recommended to act, exploit, manage, and be patient. Additionally, this level of partnership can be an opportunity to incorporate public R&D funds into development projects – when the result can help both the industry and big science.

Emphasis is given for a prudent and systematic approach during the process. Experience demonstrated that some companies lack knowledge of their internal competencies. Such usually happens when projects are based on anticipation and decisions are based on motivations other than technological ones. This undermines expectations in a context where it is usually difficult to get acquainted with the research environment.

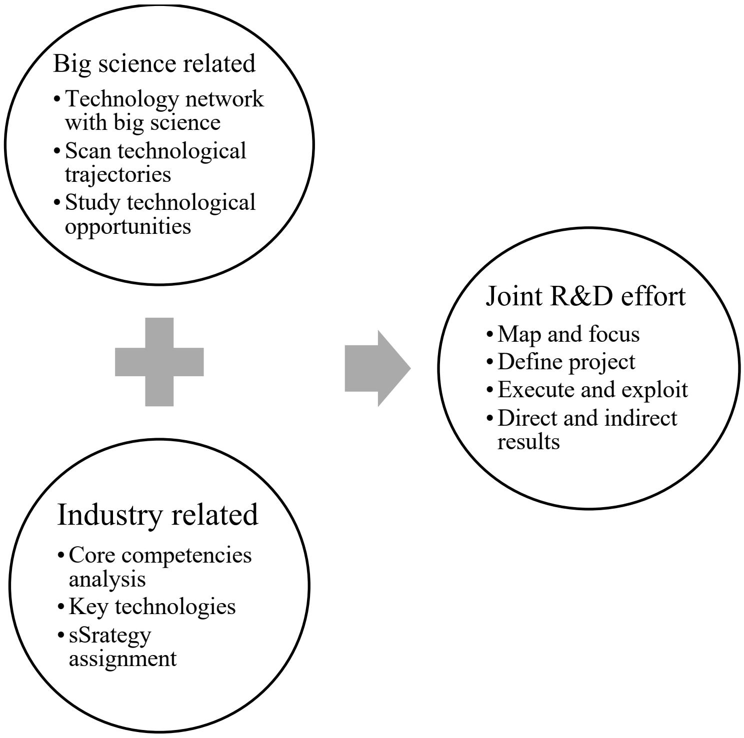

Figure 5 – Innovating from big science process. Adapted from (Hameri, Innovating from Big Science Research, 1997).

The types of innovation stemming from big-science collaboration range from radical to incremental ones. For example, these can take the form of specific solutions coming from tackling extreme and well-defined technological problems related to scientific instrumentation. These can emerge from the extreme operational conditions at the scientific environment – such as magnetics fields, radiation or low temperatures.

Innovation can sprout from the application of conventional technology in the development and construction of complex scientific instruments. For example, the construction of the accelerators cavities and tunnels provides countless civil engineering opportunities. The scale of the construction delivers unique challenges on multiple fields, such as cooling, ventilation, electronics, communication networks, power supply or general maintenance.

Finally, the environment can become a source for the development of technology drivers. That is work that can generate fundamental technological changes that can upgrade or replace existing products or services. These usually require extensive R&D collaboration as their impact goes beyond operational business. Such level of innovation requires systematic collaboration with companies pursuing strategic goals on fields of new and emerging technology – such as super conductivity or laser beams (Hameri, Innovating from Big Science Research, 1997).

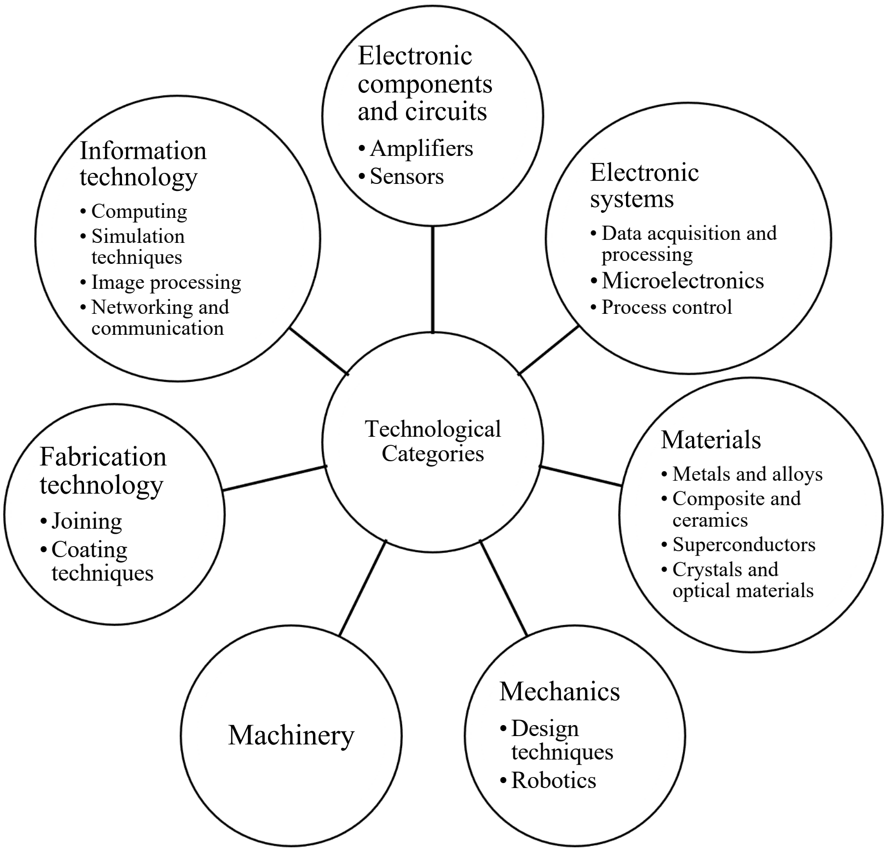

Figure 6 – Technology breakdown from big-science. Adapted from (Hameri, 1997).

However, the creation of spin-offs from CERN is not a hurdle-free road. In a public sector organization the climate, the procedures, and the decision-making bodies which are related to technology transfer may be supportive, irrelevant or counter-productive (Byckling, Hameri, Petersson, & Wenninger, 2000). Yet, CERN introduced in 2010 a policy on the management of intellectual property in technology transfer from the laboratory, moved by its strong motivation to provide its Member States with the innovations developed internally (CERN, Technology Transfer Policy at CERN, 1999).

The technology from big-science research usually finds its way to the industry in two main ways:

- Collaboration with companies to build the systems and subsystems for the scientific facilities. Through written agreements, CERN induce the industry to manufacture the systems, which then benefit from obtaining pioneering technology to support their main business activities.
- Individuals or groups that participate in big-science projects and conceive innovations by combining market needs and technology with business potential – and typically start a high technology company.

CERN follows similar rules like other basic science organizations for knowledge dissemination. New solutions, inventions and know-how are published freely to support rapid adoption when a company finds a business case for the technology. However, the success of a product requires significant investments fructify. Typically, a factor of 100 larger than the required to build the original concept or prototype. Through the analysis of a concrete case, Byckling et al. (2000), developed the following lessons for the transfer of technology throughout a spin-off company from CERN:

- There are obstacles hindering the exploitation of the numerous opportunities available. These are usually related to the fact that it is hard for the industry to appreciate the flexibility for joint efforts.
- Additionally, typically the knowledge transfer personnel do not have sufficient knowledge on the private sector and the input from industrial companies to this activity is almost non-existent.
- Revolutionary technology is created from big science projects. These stems from the need to build pioneering facilities but equally from the concentration of a large group of exceptional individuals.
- The flexible environment of science research motivates creative people to carry to fruition revolutionary ideas which in industrial companies would rarely have the chance to grow.
- The tradition of supporting the free flow of technology to the industry and to emerging spin-off companies is a most important source of high technology.
- Many scientists and administrators in science organizations are not supportive towards industrial applications and the business world. It requires strong input

from the industry and management to avoid the majority repressing applicable innovations.

In combination with other cases, the authors conclude that the best results from big-science collaboration emerge via intangible profits – such as education, new skills, products, unforeseen markets and partnerships.

3.11. Technology Competence Leveraging

Danneels (2007), proposes a systematic approach for technology competence leveraging, that is the combination of exploitation of an existing technological competence and the exploration of competences to serve new markets. Fungible resources, i.e. resources with a range of potential services are often not fully utilized and consequently their value is not totally extracted. Consequently, organizations can miss profits, but also society at large may miss benefits of technological evolution.

The author argues that leveraging technology involves the identification of a technology competence as distinct of a product description or benefits. Multiple scholars say that competences are not product-specific but lie in generic capabilities which might well find several products application (Teece, Towards an economic theory of the multiproduct firm, 1982). Additionally, literature demonstrates that market-related capabilities are needed to enter new markets – for e.g. knowledge of customer needs, purchasing processes, access to customers, brand management, communication channels and so forth. However, Danneels (2007) argues that there is a missing link on resource allocation and transformation for technology competence leveraging. While the technology competence may be identified within the firm, the creation of market-related resources may be challenging.

The process of technology competence leveraging involves two different steps: de-linking and re-linking. De-linking involves looking at the technology intrinsic properties as distinct from its embodiment into a product. Re-linking is the process of applying the technology to new products that address new customers.

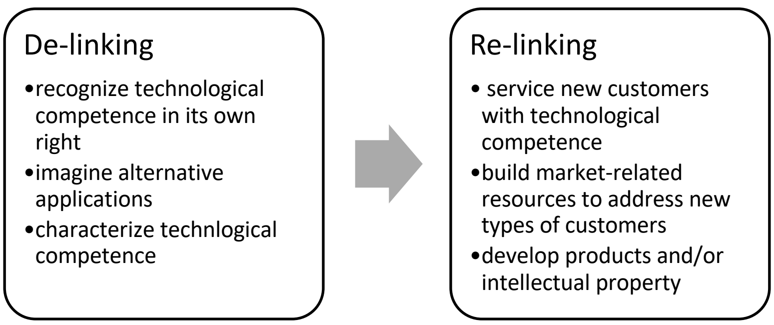

Figure 7 - Technological Competence Leveraging. Adapted from Danneels (2007).

The de-linking process involves abstracting away from the product-centric view and identify the competences on which the products are based. Consequently, de-linking involves technology characterization in order to determine the fungibility of the technology. The technology characterization is a necessary step in de-linking for both routes of new product development or IP licensing. The re-linking process, on the other hand, requires significant resources allocation and transformation to develop the necessary complementary assets to apply technology competence into new markets. As defined by Teece (1986), generic resources are general-purpose resources with a high degree of fungibility – for e.g. financial resources are highly fungible as they can be assigned to a large variety of activities. Hence, the resource transformation process is the conversion of generic resources into specific resources high limited fungibility.

Danneels (2007) argues about the importance of slack resources to firm innovation – and consequently enable the resource allocation and transformation processes. Multiple authors found that the presence of financial slack enables the investment in more specific, and less fungible, resources for autonomous strategic initiatives to become part of corporate strategy (Burgelman, 1991). Additionally, debt can serve as a buffer that allows continued financial slack for uninterrupted innovation activities independently of unstable cash-flows (O'Brien, 2003).

The author also identifies two competence traps that constrain technology leveraging: customer competence trap and marketing competence trap. A competence trap is described as the self-reinforcing exploitation of a competence that makes the exploration of new competences unattractive (Levitt & March). Consequently, firms accumulate knowledge and experience in domains of activity in which they have competence, blocking themselves to other domains. Lacking marketing competence will restrict the impetus for resource allocation, and consequently transformation to come from within the organization. The customer competence trap will narrow the firm’s focus to current customers and hinder the impetus to serve new segments.

The study concludes that technology leverage does not occur as a by-product of service current customers, but it requires the firm to deliberately devote resources to competence creation. Full exploitation of current resources requires the de-linking of those resources from the services or products – a process that removes impetus from current customers. As such, the presence of a competence to serve current customers and a lack of a marketing competence to search for new ones hinders the leveraging of the technology competence. Such technological competences manifest their influence through the resource allocation and transformation processes.

4. Research Findings

The literature review, in the topics of knowledge transfer, innovation, and commercialization of public research technology, provides a solid theoretical base to proceed with the case study analysis. It complements with an in-depth view of organizational dynamics and the context at CERN.

Multiple aspects make this organization a unique place – such as the mission, challenges, the legacy, governance model, and culture. The work continues with the result of qualitative interviews with senior managers at CERN and an analysis of internal governance policies that influence the knowledge transfer and technology capture activities.

4.1. Insights from Qualitative Interviews

The insights obtained from the interviews, lasting approximately 2-hours each, are summarized in the following sections organized by topics. This is a generalization of the multiple discussion.

4.2. A Separate Entity?

Interviewees commonly shared that multiple discussions about the creation of a separate legal entity to commercialize CERN's technology have taken place in the past. However, the debates among senior managers did not spark enthusiasm. Failed expectations from prior attempts and a research-oriented mind-set limited the discussions.

The CERN Convention, which defines the organization's purpose is clear and does not leave room for the laboratory to engage in business activity – understood as a mode to leverage CERN's early-stage technology to the market and further contribute back to society. For example, universities commonly use the licensing for equity model to support spin-offs activity, but this option is not available at CERN because of its legal status.

One can raise the question, why not adjusting the Convention to open up new opportunities? The Convention for the Establishment of CERN was ratified on September 1954 by 12 founding Member States and amended in 1971. Any amendment of the Convention recommended by the Council shall require the acceptance in writing by all Member States (CERN, 2019) – today 23 countries. Meaning that amending the convention is a highly complex process, which translates into months or years of complex negotiations, depending on the motivation and nature of the change. Pragmatically, a bottom-up approach for this case would rapidly become a dead-end.

Therefore, from a technical perspective, a separate legal entity with a privileged relationship with CERN could be a solution. The legal separation can grant enough autonomy for the knowledge transfer activities and maximize the throughput via the privileged relationship. In case of conflict, the relationship could stop, and consequently, the knowledge and technology flow from CERN. While this solution looks simple and effective, there are other factors to take into account that limit this option.

4.2.1. What is the Motivation?

We start by understanding the priority level of knowledge and technology transfer, and innovation at CERN. The Organization is determined in maximizing its technological returns to society, however becoming a social or economic innovator is not part of the core mission. CERN has a clear mandate focused on providing and operate a range of scientific instruments to enable extending the frontiers of knowledge through fundamental research on particle physics.

Technology spillovers should be transferred back to society, but the research programme is the number one priority – that is the *motto* engrained in multiple spheres of the organization. While CERN is engaged in maximizing its knowledge transfer potential, the narrow and specific scope of its mission restricts the range of mechanisms at hand. For example, universities and other public research institutes are benefiting from incubation structures, science parks or access to venture capital funds to bridge knowledge, competence and financial gaps. That is the example of the EPFL where innovation is explicit in its mission (EPFL, 2019).

One could ask, if increasing the weight of the innovation pillar could diverge CERN from its primary focus of constructing and operating complex scientific instruments? The same instruments that resulted from the unique passion of thousands of scientists and engineers working for open-science and developing expertise on accelerators, detectors, superconductivity, computing, and many other high-tech fields. Shall CERN redefine its identity and transform into a framework of international collaboration where scientists and engineers work together to solve complex issues by developing cutting-edge scientific instruments for applications beyond particle physics? Then capitalize from its critical mass following the same model as successful universities like the EPFL or MIT? Should CERN integrate strong elements of innovation in its mission to maximize the returns on investments from its Member States?

A stimulating and inspiring discussion, where as a personal reflection I believe that CERN should evolve into a regional cluster of high-tech development achievable through excellence, smart specialization in niche technologies, and cover the innovation value-chain with an innovation or science park to maximize the output – at the risk of the cost of missed opportunities linked to a narrow focus and potential long-term loss of technological competence where the brains are attracted to where the critical mass is "*boiling*". About the question on how to distribute the benefits across the Member States? Higher the value creation through innovation, higher will be the number of opportunities to capture value by the Member States. The physical location of spin-off firms may not be a valid argument today, as through economic competition firms will relocate wherever they can to develop competitive advantages. The discussion about equal distribution to Member States *ex-ante* to the creation of value may be a barrier that is limiting progress involved in a narrative that may not apply today in a globalized world.

However, these are discussions crossing the border of the scope of this case study, significantly complex that would require further research and analysis. Definitely discussions for the higher and political spheres of the management at CERN, that nevertheless, are important to understand to make the appropriate framing to ground the necessary assumptions for the final recommendations. We move to the next topic.

4.2.2. About Missed Opportunities

The topic of "*missed opportunities*" was a recurring. Are we missing opportunities to leverage the potential of in-house technology? There is the perception that yes. But is it an issue, one can ask? Or, how can we maximize the innovation potential? What is the cost of raising certain technologies to a maturity level that firms and entrepreneurs can capture and capitalize? Do we have the necessary business competence? Or the budget? And structure? Again, till what point is the responsibility of CERN to maximize its innovation potential?

Then, there is the Organization's culture. There is the famous quote allegedly attributed to Peter Drucker: "*culture eats strategy for breakfast*". How an organization grounded on open science and open innovation could react with the development of commercial activity from its technology? Additionally, there are different sub-cultures in different sectors of technology – adding different dynamics and visions to the research model.

Related with "*missed opportunities*", the following issue was exposed: how should the Organization react when a private firm makes a patent faster than CERN, which resulted from a joint project under non-disclosure agreement where both parties should benefit? Should CERN pursuit or ignore? In the case of a legal pursuit – to protect its intellectual property – how would the Member States and the public in general interpret such action? Should a publicly funded research organization make a legal action against a firm paying taxes to fund its research? As usual it depends, but if the answer is yes, how to reflect it to practice? Are CERN managers, scientists and engineers equipped enough with knowledge on intellectual property management to disclose issues, even if centralized services are available?

4.2.3. Endorsement and Support from Top Management

The different dynamics involved in this case study – legal aspects, organizational priorities, and culture – are highly complex and difficult to change. Hence, it was commonly argued, during the interviews, that only with the high motivation and endorsement from the top management and Council at CERN it could be possible to overcome the existing barriers that impact the technology transfer throughput and innovation potential.

4.2.4. Timing is Key

Timing plays a major role. The research activities are determined by the laws of nature and the experimental discovery of new physics – an unpredictable knowledge discovery process. Or as exposed during an interview with a metaphor, it is like Christopher Columbus exploring the oceans to discover unknown lands. In the absence of scientific discoveries with the current research model, it may prompt the Member States to ask for new initiatives to maximize returns on their investments or a change in strategy.

As extracted from the Council's website:

> "*[…] CERN has assumed its mandate of organising and sponsoring international cooperation in particle physics and related fields not only inside, but also outside the Laboratory. Launched in 2018, the current Strategy update process will deliver its conclusions in spring 2020. This will be an important step in defining the future priorities of European particle physics and for the infrastructures which should follow the LHC*" (CERN, 2019).

The development of such strategy demonstrates the international collaboration efforts to define the directions for new particle physics research. Like Christopher Columbus sailing the oceans and developing new, faster, or bigger ships to accomplish its mission, CERN has the mission to develop and operate the scientific instruments to support scientific discoveries. Timing, overall context and research strategies strongly influence the priorities and directions of the Organization.

Eckhard Elsen, the CERN Director for Research and Computing gave the following reflection on the open symposium of the European Strategy for Particle Physics:

> "*[…] The Granada meeting was a town meeting on physics. Yet, it is clear to all that we can't make plans solely on the basis of the available technology and a strong physics case, but must also consider factors such as cost and societal impact in any future strategy for European particle physics. With all the available technology options and open questions in physics, there's no doubt that the future should be bright. The European Strategy Group, however, has a monumental challenge in plotting an affordable course to propose to the CERN Council in March next year. There were calls for CERN to diversify and lend its expertise to other areas of research, such as gravitational waves: one speaker even likened interferometers to accelerators without beams. In terms of the technologies involved, that statement stands up well to scrutiny, and it is true that technology developed for particle physics at CERN can help the advancement of other fields. CERN already formally collaborates with organisations like ITER and the ESS, sharing our innovation and expertise. However, for me, the strongest message from Granada is that it is CERN's focus on remaining at the forefront of particle physics that has enabled the Organization to contribute to a diverse range of fields. CERN needs to remain true to that founding vision of being a world-leading centre for accelerator technology. That is the starting point. From it, all else follows."*

4.3. The Context is Unique

Egil Lillestol a particle physicist from the University of Bergen, after many years of experience at CERN collaborating in one of the LHC experiments, wrote the following:

> "*[…] On a first visit, CERN gives the impression of a huge industrial complex. The buildings crowd untidily around the large machines devoted to the production of high-energy particles. It is in the restaurants that a visiting scientist discovers the true flavour of CERN, along with the Swiss cooking. At surrounding tables animated discussions about high-flown theories, intricate experiments, or the best places for*

skiing, are going on in half a dozen languages, with Broken English predominant. Physicists from many lands, dressed informally for hard work, forge friendships over their hurried meals. With experience, one begins to take such things for granted which may be a pity, because there is nothing quite like CERN anywhere else on Earth [...]" (CERN, 2008).

This extract gives some hints about the uniqueness the environment. We move the analysis to organizational aspects that challenge knowledge transfer.

4.3.1. Knowledge is the Currency of Exchange

While margins, revenue, maximization of shareholders value, return on investments, and KPI's are part of the dominant logic of most firms and organizations, at CERN the currency of exchange between researchers is knowledge. It is the result of the pure scientific and fundamental character of the laboratory's mission, and how the organization is funded – i.e. its earnings logic.

4.3.2. The Recurring Topic of Incentives

The domain of incentives – to encourage researchers and engineers to participate in the disclosure, licensing and commercialization processes – was a hot topic discussed over all the interviews. Quotes from distinct managers demonstrate best, the context and the relevance of incentives to the case:

"*To my knowledge, CERN is the only laboratory in the world that does not give financial incentives to inventors [...]*"

"*There are three axes of analysis for innovation and knowledge transfer at CERN. The first one is the mission. The second is the incentives [...]*"

"*Lack of incentives underexploit the opportunities [...]*"

Granting direct and financial rewards to staffs at the origin of new technology was discussed in the past. A public extract of a summary record from a meeting of the External Technology Transfer Network in 2009 highlights the concerns of diverging the staff from the core tasks of building and operating accelerators, or the scenario where researchers could target the development technologies with commercial application, leaving behind technologies that could solely benefit the LHC (CERN/ENET, 2009). We further explore the incentives in the review of the governance policies later in this section.

4.3.3. CERN Innovation Paradox

Discussions around incentives at CERN developed into what we coined as the CERN Innovation Paradox:

> "*CERN openly develops technology with innovation potential to do better science, but it then can't close up and protect the results. If it did, researchers would no longer contribute with their knowledge and expertise, killing off the source of innovation".*

Technology protection – for e.g. through patenting – can be an essential mechanism to protect the financial investments needed to increase the technology maturity level. However, the logic of financial exploitation of open technology, many times, contradicts with the values of specific research communities. It is a matter of values and consequently a delicate area. On the other hand, one may ask how many technologies did not reach the status of innovation with economic or social impact because of the lack of investments to reach the necessary maturity level.

4.3.4. Distinction Between MPE and MPA

The laboratory divides its members of the personnel into two categories: employed members of the personnel (MPE) and associated members of the personnel (MPA). Both contribute to the development and operation of the scientific activities. By 2018, the lab operated with 3506 MPE's combined with 12569 MPA's (CERN Human Resources Department, 2019).

MPE's include staff members and fellows, are under the sole authority of the Director-General, employed to perform functions entrusted to them in return for remuneration. MPA's are not employed by CERN but appointed by the Director-General on the basis of a contract of association. They are appointed as participants in a collaboration based on an agreement between CERN and their home institution (CERN, 2018).

Collaboration between MPE's and MPA's is essential for the laboratory and a fundamental part of the international collaboration model. However, how does it relate with aspects of intellectual property? Who is the owner of the MPA's intellectual property? Shall CERN appropriate the knowledge and competence and invest for knowledge transfer purposes? Should CERN capitalize financially? These are concerns that can simply be answered by analysing the contracts of associations with the different institutes. Nevertheless, such distinction of categories of the personnel adds significant complexity to the process and creates potential litigation issues in the fight for licensing returns between institutes.

4.3.5. Knowledge and Competence Gap

The interviews pointed to the lack of competence to bridge technologies into marketable products. "*It's not our job and we don't know how to do it*", or from the technical sector "*we have the tendency to over-engineer, then it's not anymore what they needed, we could have used our time differently*". Additionally, there is the bridge between inventors and the knowledge transfer services. Different backgrounds create information asymmetries. The identification of opportunities in a high-tech laboratory with multiple fields of expertise is highly complex. It requires unique professionals with technical competence in very specific fields, combined with knowledge transfer and intellectual property management that master the business jargon and hold rich professional networks.

Related to the information and expectations asymmetries between technologists and knowledge transfer experts, while technologists expect business and market analysis support to leverage their technology and competence to new fields of application with innovation potential, the knowledge transfer experts are in search for novel inventions with determined economic value to define a licensing strategy to hopefully collect royalties. It reveals a mismatch in expectations that may create tension for technology leveraging.

4.4. Financial Aspects, Budget and Procurement

Financials and budgeting play a major for this matter. The generation of revenue from licensing technology spilling over from public research may spark the desire to fund research from itself. It may create a virtuous-cycle where feedback-loops between technology, market acceptance and respective financial flows, act as a mechanism to fund research. However, concerns were raised to such logic, as it may be difficult to apply to fundamental basic research – in comparison with applied sciences – that hence entail with risks in respect to the current funding model – which supports the ultimate freedom to focus solely on basic research.

4.4.1. Impact on Budget

CERN's research activities are funded by the Member States. The scale of the annual contributions is submitted to the Council for approval following a recommendation of the

Finance Committee. The contributions for 2019 totalled 1.14 BCHF (CERN, 2019 Annual Contributions to CERN budget, 2019).

During the interviews it was confirmed that CERN cannot accept private equity into its operating budget. This is confirmed by the 2017 Financial Statements, which demonstrates the sources of revenue. It includes the financial returns from knowledge transfer activities, totalling 1.6 MCHF – that is 0.14% of the total contributions (CERN, Financial Statements for the year ended 31 December 2017, 2018a).

The financial impact of licensing royalties on CERN's budget is marginal. One argued that it should be clear for the funding agents, and stakeholders in general, that a stronger maximization of the knowledge transfer throughput, will not generate enough revenue to drive the development of CERN's research activities.

While there is the perceived potential to increase the current returns 10 to 50 times, that amount will still have a minimal impact on the total 1 BCHF budget. Additionally, concerns were raised about the risk of replacing stable and dedicated budget lines by flows of royalties that can fluctuate with time, creating undesired complexity and potentially undermining the existing allocated budgets.

4.4.2. Distribution of Economic Returns Across the Member States

What model can maximize an equal distribution of the innovation benefits across all the Member States? This is a determinant matter that influences the knowledge transfer dynamics. Mentioned early in the report, the construction of an innovation park at CERN was discussed in the past, however the idea was abandoned because it was judged that such facility would grant an unfair advantage to the countries hosting the laboratory – France and Switzerland in detriment of 23 countries.

In response, CERN developed partnerships with a network of business incubators distributed across the member states. While positive results emerged from this approach, as demonstrated by the Knowledge Transfer group Annual Report (CERN Knowledge Transfer, 2018a), some ask about the impact of the physical distance between the incubators and the laboratory. Their contribution to the development of critical mass in the lab? Their competence and technology appropriability capabilities? Or the opportunity cost for local entrepreneurs at the incubators which will take other opportunities with less risk?

4.4.3. Difficulties in Building an Innovation Ecosystem

To promote the entrepreneurial activity within its community, CERN supports the creation of spin-off companies through advising, licensing of technology or on-boarding in an incubator. Additionally, the laboratory organizes regular meetups with innovators and aspiring entrepreneurs to fuel discussions, knowledge and facilitate networking.

In order to bridge gaps in the innovation and incubation value chain, one mentioned attempts to create an innovation venture lab or pre-incubator structure. However internal resistance faded the opportunity. Additionally, efforts to attract venture capital to CERN's campus did not materialize, justified by the opportunity cost of investors seeking for opportunities with less risk and higher potential returns.

4.4.4. Procurement Model

As discussed throughout the document, the development of complex scientific instruments often requires the collaboration with the industry. The tendering and contracting process at CERN, like many public tendering processes are set up to select the lowest bidder. Discussions about this method argued about how it impacts innovation opportunities.

Often, the lowest bidder principle is biased with implications for high-technology projects. Hameri & Nordberg (1999), authored a paper in the context of CERN, and identified three factors that influence the procurement process:*(i)* political interference when purchase decisions are made on international forums; *(ii)* assymetric information among tendering parties – namely when some of the bidders are involved in the early phases of specification; *(iii)* personal preferences of individuals involved in the tendering process that may unintentionally influence the range of viable bidder solutions.

The authors argue that the lowest bidder approach does not favour the collaboration with innovative firms and tends to work better for established technologies – a new source of "*missed opportunities*".

4.5. Overview of Internal Governing Policies

We briefly review the operational and governance policies discussed throughout the interviews, namely the CERN Convention, CERN IP Policy and the CERN Spin-Off Policy.

4.5.1. CERN Convention

The CERN Convention, referenced multiple times throughout the document, has an imperative role over the governance of the Organization. The Article II defines the Organization's purpose divided in seven paragraphs. The first three paragraphs are transcribed below:

1. *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.*

2. *The Organization shall, in the collaboration referred to in paragraph 1 above, confine its activities to the following:*
    - i. *the construction and operation of one or more international laboratories (hereinafter referred to as "the Laboratories ") for research on high-energy particles, including work in the field of cosmic rays; each Laboratory shall include:*
        1. *one or more particle accelerators;*
        2. *the necessary ancillary apparatus for use in the research programmes carried out by means of the machines referred to in (i) above;*
        3. *the necessary buildings to contain the equipment referred to in (i) and (ii) above and for the administration of the Organization and the fulfilment of its other functions;*
    - ii. *the organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratories; this co-operation may include in particular:*
        1. *work in the field of theoretical nuclear physics;*
        2. *the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;*
        3. *collaborating with and advising other research institutions;*
        4. *work in the field of cosmic rays.*
3. *The programmes of activities of the Organization shall be:*
    - i. *the programme carried out at its Laboratory at Geneva including a proton synchrotron for energies above ten gigaelectronvolts (1010 eV) and a synchro-cyclotron for energies of six hundred million electronvolts (6 x 108 eV);*
    - ii. *the programme for the construction and operation of the intersecting storage rings connected to the proton synchrotron described in sub-paragraph (a) above;*

iii. *the programme for the construction and operation of a Laboratory to include a proton synchrotron for energies of about three hundred gigaelectronvolts (3 x 1011 eV);*
iv. *any other programme failing within the terms of paragraph 2 above.*

4.5.2. CERN IP Policy

The IP policy sets out the principles forming the basis for the management of IP in the knowledge transfer activities at CERN. It is grounded on the Organization's mission and develops the following general principles:

(i) use knowledge transfer practices that maximise dissemination and visibility, giving preference to dissemination when in conflict with revenue generation;
(ii) use of knowledge transfer practices compatible with collaborative and open research;
(iii) Priority to CERN's scientific programme;
(iv) Equal opportunities for all CERN Member States;
(v) Preference to transfer technology to industry established in CERN Member States;
(vi) Adopt measures to avoid that technology transfer to industry impairs the principle of fair competition in future procurements;
(vii) No technology transfer for military applications, competition with the industry or commercial role of responsibility for CERN;
(viii) Transfer technology on "as-is" basis without guarantee or liability for use and commercial exploitation;

On the ownership side, CERN retains the rights on the technologies developed within the framework of its scientific programme, and will only assign to third parties under exceptional circumstances when it is considered the best route for dissemination of the technology. The scenario of joint ownership is included when technology is developed with other parties.

CERN considers patent protection when there is a perceived opportunity for commercial activity. CERN usually retains ownership of the technologies. The policy suggests other types of protection like copyrights for all forms of technical documentation or software produced by CERN personnel. Non-Disclosure Agreements from the Legal Service are available for service, consultancy or research agreements.

The policy defines the condition rules and aspects related to IP ownership, protection, and access rights for R&D collaborations, research contracts, and consultancy services where the organization engages. Funding, costs, and overheads originating from these activities revert partially to an internal fund used to support other knowledge transfer initiatives.

Exploitation by third parties is available through licensing. CERN considers exclusivity when significant investments are needed to bring the technologies to market, or if the technology is the result of an R&D collaboration financed by an industrial partner. The policy includes an incentives scheme to encourage knowledge transfer. The licensing revenues are redistributed in three equal parts between the department and respective section where the technology was developed, and the knowledge transfer fund (CERN, 2010).

4.5.3. CERN Spin-Off Policy

In 2008, CERN established an internal policy to support new companies exploiting CERN's technologies. One of the motivations was to reflect the best practices in the spirit of the European Commission Recommendation:

> *"Develop and publicise a policy for the creation of spin-offs, allowing and encouraging the public research organisation's staff to engage in the creation of spinoffs where appropriate, and clarifying long-term relations between spin-offs and the public research organisation."* (Commission of the European Communities, 2008).

In addition to the IP Policy described before, the Spin-Off Policy includes the following principles:

(i) Encouragement and support for the creation of spin-off that seeks to exploit CERN's technology through access to the technology, technical support, equipment under favourable conditions and subject to availability; Access to labels, network of incubators and network of entrepreneurs;

(ii) CERN does not invest or take equity in spin-off companies or provide funding from its regular budget;

(iii) CERN shall not be represented on boards or committees of spin-off companies;

CERN will provide support to the entrepreneur, on the categories above, when there is a demonstrated business plan with a clear path to sustainability, entrepreneurial drive and commitment to exploiting the technology and the company's business is in line with the Organization's values (CERN Knowledge Transfer Gorup, 2018a).

4.6. Projects in the Knowledge and Innovation Value Chain

4.6.1. CERN openlab

Described in the first section of the case study, CERN openlab is identified as a partner of the Knowledge Transfer Group (CERN Knowledge Transfer, 2019). Alberto Di Meglio explains that CERN openlab is a framework to develop knowledge and critical mass in collaboration with industrial and academic partners in computing related topics. Such critical mass and competence in the computing field is essential to tackle the challenges the laboratory will face with the evolution of the accelerators and detectors.

For example, the High Luminosity LHC will increase collision rates 10 times by 2026, and consequently require significantly larger data management and data analysis capabilities. Today, techniques based on Machine Learning, AI or Quantum Computing are explored to improve the data analysis model.

Hence, CERN openlab is a natural partner of the Knowledge Transfer group as a source of potential innovation that can channel back to society via this internal unit or the CERN openlab industrial partners – depending on the contractual agreements.

4.6.2. CERN IdeaSquare

CERN IdeaSquare, is an initiative started by the end of 2014 and defines itself as:

"*[…] a place where scientists and society meet to push the boundaries of knowledge and to share and explore new ways to reach societal impact through research and technology. A space designed for collaboration through curiosity, creativity and science. A place where people have a licence to dream*" (CERN IdeaSquare, 2019).

It positions as an element bridging society and CERN through education and collaboration using CERN's technology to create positive impact on society and is driven by principles of open science and open innovation.

One important aspect, IdeaSquare is not an incubator as commented by Markus Norberg co-founder of IdeaSquare:

"*We are not talking here about constructing a startup accelerator or an incubator. We are trying to make a link between technology developed for physics research with possible new applications having societal significance. Our primary goal is not to set up companies, the goal is to see whether our scientific knowledge can inspire new ideas that can create value for society in a wide variety of ways*".

Marzio Nessi, the second co-founder describes the context:

"*Our scientific community is very strong in finding and using technology in different ways, so why not allow students and other curious people to have the same possibility? Only a few researchers have an idea how to use certain specific technology or knowledge and as a result, new technologies often die in the labs, while industry has no idea how to make the most of the knowledge as they want more mature, applicable technologies to begin with. Why not think about projects along a 3-4 year timeline to develop something, to come up with completely new ideas that go beyond their mere exploitation by industry?*"

IdeaSquare develops projects by combining scientists, researchers, engineers from CERN and other research centres, PhD and MSc students, NGOs, people from innovation networks, companies and EU institutions, to generate new ideas, develop, and test in an open innovation ecosystem. Translating into hosted or supported R&D projects, hackathons, courses, events, seminars, and workshops.

For example, the TT-PET collaboration, a 3-year project, to produce a pre-clinical PET Scanner based on silicon detector technology insertable in an MRI machine and with 30ps RMS time resolution. This is a project co-lead by the University of Geneva, CERN, INFN of Roma Tor Vergata, University of Bern, Hôpital Cantonal de Genève and Stanford University.

Additionally, it started the Challenge Based Innovation (CBI) activities, with a student programme where multidisciplinary student teams and their instructors from universities worldwide collaborate with CERN researchers to discover novel solutions for the future of mankind. The projects are a mixture of technologies inspired by research environments addressing societal needs.

Since its beginning IdeaSquare hosted over 600 students. Furthermore, in collaboration with the Knowledge Transfer group, IdeaSquare organizes the Entrepreneurship

Meet-ups, the CERN Entrepreneurship Student Programme, the CERN-NTNU Technology Screening Week, and a technology hackathon on the medical field.

CERN IdeaSquare publishes its own journal on experimental innovation with empirical and theoretical research on the practice of strategic technology and innovation management to better understand the innovation process. It reports the outcomes of innovation experiments at IdeaSquare, with the purpose to, as expressed by the founders:

> "*Through reporting the outcomes of innovation experiments at IdeaSquare, we can pursue our dream of systematising serendipity and contribute to a better world through new knowledge and technology*".

4.6.3. ATTRACT Project

The ATTRACT project, a pan-European initiative where IdeaSquare played a leading role, aims at creating a co-innovation ecosystem between fundamental research and industry communities to develop breakthrough technologies in the detection and imaging fields, for scientific and commercial purposes. It includes a Phase 1 to act as a seed funder for 170 selected technology concepts to lead the next generation of detection and imaging technologies. Each successful project proposal receives a lump sum of € 100,000.

The ATTRACT Programme Consortium expects that 4-to-6 of the submitted ideas during the first phase will have potential to transform society. These will be supported during a second phase – to be submitted under the H2020 2018-2020 Work Programme – to provide the necessary financial up-scaling for the technologies validated during the Phase 1, by enlisting large companies, experienced venture capitalists and individual investors (ATTRACT, 2019).

5. Recommendations

5.1. Fundamental Assumption

As mentioned earlier, this case study does not aim at answering whether CERN should or should not embrace innovation as a pillar of its mission and consequently, for example, convert into an innovation park, a regional technology cluster or similar. The objective is to identify the organizational dynamics that influence the optimal knowledge transfer throughput and innovation potential. Based on these, develop a set of recommendations supported by the current analysis, academic literature review, and results from qualitative interviews, to propose a path that can optimize knowledge transfer and the innovation potential at CERN. Hence, the recommendations are based on the assumption that such becomes a strategic priority to maximize returns to the Member States and society in general.

5.2. Weaknesses

These are considered major weaknesses in the current organizational model that deserve discussion at the higher levels of the management.

5.2.1. Lack of Incentives

The literature review demonstrates that direct incentives to inventors are crucial to promote the disclosure of novel technologies and ensure the cooperation to fill the knowledge gaps necessary to increase the technology maturity level. Consequently, it is recommended to review the existing incentives policy and introduce an innovation incentives scheme. Direct attribution of a percentage of royalties or a share of new ventures equity reveals to be efficient. Concerns may raise about the staff diverging from its primary focus of contributing to the research programme. Such could be overweighed. To support decision-making, there is literature that focused on the potential conflict of interest, commitment, and equity in university-industry relationships (Campbell & Slaughter, 2016). Such could be an area of future research, understanding these implications for public research organizations and big science institutes.

5.2.2. Licensing for Equity

Licensing for equity became a strategic way to support spin-offs when technologies are at early stages of development, or the demand is uncertain. The literature demonstrates that licensing for royalties performs best for technologies at higher maturity stages where the market demand is well defined. Such is hardly the case for technologies developed at CERN.

Byckling et al. (2000), estimate that a successful product typically requires an investment 100 times larger than it was required to build the original concept. In a context of business uncertainty and risk, it is hard to attract the necessary financial and human capital to bring these technologies to the market – as argued multiple times, the opportunity cost is high.

Licensing for equity, can support innovation in multiple ways: *i)* send a strong signal to the market that the organization believes and supports the project and team behind; *ii)* support the technology development at an early stage, in exchange of equity, in place of royalties that are difficult to finance at the spin-off stage; *iii)* benefit from future financial returns in the case of success; *iv)* in case of failure, the organization can get back the rights on the technology, and hopefully re-license at a higher stage of development.

5.2.3. Competence Gap and Culture

It was argued during the interviews, that the necessary competences to build innovations, either with economic or social value, are not abundant in the laboratory – being neither its mission. Knowledge and competence gaps happen at different layers of the innovation value chain – as discussed in the fourth section with the expectations asymmetries between technology sectors and knowledge transfer services. Additionally, the entrepreneurial spirit and business competence needed to discover valuable opportunities is not part of the organization's DNA – achieving those require a significant cultural change and cost accordingly.

Universities and other public research organizations faced the same challenge with the implementation of the Triple Helix. There is abundant literature on the subject. For example Ambos et al. (2008), focused on the creation of ambidexterity in research institutions – ability to perform research and achieve commercial outcomes – by analysing the tensions between these two dynamics, showed that these are more salient at the level of the individual researcher than at the level of the organization. The same authors use the aphorism "you cannot teach an old dog new tricks" to suggest that better strategies may be targeting young high-achievers or young high-researchers who demonstrate high potential to increase the number of ambidextrous individuals.

Knowledge transfer offices have a dominant role in managing organizational and individual tensions – and should not, on the other hand, become a source of tension. Researchers are usually overcommited becoming difficult to engage in knowledge transfer or consultancy activities if the value proposition is not clear, or if knowledge transfer is not a strategic pillar of the departments and the Organization. To develop closer tights between research groups and kowledge transfer structures, Debackjere & Veugelers (2005) suggest the implementation innovation coordinators. Such coordinators are partially paid by knowledge transfer units to act as liaison officers and the rest of the time they act as researchers within one division.

5.3. Recommendations

Based on the weaknesses and the overall analysis, we develop recommendation strategies that can support the development of innovation and maximize knowledge transfer throughput. The implementation of the Smart Specialisation Strategies from the Horizon 2020 programme provides valuable insights that can translate into the context of CERN – which can be seen as an independent region with economic potential, its characteristics and unique assets. With such strategy develop an excellence-driven vision of the future to strengthen its regional innovation potential. Note that we are not finalizing this work with a Smart Specialization strategy, but rather focusing on the specific weaknesses identified throughout the case. Nevertheless it is an interesting suggestion for future work.

5.3.1. Systematic Approach to Opportunity Discovery and IP Management

This recommendation suggests the adoption of a systematic approach for the discovery of opportunities with innovation potential. It decomposes on a series of sub-recommendations which apply to the discovery process of opportunities, but also at the organizational level aiming at mitigating communication and expectation asymmetries.

5.3.1.1. Systematic Intellectual Property Audits

Perform systematic intellectual property audits to review, identify and monitor the complete intellectual asset portfolio. Such can be a crucial tool to develop a deeper understanding of the innovative potential of CERN’s intellectual property.

5.3.1.2. Adopt the Technology Competence Leveraging Methodology

Described in the section 3.11, it is a systematic process to search for new applications of existing technologies of solutions. It is based on the de-linking and re-linking processes enabling the exploitation of underutilized potential by finding new fields of application.

5.3.1.3. Adopt the Technology Readiness Level Scale

Systematically introduce the Technology Readiness Level (TRL) scale (Enspire.science, 2018) in the organization’s jargon. It becomes a tool that facilitates communication and common understanding between technology developers, users, managers, and the industry in general. Taking the experience from the implementation of the TRL in the Horizon 2020 framework:

“*Due to the increasing complexity of European funding landscape with broader number of programmes funding different project phases and managed under different European Commission Directorate Generals and agencies, TRL has become an extremely helpful tool to understand the complementarity of existing programmes and a more coherent and targeted support of research and innovation activities.*” (European Commission, 2019).

Additionally, it is a tool that can support the mapping of technologies throughout a linear innovation scale.

5.3.1.1. Role of Innovation Coordinators

As suggested in the section 3.2.3, innovation coordinators with a close relationship with research groups and the knowledge transfer structure can strengthen the bridge between these entities. To be noted that these are not purely liaison officers, but active researchers with a 50% focus on innovation, knowledge, and technology transfer.

5.3.1.2. Case Study Methodology to Deepen Understanding of the Context

As a personal reflection, CERN is unique in itself by the vast amount of case studies it could generate. As mentioned in the section 2, case studies are an excellent tool to help understanding complex social changes associated with emerging technologies in the context of innovation.

For example, the Indico project developed by the IT Department at CERN. An event-management solution for lectures, meetings, workshops, and conferences, that according to the project manager Pedro Ferreira, is used by 200 institutes and organizations worldwide (CERN, 2019). Could the case study methodology help answering why this open-source project did not scale and became autonomous and self-sustainable so far? Why is no company offering Indico as a service at scale? Why no spin-off started when dozens of technical students, project associates, and fellows contributed to the development of the project during their stay at CERN? Lack of entrepreneurial attitude, financial support, or incubation structure? Ultimately, how could it happen?

Thus, we suggest exploring the case study methodology at CERN to develop and formalize a deeper understanding of the internal dynamics and shed light on generic questions related to knowledge transfer and the innovation process – this work is an example in itself.

5.3.2. Develop Entrepreneurial Spirit

Grounded on the Competence Gap described at the section 5.2.3 and recommendations from an Expert Group on Knowledge Transfer and Open Innovation study for the European Commission, we suggest the need to further encourage entrepreneurship. As suggested in this same study "*the role of universities and public research organizations as co-creators in innovation systems needs to be further enhanced"* (EU Publications, 2014).

This same study highlights the challenges with respect to enabling co-creation capabilities, the design of incentives for researchers, and with the absorptive capacity of academic knowledge within firms. For reference, the complete action item and respective recommendations are transcribed on the Appendix.

5.3.3. Spin-Off the Knowledge and Technology Transfer to Develop Innovation

Last and the most central recommendation of this work, suggests transferring the knowledge and technology transfer activity to a separate legal entity under the format of an independent non-profit research organization. Such entity requires an exclusive partnership with CERN – such as for the case of EMBL and EMBLEM, or CERN and CERN & Society Foundation – with the purpose to leverage unique knowledge, technology and competence from CERN to develop innovations – with economic or social value – and maximize the returns to the Member States and society in general.

Compared with CERN, the entity should benefit higher autonomy to operate including: *(i)* ability to recruit competence in the business ecosystem; (*ii)* ability to exploit all technology licensing methods including licensing for equity; *(iii)* ability to raise external funding from investors or donors for the purpose of innovation; *(iv)* ability to focus and exploit innovation mechanisms, including but not exclusive to: pre-incubation, incubation, innovation lab, venture lab, accelerator, science park, – according to its own budget availability; *(v)* materialize a signal of commitment of the Organization towards knowledge transfer and innovation to its Member States and society – including industries and firms; *(vi)* channel human capital ending the affiliation with CERN to contribute to projects under the structure; *(vii)* grant stronger legal protection to CERN from licensing activities;

The choice between for-profit or non-for-profit lies in the assumption that a significant part of the innovation potential of CERN's knowledge and technology will have higher impact when given back to society as a whole instead of embarking on a pure for-profit and commercial activity. Though for other projects – namely Indico – commercialization could be a catalyser to enable the project to scale and become self-sustainable.

In this sense, within CERN the activity should focus on intellectual property discovery, management, and orchestrate its internal organizational structure – as allowed per its mission and statutes – to then channel the results to this external entity who should complete the innovation value chain.

Appendix

Boosting Open Innovation and Knowledge Transfer in the European Union
Action 3: Make Universities and PROs More Entrepreneurial (EU Publications, 2014)

A third priority focuses on encouraging Europe's universities and PROs to become still more entrepreneurial. The role of universities and PROs as co-creators in innovation systems needs to be further enhanced. This provides challenges a) to Universities' co-creation capabilities, b) to the design of incentives for academics when working with users and c) to the absorptive capacity of academic knowledge within firms.

The arrangements in many EU universities and PROs have been reported to be still too bureaucratic. The focus seems to be more on managing innovation relationships rather than supporting the delivery of outputs. Evidence suggests that individual scientists are the strongest source of initiating interactions with the stakeholders of innovation ecosystems – often with limited involvement of university administrators. It is important to focus on nurturing and accelerating the development of universities and PROs into entrepreneurial institutions, so that they may become catalysts of Triple Helix interactions. For this to happen, the role of scientists as knowledge providers would need to be complemented with a role as co-creators. Furthermore, the role of knowledge transfer offices (KTOs) would have to be transformed from isolated entities into fully embedded professional service units within universities and research organizations.

Universities and PROs should therefore be encouraged to develop and adopt a Charter and Code in their Entrepreneurial and Innovation Policy. This Charter and Code in universities and PROs' is not about implementing more rules, but about ensuring that their scientists are encouraged to actively embrace more entrepreneurial objectives. This must also allow for more strategic flexibility at the national and regional level, accepting that research institutions become more autonomous and rewarded for their dedicated and targeted contributions to the innovation ecosystem.

Professionalism must be linked to the new imperative of open innovation. Measures should be put in place to ensure that OI and KT as a 'profession' is recognized in universities and PROs, in order to update the skills to support OI. Skill development should be aimed at a) developing the entrepreneurial and innovation skills of scientists and b) the legal, administrative and coordination skills of support staff that facilitates this.

An appropriate incentive schemes should be further developed to stimulate scientists, academics and KTO staff to engage in co-creation processes with the users of their knowledge. This involves recognition of the entrepreneurial engagements of academics/scientists beyond the traditional recognition of publications and scientific impact. It also involves willingness to support the services provided by KTOs to engage in different co-creation mechanisms with businesses, social institutions, governments, and citizens etc. These incentives should be incorporated into performance indicators for career progression. This should be anchored at stakeholder (University/PRO) level.

Thus, our proposed Charter and Code in policies and practices for making universities and PROs more entrepreneurial and innovative should aim to stimulate scientists to become co-creators with the stakeholders of innovation ecosystems. Those measures can also be integrated in the HRS4R policy that is now gaining ground within a plethora of EU universities and PROs.

The EC thus needs to support and encourage the adoption of good practices that enables universities and PROs to co-create knowledge with their collaborative partner-innovators. Research institutes need to be supported to adopt good practices when engaging with users. This enables them to build trustworthy, transparent and long-term relationships with those users. It means that universities and PROs need to implement effective strategies to reap the full benefits of cocreation. This leads to the following recommendations:

- MS and the EC should stimulate universities and PROs to develop and adopt a Charter and Code on their entrepreneurial and innovation Policy. This policy code can build upon the same approach as the ‘HR Strategy for Researchers’ (HRS4R). The articulation and adoption the code should be recognized as a quality label, for instance in funding programs.
- The EC needs to put measures in place to ensure that ‘OI and KT’ as a ‘profession’ is recognized in universities and PROs, in order to update the skills to support OI. The Knowledge Transfer Offices (KTOs) should play a central role in this process of professional development and maturation.
- European universities and PROs need to adopt appropriate incentive schemes for scientists and KTO staff to engage in co-creation processes with the users of the knowledge they generate. These should be incorporated into performance indicators for career progression. These should be anchored on University-PRO level.

References

Ambos, T. C., Makela, K., Birkinshaw, J., & D'este, P. (2008). When Does University Research Get Commercialized? Creating Ambidexterity in Research Institutions. *Journal of Management Studies*, 1424-1447.

Anelli, G. (2019, 01 14). *CERN releases a new Policy on Software Dissemination*. Retrieved from https://home.cern/news/official-news/computing/cern-releases-new-policy-software-dissemination

Antelman, K. (2004). *Do Open Access Articles Have a Greater Research Impact?* Retrieved from http://eprints.rclis.org/5463/

Argyropoulou, M., Soderquist, K. E., & Ioannou, G. (2019). Getting out of the European Paradox trap: Making European researchagile and challenge driven. *Econonomic Management Journal*, 1-5.

ATTRACT. (2019). *Markus Nordberg*. Retrieved from https://attract-eu.com/profile/markus-nordberg/

ATTRACT. (2019). *The Project*. Retrieved from ATTRACT: https://attract-eu.com/the-project/

Audretsch, D. (2002). Standing on the shoulders of midgets: theUS, small business innovation research (SBIR) program. *Small Business Economics*, pp. 129-135.

Autio, E., Hameri, A.-P., & Vuola, O. (2004). A framework of industrial knowledge spillovers in big-science centers. *Research Policy*, 107-126.

Baxter, P., & Jack, S. (2008, 11). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*, pp. 544-559.

Binks, M., Wright, M., Lockett, A., & Vohora, A. (2004). Venture CapitalFinance and University Spin-outs. *University of Notting-ham Institute for Enterprise and Innovation*.

Brazil, R. (2018, 09). *Open-science hardware in the developing world*.

Burgelman, R. (1991). Intraorganizational ecology of strategy making and organizational adaptation: theory and field research. pp. 239-262.

Byckling, E., Hameri, A.-P., Petersson, T., & Wenninger, H. (2000). Spin-offs from CERN and the case of TuoviWDM. *Technovation*, 71-80.

Campbell, A. (2007). How to set up a technology transfer office: experiences from Europe. *Intellectual Property Management in Health and Agricultural Innovation*.

Campbell, T. I., & Slaughter, S. (2016, 11). Faculty and Administrators' Attitudes toward Potential Conflicts of Interest, Commitment, and Equity in University-Industry Relationships. *The Journal of Higher Education*, pp. 309-352.

Carayannis, E. (2001). *The strategic management of technological learning: Learning to learn and learning to learn-how-to-learn as drivers of strategic choice and firm performance in global, technology-driven markets.* Boca Raton.

Carayannis, E., & Grigoroudis, E. (2016). Quadruple innovation helix and smart specialization: knowledge production and national competitiveness. *Foresight and STI Governance*, pp. 31-42.

CERN. (1999). *Technology Transfer Policy at CERN.* Geneva: Finance committee.

CERN. (2008). *CERN: a unique experience*. Retrieved from https://public-archive.web.cern.ch/en/People/UniqueExperience-en.html

CERN. (2010, 03). *Another of CERN's many inventions!* Retrieved from https://cds.cern.ch/record/1248908

CERN. (2010). *Policy on the management of intellectual property in technology transfer activities at CERN.*

CERN. (2012, 06). *CERN adopts new intellectual-property access scheme*. Retrieved from https://home.cern/news/news/knowledge-sharing/cern-adopts-new-intellectual-property-access-scheme

CERN. (2015, 03). *Contract Policy* . Retrieved from https://hr-dep.web.cern.ch/content/contract-policy

CERN. (2017). *CERN Knowledge Transfer*. Retrieved from https://kt.cern/sites/knowledgetransfer.web.cern.ch/files/file-uploads/annual-report/knowledge-transfer-report-2017.pdf

CERN. (2017, 04). *Open Access Policy for CERN Publications*. Retrieved from http://cds.cern.ch/record/1955574/files/CERN-OA-Policy-27Apr2017-1.pdf

CERN. (2018, 09). *Categories of members of the personnel*. Retrieved from http://newcomersguide.web.cern.ch/categories-members-personnel

CERN. (2018a). *Financial Statements for the year ended 31 December 2017.* Retrieved from https://cds.cern.ch/record/2631935/files/English.pdf

CERN. (2019, 05). Retrieved from Our history: https://home.cern/about/who-we-are/our-history

CERN. (2019, 08). *2019 Annual Contributions to CERN budget*. Retrieved from https://fap-dep.web.cern.ch/rpc/2019-annual-contributions-cern-budget

CERN. (2019, 08). *CERN Convention*. Retrieved from https://council.web.cern.ch/en/convention

CERN. (2019, 05). *CERN Mission*. Retrieved from https://home.cern/about/who-we-are/our-mission

CERN. (2019, 04). *Data Centre*. Retrieved from http://information-technology.web.cern.ch/about/computer-centre

CERN. (2019, 01). *FCC publishes concept design for a post-LHC future circular collider at CERN*. Retrieved from https://fcc.web.cern.ch/Pages/news/FCC-publishes-concept-design-for-a-post-LHC-future-circular-collider-at-CERN.aspx

CERN. (2019, 05). *Information Technology Department*. Retrieved from http://information-technology.web.cern.ch/

CERN. (2019, 04). *Key achievements*. Retrieved from https://home.cern/about/key-achievements

CERN. (2019, 05). *Member States*. Retrieved from https://home.cern/about/who-we-are/our-governance/member-states

CERN. (2019, 05). *Open source for open science*. Retrieved from https://home.cern/science/computing/open-source-open-science

CERN. (2019). *Our education programmes*. Retrieved from https://home.cern/about/what-we-do/our-educational-programmes

CERN. (2019, 05). *Our research*. Retrieved from https://home.cern/about/what-we-do/our-research

CERN. (2019, 05). *Processing: What to record?* . Retrieved from https://home.cern/science/computing/processing-what-record

CERN. (2019, 05). *Root Data Analysis Framework*. Retrieved from https://root.cern.ch/

CERN. (2019, 05). *The accelerator complex*. Retrieved from https://home.cern/science/accelerators/accelerator-complex

CERN. (2019, 05). *The CERN History Study*. Retrieved from CERN Scientific Information Service: http://library.cern/archives/history_CERN/history_project

CERN. (2019). *The effortless open-source tool for event organisation, archival and collaboration*. Retrieved from https://getindico.io

CERN. (2019, 08). *Welcome to the CERN Council*. Retrieved from https://council.web.cern.ch/en

CERN Human Resources Department. (2019, 03). *CERN Personnel Statistics 2018.* Retrieved from https://cds.cern.ch/record/2677223/files/CERN-HR-STAFF-STAT-2018-RESTR.pdf

CERN IdeaSquare. (2019). *IdeaSquare - Licence do dream Progress Report 2017-2018.* Retrieved from https://ideasquare.web.cern.ch/sites/ideasquare.web.cern.ch/files/IdeaSquare%20Progress%20Report%202017-2018.pdf

CERN Knowledge Transfer. (2018a). *Knowledge Transfer 2018.* Retrieved from https://kt.cern/sites/knowledgetransfer.web.cern.ch/files/file-uploads/annual-report/knowledge-transfer-report-2018.pdf

CERN Knowledge Transfer. (2019, 08). *Giovanni Anelli*. Retrieved from https://kt.cern/team/giovanni-anelli

CERN Knowledge Transfer. (2019, 08). *Knowledge Transfer partners @CERN*. Retrieved from https://kt.cern/about-us/partners

CERN Knowledge Transfer Gorup. (2018a, 08). *CERN policy on support for companies established to exploit CERN technologies*. Retrieved from https://knowledgetransfer.web.cern.ch/sites/knowledgetransfer.web.cern.ch/files/file-uploads/intellectual-property-reference/spin-policy.pdf

CERN openlab. (2017, 11). *Future ICT Challenges in Scientific Research*.

CERN openlab. (2018). *Annual Report*.

CERN openlab. (2019, 08). *Alberto Di Meglio*. Retrieved from https://openlab.cern/team/alberto-di-meglio

CERN openlab. (2019, 05). *Our Work*. Retrieved from https://openlab.cern/our-work

CERN/ENET. (2009, 11 10). *13th meeting - External Technology Transfer Network.* Retrieved from https://indico.cern.ch/event/73360/attachments/1040842/1483388/ENET_November_09_draft_summary_record-final.pdf

Clarysse, B., Wright, M., Lockett, A., Velde, E. V., & Vohora, A. (n.d.). Spinning out new ventures: a typology of incubation strategies from European research institutions. *Journal of Business Venturing*, 183-216.

Cohen, M., & Levinthal, A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Technology, Organizations, and Innovation*, 128-152.

Commission of the European Communities. (2008). *COMMISSION RECOMMENDATION on the management of intellectual property in knowledge transfer activities and Code of Practice for universities and other public research organisations* . Retrieved from https://ec.europa.eu/invest-in-research/pdf/ip_recommendation_en.pdf

Commission, E. (1995). *Green Paper on Innovation.*

Commission, E. (2012). *RIS3 guide.* Brussels: European Commission.

Commission, E. (2014). *National/Regional Innovation Strategies for Smart Specialisation (RIS3).* Commission, European.

Crabtree, B., & Miller, W. (2008). *Doing Qualitative Research.* London: Sage.

Curley, M., & Salmelin, B. (2013). *Open Innovation 2.0 - A New Paradigm (EU Open Innovation and Strategy Policy Group.*

Danneels, E. (2007). The Process of Technological Competence Leveraging. *Strategic Management Journal*, pp. 511-533.

Debackere, K., & Veugelers, R. (2005). The role of academic technology transfer organizations in improving industry science links. *Research Policy*, pp. 321-342.

Debackjere, K., & Veugelers, R. (2005). The role of academic technology transfer organizations in improving industry links. *Research Policy*, pp. 321-342.

Dedrick, J., & Kraemer, K. (2015). Who captures value from science-based innovation? The distribution of benefits from GMR in the hard disk drive industry. *Research Policy*, pp. 1615-1628.

Dosi, G., Llerena, P., & Labini, M. S. (2006). The relationshio between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called "European Paradox". *Research Policy*, pp. 1450-1464.

Doussineau, M., Arregui-Pabollet, E., Harrap, N., & Merida, F. (2018). *Drawing funding and financing scenarios for effective implementation of Smart Specialisation Strategies*. Retrieved from https://s3platform.jrc.ec.europa.eu/documents/20182/201464/Drawing+funding+and+financing+scenarios+for+effective+implementation+of+Smart+Specialisation+Strategies/4296838f-13ea-433e-88c2-689456f01b95

Eliasson, G., & Eliasson, A. (1996). The biotechnological competence bloc. *Revue d'économie industrielle* , 7-26.

Engels, F., Wentland, A., & Pfotenhauer, S. M. (2019, 11). Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance. *Research Policy*.

Enspire.science. (2018, 07). *TRL Scale in Horizon 2020 and ERC – Explained*. Retrieved from enspire.science: https://enspire.science/trl-scale-horizon-2020-erc-explained/

EPFL. (2019, 09). *EPFL missions*. Retrieved from EPFL: https://www.epfl.ch/about/overview/epfl-missions-and-values/

Escribano, A., Fosfuri, A., & A.Tribó, J. (2009). Managing external knowledge flows: The moderating role of absorptive capacity. *Research Policy*, pp. 96-105.

Etzkowitz, H. (2003, 09 01). Innovation in Innovation: The Triple Helix of University-Industry-Government Relations. *Social Science Information*, pp. 293-337.

Etzkowitz, H. (2007). *University-Industry-Government: The Triple Helix Model of Innovation.* Newcastle University Business School.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations. *Policy Research*, pp. 109-123.

Etzkowitz, H., & Zhou, C. (2017). *The Triple Helix.* London: Routledge.

EU Publications. (2014, 06 20). *Boosting open innovation and knowledge transfer in the European Union.* Retrieved from Publications Office of the European Union:

https://publications.europa.eu/en/publication-detail/-/publication/5af0ec3a-f3fb-4ccb-b7ab-70369d0f4d0c

European Commission. (2014). National/Regional Innovation Strategies - Cohesion Policy 2014-2020.

European Commission. (2019, 04). *Commission invites top experts to shape new research and innovation missions*. Retrieved from https://ec.europa.eu/info/news/commission-invites-top-experts-shape-new-research-and-innovation-missions-2019-may-13_en

European Commission. (2019). *Funding & tender opportunities*. Retrieved from https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home

Flick, U. (2010). Qualitative Sozialforschung. *Technische Universitat Dortmund*.

Foray, D. (1995). Accessing and expanding the science and technology knowledge base. *STI-Review*, pp. 13-68.

Foray, D., & Goenaga, X. (2013). *The goals of Smart Specialization: S3 policy brief series.* Brussels: European Commission.

Foundation, H. S. (2017, 12). *A Roadmap for HEP Software and Computing R&D for the 2020s*. Retrieved from https://arxiv.org/pdf/1712.06982.pdf

Franklin, S., Wright, M., & Lockett, A. (2001). Academic and surro-gate entrepreneurs in university spin-out companies. *Journal of Technology Transfer*, pp. 127-141.

Galbraith, J. (2011). The Star Model.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societie.* London: Sage.

Gibson, C. B., & Birkenshaw, J. (2004). The antecedents, Consequences and Mediating Role of Organisational Ambidexterity. *Academy of Management Journal* , 209-226.

Hameri, A.-P. (1997). Innovating from Big Science Research. *Journal of Technology Transfer*, 27-35.

Hameri, A.-P., & Nordberg, M. (1999). Tendering and contracting of new, emerging technologies. *technovation*, pp. 457-465.

Haug, I. (2015, 03). *Career Opportunities at CERN for students and recent graduates*.

Herranz, N., & Ruiz-Castillo, J. (2012). The end of the "European Paradox". *Scientometrics*, pp. 453-464.

Jensen, R., & Thursby, M. (n.d.). Proofs and prototypes for sale: the tale of university licensing. *Am. Econ.*, 240-259.

Jewell, C. (2008, 12). *CERN and Innovation – The Heart of the Matter*. Retrieved from https://www.wipo.int/wipo_magazine/en/2008/06/article_0005.html

Kissell, K. D. (2018, 11). *Subatomic particles and big data: Google joins CERN openlab* . Retrieved from https://cloud.google.com/blog/topics/inside-google-cloud/subatomic-particles-and-big-data-google-joins-cern-openlab

Landry, R., Amara, N., Cloutier, J.-S., & Halilem, N. (2013). Technology transfer organizations: Services and business models. *Technovation*, pp. 431-449.

Lather, P. (1992). Critical frames in educational research: Feminist and post-structural perspectives. *Theory Into Practice*, pp. 87-99.

Leitch, C., & Harrisson, R. (2005). *Maximising the potential of university spin-outs: the development of second-order commercialisation activities*. Retrieved from https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1467-9310.2005.00388.x

Levitt, B., & March, J. (n.d.). Organizational learning. *Annual Review of Sociology*, pp. 319-340.

Leydesdorff, L. (2011). The Triple Helix, Quadruple Helix, and an N-Tuple of Helices: Explanatory Models for Analyzing the Knowledge-Based Economy. *Journal of the Knowledge Economy*, 25-35.

Lockett, A., Siegel, D., Wright, M., & Ensley, M. D. (n.d.). The creation of spin-off firms at public research institutions:Managerial and policy implications. *Research Policy*, pp. 981-993.

Lockett, A., Wright, M., & Franklin, S. (2003). Technology Transfer and Universities' Spin-out Strategies. *Small Business Economics*, pp. 185-201.

Macho-Stadler, I., Pérez-Castrillo, D., & Veugelers, R. (2007). Licensing of University Innovations: The Case of a Technology Transfer Office. *International Journal of Industrial Organisation*.

Markman, G. D., Siegel, D. S., & Wright, M. (2008). Research and Technology Commercialization. *Journal of Management Studies*, 1401-1423.

Markman, G., Phan, P., Balkin, D., & Gianiodis, P. (2005). Entrepreneurship and university-based technology transfer. *Journal of Business Venturing*, pp. 241-263.

Markman, G., Siegel, D., & Wright, M. (2008). Research and Technology Commercialization. *Journal of Management Studies 45*, 1401-1423.

Marks, P. (2010, 9). *Innovation: CERN collides with a patent reality*. Retrieved from https://www.newscientist.com/article/dn19407-innovation-cern-collides-with-a-patent-reality/

McAdam, M., Miller, K., & McAdam, R. (2018). Understanding Quadruple Helix relationships of university technology commercialisation: a micro- level approach . *Studies in Higher Education*, 1058-1073.

Miller, K., McAdam, R., & McAdam, M. (2018). A systematic literature review of university technology transfer from a quadruple helix perspective: toward a research agenda. *R&D Management*, pp. 7-24.

MindGate, L. (2019). *https://www.leuvenmindgate.be/about-leuven-mindgate*. Retrieved from About Leuven Mindgate: https://www.leuvenmindgate.be/about-leuven-mindgate

Morsing, M., & Schultz, M. (2006). Corporate Social Responsibility Communication: Stakeholder Information, Response and Involvement Strategies. *Business Ethics: A European Review*.

Mowery, D., & Oxley, J. (1995). Inward technology transfer and competitiveness: the role of national innovation systems. *Cambridge Journal of Economics*, pp. 67-93.

Muscio, A., & Pozzali, A. (2013). The Effect of Cultural Distance in University-industry Collaborations. Some evidence from Italian universities. *Journal of Technology Transfer*, 486–508.

Muscio, A., & Vallanti, G. (2014). Perceived Obstacles to University-industry Collaboration: Results from a Qualitative Survey of Italian Academic Departments. *Industry and Innovation*, 410-429.

Nelson, R. (2001). Observations on the Post-Bayh-Dole rise in patenting in American universities. *The Journal of Technology Transfer*, pp. 13-19.

Nilsen, V., & Anelli, G. (2016, 03 12). Knowledge Transfer at CERN. p. Technological Forecasting & Social Change.

O'Brien, J. (2003). The capital structure implications of pursuing a strategy of innovation. *Strategic Management Journal*, pp. 415-431.

OECD. (2001). *Benchmarking Industry-Science Relationships, Science, Technology and Industry Outlook 2000.*

OECD. (2011). *Innovation Policy Platform TTOs.* Technology Transfer Offices.

OHWR. (2019, 05). *OHWR Companies*. Retrieved from https://ohwr.org/companies

P, P. (2010). *Personal interview.* San Jose, CA.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Brostrom, A., D'Este, P., & Fini, R. (2013). Academic Engagement and Commercialisation: A Review of the Literature on University Industry Relations. *Research Policy 42*.

Polt, W. (2001). *Benchmarking Industry Science Relations: the role of framework conditions.*

Prajapati, V., Tripathy, S., & and Dureja, H. (2013). Product lifecycle management through patents and regulatory strategies. *Journal of Medical Marketing*, pp. 171-180.

Schacht, W. H. (2005). Patent Law and Its Application to the Pharmaceutical Industry: An Examination of the Drug Price Competition and Patent Term Restoration Act of 1984. *Congressional Research Service*.

Schumpeter, J. (1942). *Capitalism, Socialism, and Democracy.* London: Routledge.

Searle, J. (1995). *The Construction of Social Reality.* Free Press.

Sein, M., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. (2011, 03). Action Design Research. *MIS Quarterly*, pp. 37-56.

Sharif, H., W., L., & Ismail, S. (2014). Higher Education System and the 'Open' Knowledge Transfer: A View from Perception of Senior Managers at University Knowledge Transfer Offices. *Studies in Higher Education*.

Siegel, D. S., Veugelers, R., & Wright, M. (2007). Technology transfer offices and commercialization of university intellectual property: performance and policy implications. *Oxford Review of Economic Policy*, pp. 640-660.

Siegel, D. S., Westhead, P., & Wright, M. (2008). Assessing the impact of science parks on the research productivity of firms: exploratory evidence from the United Kingdom. *Journal of Management Studies*, 1401-1423.

Siegel, D., Waldman, D., & Link, A. (1999). Assessing the impact of organizational practices on the productivity technology transfer offices: an exploratory study. *NBER Working Paper Series No 7256*.

Siegel, D., Waldman, D., & Link, A. (2003). Assessing the impactof organizational practices on the productivity of university tech-nology transfer offices: an exploratory study. pp. 27-48.

SPARC. (2019, 05). *SPARC Open Access*. Retrieved from https://sparcopen.org/open-access/

Stumpe, B., & Sutton, C. (2010, 03 31). *The first capacitative touch screens at CERN*. Retrieved from CERN Courier: https://cerncourier.com/the-first-capacitative-touch-screens-at-cern/

Teece, J. (1982). Towards an economic theory of the multiproduct firm. *Journal of Economics Behavior and Organization*, pp. 39-63.

Teece, J. (1986). Profiting from technological innovation: implications for integration, collaboration, licensing and public polict. *Research Policy*, 285-305.

Transfer, C. K. (2019, 05). Retrieved from Compact Accelerator for Art Analysis: https://kt.cern/success-stories/compact-accelerator-art-analysis

Transfer, K. (2019, 05). *BIC Network*. Retrieved from https://kt.cern/bic-network

Transfer, K. (2019, 05). *Entrepreneurship Meet-Ups*. Retrieved from https://kt.cern/entrepreneurship-meet-ups

Upstill, G., & Symington, D. (2002, 03). Technology transfer and the creation of companies: the CSIRO experience.

Vetle, N., & Anelli, G. (2016). Knowledge transfer at CERN. *Technological Forecasting and Social Change*, 113-120.

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

West, J. (2008). Commercializing open science: deep space communications as the lead market for Shannon Theory. *Journal of Management Studies*.

WIPO. (2010, 12). *Managing IP at CERN*. Retrieved from https://www.wipo.int/wipo_magazine/en/2010/06/article_0003.html

WLCG. (2019, 05). *Worldwide LHC Computing Grid*. Retrieved from http://wlcg.web.cern.ch/

Wright, M. (2014). Academic entrepreneurship, technology transfer and society: where next? *Journal of Technology Transfer*, pp. 322-334.

Wright, M., Clarysse, B., Lockett, A., & Knockaert, M. (2008). Mid-range universities' linkages with industry: knowledge types and the role of intermediaries. *Research Policy*.

Yin, R. (1994). *Case Study Research Design and Methods.* London: Sage Publications.