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Knowledge transfer in Big Science

What benefits can be gained and how?

International Business
Bachelor's thesis
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Knowledge transfer is gaining bigger and bigger emphasis in the context of Big Science. It is quick way for them to show their relevance to society in this moment because it may take decades before the pure research results will have an impact. Also, they are usually publicly funded which makes it even more important for them. As Big Science centres are unique environments, there is a lot of knowledge, and especially technology-wise, that they can offer through knowledge transfer.

This thesis introduces different mechanism and modes of how knowledge transfer and knowledge spillover is taking place. Most focus is put on CERN as the example organization due to its long and successful history on the topic. Example cases of different modes of knowledge transfer are introduced to highlight the variety of applications where a knowledge originating from particle physics can be relevant. After that, the focus is moved to the knowledge transfer and knowledge spillover processes themselves to identify potential benefits and gains from those processes. Lastly, attributes of the processes are studied to identify the most crucial ones for effective process.

Overall, this thesis shows that there are many modes for knowledge transfer and each of them offering a different way to access the knowledge of Big Science organization. Also, the importance of procurement for knowledge spillover is recognized. This thesis also shows that pure learning is not the only relevant benefit a company may gain and that communication plays an important role when it comes to effective knowledge transfer process.

Key words: Big Science, knowledge transfer, knowledge spillover.

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1 Introduction

1.1 Background

Big Science organizations, such as CERN, are focusing more and more on their knowledge transfer activities. For example, in the latest update of European strategy for particle physics the importance of knowledge and technology transfer was highlighted and that it should be promoted more as it benefits society (European Strategy Group, 2020, p. 13). Even though the scientific research is the main objective for the organizations, knowledge transfer is also a way to show their contribution to a bigger scene. Also, the impact of knowledge transfer activities become visible much faster than those of fundamental research. For example, in the case of physics research it may take tens of years before the obtained result of the research lead to an impact on society.

Big science organizations and their research infrastructures are unique and most of the time complex and massive, especially when it comes to physics research. For example, in the case of particle physics, the smaller the things to be studied, the bigger the tools need to be. What that means is that there is higher and higher energy demand for particle colliders all the time, which means bigger machines that can reach those demands. Currently CERN is operating Large Hadron Collider (LHC) that has a circumference of approximately 27 kilometres and studies on the next major collider options, Future Circular Collider (FCC) and Compact Linear Collider (CLIC), are underway to replace that and FCC would have circumference of almost 100 kilometres while CLIC would be about 50 kilometres long giving examples how massive those infrastructures could be. (Aicheler *et al.*, 2018, 187; Kasemann *et al.*, 2019, 172.)

When it comes to complexity of the infrastructure, the demands and capabilities of them might be difficult to understand for someone who has no experience of them. For example, the collision energy of the proton beams is about 13 teraelectronvolts (TeV) which does not tell much, just that there are really small things colliding with very high speed. But that energy is similar to if two passenger trains would crash headfirst with speed of 140 km/h. Or the accuracy requirement for CLIC is similar to if two needles where thrown, one from Paris and from New York, and they should hit each other in the middle of Atlantic Ocean. These examples underline that often Big Science organizations need specific high-tech technology but also that they impose vast technological knowledge that could be applied to other contexts too.

Although the main topic is Big Science, this thesis will focus mostly on CERN as the prime example. There are couple reasons behind it. First is the size and longevity of it as an organization. CERN is celebrating its 70th anniversary this year and it also has a long history with knowledge transfer. The second reason is that the author of this thesis has worked at CERN with similar topic to this thesis.

1.2 Aim of the thesis

This thesis aims to showcase what kind of knowledge transfer and knowledge spillover opportunities there are in Big Science and what kind of things are affecting how efficient they are. This helps the Big Science organizations to facilitate their activities more efficiently and to improve their impact to wider society and thus making themselves more relevant to bigger audience. The main research question of this thesis is **How knowledge transfer and knowledge spillover are happening in Big Science organizations?**

The sub-questions for this thesis are:

- In what kind of settings and activities knowledge transfer and knowledge spillover takes place?
- What kind of knowledge benefits there are?
- What is needed for successful knowledge transfer process?

The first sub-question aims to help to identify the context and mechanisms where knowledge transfer and knowledge spillover is happening. As mentioned, knowledge transfer is becoming more and more important to Big Science organizations and there are different maturity levels of knowledge transfer activities between different organizations. Thus, it is important from their point of view to understand the different mechanisms, especially when it comes to knowledge spillover, so that they can maximise their impact. Also, it helps companies to identify the mechanisms that would be most suitable for them. This question is answered by introducing different knowledge transfer modes that are currently in use and by having an overview on procurement activities in Big Science context.

The second sub-questions will look further into what there is to gain from the above-mentioned activities. For example, procurement activities are not only limited to technical or knowledge intense supplies so the hypothesis is that pure learning is not the only relevant benefit that a company may gain from interacting with Big Science organization. This sub-question is answered by looking into existing studies on the topic and what are they key findings.

The third sub-question focuses on attributes that facilitates knowledge transfer and knowledge spillover processes. This sub-question is answered by identifying attributes that affects the most these processes. This way it is possible to define what is needed to maximise the learning effects and potentially other benefits from knowledge transfer or knowledge spillover processes.

1.3 Key concepts

As was introduced above, this thesis focuses on Big Science, and knowledge transfer and spillover and this section will introduce them briefly.

1.3.1 Big Science

Overall, Big Science could be described as an umbrella for huge scientific projects and research centres and organizations running them. As was mentioned previously, the infrastructure required for Big Science projects can be massive which also results into massive budgets. For example, the cost estimations for both future collider options are counted in billions of Swiss francs (Willman, 2020, p. 21).

The main purpose of the Big Science organizations is to find answer to fundamental questions of the Universe. At the same time, they are developing new technology for their experiments which can have an impact on society. (Scarrà and Piccaluga, 2022, 2.)

This thesis focuses mostly on CERN, especially on examples, when talking about Big Science organizations. CERN is one of the largest Big Science organizations and its LHC collider is consider as one of the biggest Big Science projects in the world currently. It also has a long history as an organization as it is celebrating its 70th anniversary this year and it started its knowledge transfer activities in 1988 (Nilsen and Anelli, 2016, 114).

1.3.2 Knowledge transfer and knowledge spillover

Knowledge transfer and knowledge spillover are both related to movement of knowledge between two different organizations. One often used definition for technology and knowledge transfer that is “the movement of know-how, technical knowledge, or technology from one organisational setting to another” (Roessner 2000 according to Nilsen and Anelli 2016, 1; Scarrà and Piccaluga 2022, 1). This same definition can be used also to describe knowledge spillover.

The biggest difference between knowledge transfer and knowledge spillover is how intentional it is. While knowledge transfer is intentional and structured by different type of modes, knowledge spillover is unintentional byproduct of other activities. One of the most common environments where knowledge spillover takes place in Big Science is procurement activities. Different modes of knowledge transfer and procurement, in case of knowledge spillover, are discussed more later in this thesis.

2 Knowledge transfer and spillover in Big Science

This chapter introduces different modes of how knowledge transfer activities are conducted. CERN is used as the main example for the activities. This due to the long history of the organization and the vast variety of the activities. Other organizations, such as ITER or ESS which both are much younger, may utilize some of the same modes but often in smaller extent and there are not studied as extendedly as CERN's. Even though procurement is not directly part of knowledge transfer, it still involves spillover effects and thus it is also included.

2.1 Modes of knowledge transfer

There are many different ways how knowledge transfer is facilitated within Big Science. This section introduces some of those ways and how they facilitate knowledge transfer within them.

Before going more deeply in those different modes of knowledge transfer, Table 1 shows how knowledge transfer contracts at CERN have divided between different modes during last three years. It clearly shows the importance of licensing and collaborative research activities when it comes to contract-based modes.

Table 1. Contract types from 2021 to 2023 at CERN (CERN, 2022a, 2023, 2024a)

Mode	2023	2022	2021
Licensing	23	15	21
Collaborative R&D	21	15	15
Service & Consultancy	4	5	3
Contract Research	1	1	4
Other	2	6	4
Total	51	42	47

It is also important to point out that not all knowledge transfer is based on contracts. On top of them, there are also modes of open-source software and open hardware which are not shown in the table but still have great impact, most notable being the world wide web (WWW). (Nilsen and Anelli, 2016.)

2.1.1 Licensing

Licensing of technology used to have the biggest emphasis of knowledge transfer. The importance has then reduced overtime as Big Science organizations are moving more and more towards open models, such as open software and open hardware which are introduced later. It is also important to note that academic partners and industrial partners are treated differently when it comes to licensing agreements. Academic partners receive licenses most of the time free, while licenses for commercial use include return payment that usually means royalties and up-front payments. These payments are used for funding of the research activities that enabled the innovation in the first place. (Nilsen and Anelli, 2016, 115.)

Even though one could think that licensing would not require extensive input from the researcher, the nature of the technology in Big Science changes that. The inventor quite often needs to offer an input to the user of the license so that the technology can be exploited in a proper way. In that sense, it is important to involve the inventor extensively enough so to that the knowledge transfer process is successful. (Nilsen and Anelli, 2016, 115.)

One example of licensing is Medipix which is described as one of the most successful cases of knowledge transfer in CERN. The initial technology was originally developed for particle detector used at CERN in 1995 and now it has reached its fourth generation introduced in 2016. Nowadays, commercial activities regarding Medipix technology include application areas such as medical imaging and material analysis to name a few. (*Medipix*, 2024.)

2.1.2 Collaborations, service and consultancy

All the licensed technology may not be directly suitable for a company, but the company could still get its hands on the knowledge available in Big Science that they need through collaborations, services, or consultancy. In the case of CERN, collaboration in this context means only means the collaborations that aim to create services and products with commercial potential and are not directly related to the high-energy physics, i.e. they are not directly usable in CERN but can gain from CERN specific knowledge.

CERN specific knowledge is a key term in this context. This due to that the needed knowledge should be only available at CERN and nowhere else. For example, in case of services, this could mean the use of the unique testing facilities of CERN. And in fact that was the case for the collaboration between European Space Agency’s Jupiter Icy Moons Explorer mission and CERN. In that case, some of the components were tested for radiation resistance at CERN because it was the only place to have facilities that could replicate the environment that those components would face when eventually reaching Jupiter. (CERN: Juice: From CERN to Jupiter.)

There is also a clear connection between licensing and consultancy. As mentioned previously, an involvement from the inventor is often required in licensing cases to reach successful knowledge transfer process. For that reason, the license agreements include sometimes consultancy to ensure that the licensed technology is used effectively (Nilsen and Anelli, 2016).

2.1.3 Open-source software and Open hardware

As was mentioned earlier, open-source software and open hardware are also important modes for knowledge transfer, even though they are not shown in Table 1. When it comes to the impact open-source software has, a study estimated that two software that were originally developed to analyse data from Large Hadron Collider at CERN benefited society over five billion euros (Florio, Forte and Sirtori, 2016).

In essence, open-source software and open hardware means that those technologies are made available to the public to use and develop further without the need of obtaining a separate license to use them. That still does not mean that they could be used anyway possible. Those technologies are released under licenses that basically requires that all the new modifications are made available similar to the original one. While open-source software uses general licenses, CERN has its own license for open hardware and this license has been adopted also by many entities outside of CERN. (Nilsen and Anelli, 2016.)

Although making software open source is a common approach, there are some cases where it is not used. Some of these reasons are related to the readiness of the software for public release. This could mean that the amount of extra development work required to make the software suitable for release would be way more than what would be justified by the possible benefits or then the quality is just not good enough. Also sometimes there might be external restrictions due to agreements, for example related to funding.(Nilsen and Anelli, 2016.)

Open hardware is a more recent mode for knowledge transfer compared to open-source software and, for example, CERN started to use it in 2009, while the first open-source release took place in 1990's when World Wide Web was released (*Licensing the Web*, 2024). Nowadays there are more than hundred projects in the Open Hardware Repository. One example of them is CERN White Rabbit which is originally developed for control and timing networks for the needs of CERN. One entity that has implemented that technology is Deutsche Börse which uses it for time stamping of transactions in trading. (Nilsen and Anelli, 2016; Kauttu, 2018.)

2.1.4 Spin-offs and start-ups

The three above mentioned modes may have the most impact when it comes to knowledge transfer but there are more and more efforts put into spin-offs and start-ups. One notable effort is related business incubation centres (BICs). These centres usually form a network of centres, and they provide support and access to the knowledge that Big Science can offer. CERN is not the only Big Science organization that establish this type of network but for example European Space Agency also has its own for space related start-ups. (CERN: BIC Network; ESA: ESA BUSINESS INCUBATION CENTRES.)

2.1.5 EU projects

From an industrial point of view, EU projects are interesting mode of knowledge transfer as they gather many different actors, such as research institutes, universities and industrial partners, into same table. All the EU projects are based on and funded by EU's Framework Programmes dedicated to research and innovation. The current framework programme running from 2020 to 2027 is called Horizon Europe which has a budget of 95.5 billion euros (*Horizon Europe - European Commission*, 2024). These projects are also significant for Big Science because they enable funding for research that may not be part of their core mission. Big Science centres often have a key role in those projects. For example, during the previous Framework Programme called Horizon 2020, CERN took part into more than 90 projects and had a coordinator role in 29 of those. (*Projects at CERN | EU Projects Office*)

2.2 Procurement

Procurement activities may not be officially a mode for knowledge transfer in Big Science, but they still often involve great amount of knowledge transfer and knowledge spillover effects. They are also one of the most vital activities and they importance cannot be underestimated. For example, Table 2 shows how much CERN has spent on supplies from 2019 to 2021 and it can be seen that the amount has been constantly more than 200 million Swiss francs every year even when there are no major updates for infrastructure going on. It is a very big topic already in itself and could be a worth of its own thesis so its main aspects are now introduced only briefly.

Table 2. Payments for Supplies at CERN. (CERN, 2020, 2021, 2022b)

	2021	2020	2019
Payments for supplies (kCHF)	229 279	234 992	287 579

One of the key things in Big Science Procurement is that with it the intergovernmental nature of Big Science organizations comes into play. As many Big Science organizations involve multiple member states, there are usually set of rules placed to support member states that are not receiving as many contracts as they should, based on their contribution. There are different ways how these are implemented into the procurement processes in different organizations, but this thesis will only focus on CERN as an example.

At CERN, the member states are divided into well balanced and poorly balanced ones based on the return coefficient. These statuses are updated every year, and they define how the alignment rule will affect them during a procurement process where it is applicable. There are three different types of procurement processes based on the size of the order and main selection criteria and the alignment rule is included in two of them. In those two, the selection is based the lowest bid, while the one without it is for Best Value For Money approach. In practice, the alignment rule means that if the lowest bid is from a well-balanced member state it is not guaranteed that it will be selected and awarded the contract in question. In those cases, if there is a bid from poorly balanced member state that falls within 20% of the lowest bid, that bidder is given a chance to align its price to that of the lowest original bid. If they agree to align their price, they will receive that contract and the bid from well-balanced country will be left empty handed. (CERN: Procurement Process.)

3 Gaining from knowledge transfer

This chapter focuses first on what kind of benefits knowledge transfer activities can have. The second part of this chapter then focuses on what kind of attributes affect to the success of the knowledge transfer process.

3.1 Benefits from knowledge transfer

The main benefits companies can achieve from working with Big Science organizations are often socio-economical by nature. Most of these benefits are originated from the process models that Big Science organizations utilize for collaborations. One example is the requirement for documentation that the company needs to provide. Due to the high demands regarding that, companies need to evaluate their own processes which often leads to improvements on their own side. This is a good example on the spillover effects that can occur during collaborations on top of the main knowledge transfer activities. (Autio, Hameri and Nordberg, 1996.)

The benefits that can be gained from knowledge transfer in Big Science can be divided into social capital, learning potential and innovation benefits on a framework level. Looking first into social capital aspects, they can be further divided into cognitive, structural, and relational social capitals. From those structural social capital includes most benefits for a company. These benefits include things such as access to new markets through the networks Big Science centres have, valuable reference when looking for new customers, and overall access to the networks Big Science centres may offer. (Autio, Hameri and Vuola, 2004, 119.)

Learning potential can be also divided into four smaller pieces. Those are cognitive diversity, border-crossing to scientific community, isolation and sheltered social space, and frontier-pushing needs and technology standards. There are different ways how they may affect to a company, but the end result may be similar. For example, cognitive diversity can help to find a way to enhance existing products as it includes different ways to look into things, while border-crossing to scientific community can have the same effect just with the access to CERN. Frontier pushing needs, such as those introduced at the start of this thesis, can help a company to develop its product to a certain level before their main general market will have similar needs. (Autio, Hameri and Vuola, 2004, 120.)

Innovation benefits revolves around uncertainty, complexity and experimentation. Working with a Big Science centre may help to reduce the uncertainty that innovation may involve. This is partly related to the fact that Big Science projects have a long timeline resulting into long-term objectives. These can help a company to set a clear timetable for the development work. It is important to also notice that some of the projects in Big Science may lack the certainty over their future, which then reduces their appeal in the eyes of companies (Willman, 2020, 39). The complexity on the other hand may only help in some cases but then its impact is significant. As the technology in Big Science is usually highly complex, the Big Science centres have a lot of knowledge on how to handle that and that knowledge can help for example to integrate new technology to existing products. Experimentation is directly related to the collaboration, service and consultancy mode of knowledge transfer. This due to the unique testing facilities Big Science centres often have. They also have extensive knowledge on testing prototypes which is also beneficial.(Autio, Hameri and Vuola, 2004, 121-122.)

There have been some studies that support those findings presented above. First of them (Autio, Bianchi-Streit and Hameri, 2003) included questionnaire answers from 154 companies that were seen as a technology intensive supplier considering the effect of their relationship with CERN. As was mentioned earlier that CERN serves as a valuable reference for companies and that study found that it applied to most of the companies and was the most identified benefit of the survey. Another significant outcome was that connection with CERN had help over half of the companies to gain new customers. When it comes learning effects, about of the companies said that technological learning had taken place. This indicates that benefits related to marketing are more often felt by the companies compared to learning.

A more recent study (Florio *et al.*, 2018) which had a wider scope of companies supplying CERN, i.e. not only technology intensive suppliers, also found support for the importance of CERN as a reference. In that study, 62% out of the 669 companies agreed to some extend that they had used CERN as a reference. Also, the results for the learning effects are line with the study introduced above as 55% of the companies indicated increase in their technical know-how. On the other, approximately 20% of those companies only had managed to have new customers due to their commitments with CERN. (Florio *et al.*, 2018, 923.)

Similar results and benefits have been identified also in other Big Science centres than just CERN. A much smaller study (Puliga, Manzini and Batistoni, 2019) focusing on ITER, which is a Big Science centre dedicated to fusion energy, found that 87% of the companies had managed to improve their brand image by working with ITER. Also, 73% of the companies had managed to gain new customer. These figures are a bit higher than those from CERN but still point to same direction. When it comes to learning effects, the results are also higher than in CERN as 93% of the companies said that they had improved their technical competencies. Even though, the comparison to the results from CERN may not be that meaningful due to much smaller sample size, these results still give similar image on the benefits that companies can have when working with Big Science centres.

3.2 Effective knowledge transfer process

Even though there are a lot of benefits on offer when engaging with Big Science, just taking part in knowledge transfer activities does not guarantee learning effects or other positive impacts by itself. There are many underlying things that affect that process. For example, in the case of learning, many of these are related to social capital but there are also other things to consider.

One of the key things that affects the learning outcomes of the knowledge transfer process is the communication between the company and Big Science centre. Basically, that means how the employees of the company and researchers on the other side are interacting. One of the contributing factors is how frequent that communication is. It is shown that frequency itself is more important for the learning outcomes than just the duration of the process. The higher frequency on communication increases the learning benefits. This directly related to relational social capital, as it includes things such as trust, which can be built through frequent communication (Autio, Hameri and Vuola, 2004, 119; Florio *et al.*, 2018, 932.)

Another important aspect is the cognitive social capital mentioned above, and shared language more specifically. When the employees of the company and researchers from Big Science centre understand each other, there is a bigger chance that learning outcomes will take place. Overall it has a similar importance as the frequency of communication has. (Florio *et al.*, 2018, 932.)

4 Conclusions

Big Science organizations offer multiple ways for companies to gain knowledge from them. Not all of the different modes of knowledge transfer fit for everyone and often there may be only one that is suitable for a company. It is also good to notice that some of the modes are linked to each other, so taking part to one of them can open doors to also some other modes. For example, as it was mentioned when introducing different modes, licensing contracts often include also consultancy that is also its own mode that can be employed separately in other cases.

Knowledge transfer in Big Science is mostly related to technology which is understandable due to their nature. Big Science centres houses some of the most unique and advanced technologies in the world and the amount of knowledge needed to build them is extraordinary. Also, some of the Big Science centres have been operational for decades so they have been able to massive amounts of knowledge and know-how through their own development work over those years. In that sense, for a company who wants to tap into complex and frontier-pushing technology, the Big Science centres are a great starting point.

Even though Big Science centres main focus is on their basic research mission, such as particle physics at CERN or fusion energy at ITER, their technology and knowledge can be applied to multiple different industries which may not be directly related to the initial use purpose of the technology. A good example of that is the mentioned example about White Rabbit technology that is now also used by Deutsche Börse for trading. Some of the use cases of the technology may be more obvious and more related to the original purpose. Example of that is the Medipix technology. It was originally developed for a particle detector to create an image of the collision taking place in a particle collider, and now it used in medical imaging, where it, once again, is creating images from radiation.

New knowledge is not the only thing that companies can gain from Big Science centres. Working with Big Science centres can also help with marketing of the company. As it was mentioned, one of the biggest benefits for companies is the reference that Big Science offers. It was also shown that this is more frequent benefit that companies gain than pure technological learning, even though it is still playing incremental part for knowledge transfer.

But it is not automatic that those benefit are gained by companies. Especially, learning outcomes require efforts from both sides to maximise the benefits. It is important that both sides understand each other and also trust each other. Fortunately, there are ways how that can be achieved.

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