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External Effects of Basic Research Infrastructure

Master's Thesis

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Abstract

This thesis reviews economic justifications for public funding of basic research as well as how these justifications are applied in recent european research and innovation policy. Here, economic effects of basic research play a central role. Based on a questionnaire-based survey which was performed for this thesis, it is analyzed which economic effects of basic resarch are generated during the special case of the construction phase of large basic research infrastructure. The European XFEL project was taken as an empirical example. The questionnaire which focused on learning effects among suppliers of custom developed or technologically demanding construction elements reported significant technological, organizational and social learning effects. They are interpreted as a stimulus for commercial technology development which is based on the contrasting motives and organizational structures of basic science.

CONTENTS

LIST OF FIGURES

ABBREVIATIONS

ATCA	Advanced Telecommunication Computing Architecture
CERN	*french*: Conseil Européen pour la Recherche Nucléaire *english*: European Organization for Nuclear Research
DESY	Deutsches Elektronen Synchrotron
DORIS	Doppel-Ring-Speicher *large research instrument at DESY*
ERA	European Research Area
ESFRI	European Strategy Forum on Research Infrastructures
ESS	European Spallation Source
FLASH	Freie-Elektronen-Laser in Hamburg *prototype of the European XFEL*
GDP	gross domestic product
HERA	Hadron-Elektron-Ring-Anlage *large research instrument at DESY*
HF	High Frequency
ISS	International Space Station
ITER	English: International Thermonuclear Experimental Reactor Latin: "the way" or "the road"
LCLS	Linear Coherent Light Source *Large research instrument at the californian institute SLAC, comparable to the European XFEL*
LHC	Large Hadron Collider
LINAC	Linear Particle Accelerator
MTCA	Micro Telecommunications Computing Architecture
MTCA.4	Micro Telecommunications Computing Architecture for Physics *Substandard of MTCA, developed at DESY for scientific applications*
NMR	Nuclear magnetic resonance
PETRA	Positron-Elektron-Tandem-Ring-Anlage *large research instrument at DESY*
RI	research infrastructure
SLAC	Stanford Linear Accelerator Center
SME	small and medium enterprises
SPS	Super Proton Synchrotron *Large particle collider at CERN, predecessor of the LHC*
TESLA	Tera electron volt Energy Superconducting Linear Accelerator *a special type of particle acceleration technology*
TTF	TESLA Test facility
XFEL	X-Ray Free Electron Laser
ZIM	Zentrales Innovationsprogramm Mittelstand *central innovation program for small and medium- sized enterprises; a german funding instrument for innovation policy*

1 Introduction

1.1 Motivation

"Innovation is the whim of an elite before it becomes a need of the public."
- Ludwig von Mises

What Mises is pointing at can be exemplified by the history of capacitive touch screens: This technology was developed in the 1970's for the control system of the Super Proton Synchrotron (SPS) at CERN. The complexity of this machine of nearly 7km circumference created the need for a new multi-functional input and control device that was able to reduce the amount of single-function buttons and cables. At the same time, the developer of the SPS control system profited by the recent appearance of commercially available microcomputers like the Intel 8080. The motivation for the development of the SPS was to understand the fundamental structure and interaction of matter, for example in the successful detection of the prognosticated W and Z bosons.[1] But about thirty years later, its technological ideas can be found in the displays of modern smart phones and tablet PCs.[2]

a) control terminal of the SPS (1976)

b) capacitive touchscreen of the SPS terminal

c) first smartphone with capacitive touchscreen (2006)

Figure 1.1: Scientific and commercial application of capacitive touch screens

[1] DiLella 1988, p. 7.
[2] Stumpe and Sutton 2010.

This example allows two observations which are important for this thesis: Firstly, science and industry can mutually profit from each others' technological developments. Secondly: While the intended scientific success of large research infrastructure is rather easy to evaluate, its wider societal and economic impact is uncertain at the time of planning and construction, and eventually only becomes visible after a large time delay of up to a few decades.

This complex relationship of science and industry and its role for economic growth and welfare had already been anticipated in the first half of the 19th century, for example by Friedrich List, who laid the grounds for the political framework of Prussia's industrialization:

> "There scarcely exists a manufacturing business which has no relation to physics, mechanics, chemistry, mathematics or to the art of design, etc. No progress, no new discoveries and inventions can be made in these sciences by which a hundred industries and processes could not be improved or altered. In the manufacturing State, therefore, sciences and arts must necessarily become popular."[3]

In the 20th century, both Bernal (1939) and Bush (1945) pointed at the importance of basic science for national security, health and economic growth and emphasized the potential economic impact of investments in science.[4] The importance of Bush's pivotal report *Science: The endless frontier* cannot be overestimated, because it was the guide to capture the scientific momentum of WWII and transfer it into the paradigm for post-war science policy.[5] By doing this, Bush introduced the terms of curiosity-driven *basic research* and use- or product-directed *applied research*. This distinction laid the grounds for the linear model of innovation and legitimated the public involvement in basic science funding.[6]

In the following decades scholars developed refined models of technological innovation and improved their empirical tools for the evaluation of the socio-economic impact of science. This highlighted the fuzziness of the term "basic research" and enabled policy makers to closer connect their funding decisions for science with expected practical use. Additionally, the zeitgeist of the late 20th century was very critical about the role governmental action can play. As a striking example, Kealey (1996) demanded to completely stop public funding of science and to leave it to the market forces: "*The Market Place does not worship false Idols, it makes empirically*

[3] List 1904 [1841], p. 162, cited from Freeman 1995, p. 6.
[4] Lundvall and Borrás 2005, p. 605.
[5] Stokes 1997, p. 2; Pielke Jr 2010, p. 922.
[6] Pielke Jr 2010, p. 923.

correct judgments. It is the government funding of science that is an Idol of the Tribe."[7] Stokes (1997) tried to re-establish the importance of public funding of basic science by reinterpreting Bush's diametric separation of basic and applied science as an orthogonal and mutually beneficial relation. In his view, public funding can play an important and legitimate role for basic research if it is at least *inspired* by societal needs.[8] Nelson (2004) argues that purely private, market-financed science would struggle to contribute to these societal needs. To be commercially profitable, basic research would demand for strong protection of intellectual property rights, not only for technological knowledge but also for scientific knowledge. This would not only complicate further research,[9] it can also lead to a tragedy of the anti-commons when the use of scientific knowledge for societal needs can be hindered in the name of private commercial interests.[10]

This thesis is picking up this ongoing discussion about the economic interpretation of (basic) science and will focus on the economic role of publicly funded basic science *infrastructure*. This happens in anticipation of two developments: First, during WWII and the cold war, the largest research programs like the Manhattan- and the Apollo-programs were motivated by war and a period of ideological competition. With the end of the cold war and the decline of ideological competition, international cooperation for large and expensive projects like the ISS, the LHC and the ITER became much easier. Secondly, the scientific progress in basic research made larger machines like the LHC *necessary*, while the connected technological progress made them *possible*. Besides these big projects, the EU currently plans about 35 research facilities with expected total construction costs of more than 12 billion €.[11] Especially these construction-related investments generate intense procurement activities and therefore close contact, exchange and cooperation between the scientific community and industry. Hence, the analysis of the construction phase of publicly funded basic research infrastructure and its impact on industrial innovation processes is a rich source of empirical insights. Based on a Survey I performed, this source will be used as the core of this thesis to illuminate the role publicly funded basic research plays for technological progress.

[7] Kealey 1996, p. 345.
[8] Stokes 1997, p. 107.
[9] Nelson 2004, p. 464.
[10] Murray and Stern 2007, p. 650.
[11] ESFRI 2011, p. 22. This number only includes planned or currently started projects. Older projects like the European XFEL or national projects like the Wendelstein 7-X, of which each costs more than 1 billion are not included.

To approach this complex topic, this thesis will be structured by asking two interconnected questions. The first one will be:

Why do public authorities fund basic research and its infrastructure?

In Chapter 2, this question will be approached from two sides: At first from the point of view of economic literature, and then from the perspective of recent European research policy. Regarding economic literature, the market failure and the system failure argument will be presented as two answers which have distinct theoretical foundations. Here it is of special interest how these perspectives assess the economic impact of basic research. For the political perspective, it will be analysed how these theoretical arguments are applied in research policy and its considerations for funding. Here, a special focus will be put on how large research infrastructure is put into the general political framework. This leads to the second question:

What are the economic effects of basic research infrastructure?

This question is the central topic of this thesis: It is of relevance for the previous question, but received only minor attention in the literature. To broaden the empirical basis for answering this question, an explorative, questionnaire-based survey was conducted as empirical basis for this thesis. It focused on the construction phase of the European XFEL project and its impact on industrial suppliers. This impact was especially assessed in its "soft" forms such as knowledge transfer, learning effects, social network access and reputation effects. Following the hypothesis that these forms of economic impact have a stimulating effect on commercial technology development besides technology transfer, The survey results are presented and analysed in Chapter 3.

As a conclusion, chapter 4 will take the general implications of the empirical results presented in chapter 3 and put them in the context of the theoretical and political concepts presented in chapter 2. Here, the empirical results will be taken as a starting point for further theoretical considerations on the stimulating effect of basic research on industrial innovation and on the question wether this impact should be regarded as an "external" effect or not. This thesis will be concluded by opening up further research questions.

1.2 The European XFEL Project

The European XFEL serves as the empirical example and data source for this thesis. It will be a 3.4 km long, mainly underground research facility which is currently under construction between Hamburg and Schenefeld in Schleswig-Holstein. It consists of a superconducting electron linear accelerator and a photon beam system including so-called undulators, which use the accelerated electrons to generate ultra-short and coherent (laser-like) x-ray flashes.[12] These flashes will have a repetition rate of ca. 27 000 flashes per second, a wavelength between 0.05 and 6 nanometres, a duration of below 100 femtoseconds (less that 100 trillionth of a second), and a brilliance (intensity) which is about 10000 times higher than conventional scientific x-ray sources such as synchrotron rings.[13] The European XFEL will be the first research infrastructure which combines these properties. The short wavelength allows experiments which analyze smallest structures like nano-materials and biomolecules. The fast repetition rate and short length of the flashes allow new types of analysis of ultrafast processes like chemical reactions. And the intensity of the flashes allows experiments with matter under extreme conditions.[14]

Our introductory example of the capacitive touch screen suggested that basic research and its tool development have other relevant time constraints than purely commercial innovation processes. This aspect reappears in the European XFEL project: Based on a newly developed accelerator technology, DESY published plans for a machine like the European XFEL already in the mid-90's.[15] But at that time only as a secondary function of a linear collider of about 30km length. The plans for the large collider in Hamburg were cancelled, but the plans for the former secondary function remained and became the primarily function of a new, less costly machine of about $\frac{1}{10}$ the size. In 2003, Germany decided to build the European XFEL as an international cooperation, which was set up until 2005 with then 7 (today: 12) other countries. In 2009, the construction work started, and its first beam production is planned for 2016.

The construction and commissioning costs amount to ca. 1.15 billion € in price levels of 2005 and ca. 1.38 billion €[16] in 2013 price levels. This amount is contributed by 11 countries of the EU and Russia. Germany as the host country pays 54 %,

[12] European XFEL GmbH 2012, p. 128.
[13] http://www.xfel.eu/ueberblick/zahlen_und_fakten/
[14] European XFEL GmbH 2013.
[15] Brinkmann et al. 1997.
[16] calculation based on the EU-wide inflation rate since 2005

Russia 23 %, and the other countries between 1 and 3.5 %. Research institutes of these countries as well as other institutes and universities concerned with photon science form an international cooperation, which contributes to the development and construction of the XFEL and allows scientists to prepare for the experimental possibilities of the European XFEL.

The relevance of the socio-economic impact of such a project becomes visible in its funding structure: Contributions of participating countries can be done in-kind: Institutes or companies in the respective country get paid by this country to deliver a certain component of the XFEL project. This ensures that the local economy and scientific community can capture further socio-economic benefits of the European XFEL project, such as knowledge creation and access to scientific networks. Consequentially, about 50% of the total budget are contributed in kind.[17]

Here it has to be emphasized why it is necessary to speak of basic research *infrastructure*: The European XFEL will be a multi-purpose-tool, and its users will be selected based on the scientific importance of their proposals, evaluated by peer review. This means that the XFEL will not be a basic research experiment, but a research instrument with a multidisciplinary scientific user community which will be concerned with the fundamental questions of their disciplines. To be able to use the new levels of pulse intensity and speed, these intended scientific applications of the XFEL call for new technological solutions at the edge of the technically feasible. Due to the size of the project, a large number of its construction elements are cooperatively developed by research institutes and industrial suppliers, who finally produce them.

The resulting organizational structure of the construction process is rather complex: 8 (in the near future, probably 11) countries contribute to the budget and are shareholders of the European XFEL GmbH,[18] and 17 international research centers and universities act as partners either for development or future research.[19] The local construction in Hamburg is shared between two interlinked, but independent organizations, which are the European XFEL GmbH for the photon beam line and DESY for the electron accelerator as well as further civil construction and underground engineering.[20]

[17] http://www.xfel.eu/project/in_kind_contributions/
[18] http://www.xfel.eu/organization/company/shareholders/
[19] http://www.xfel.eu/organization/cooperations
[20] http://www.xfel.eu/overview/desy/

1.3 The economic relevance of external effects

As the title of this thesis indicates, the economic concept of "external effects" will play a central role throughout the whole document. In respect to a non-economic audience, this section will serve as an introduction to this concept and point out its further implications.

1.3.1 Definition of external effects

External effects, or "externalities" how they also can be called, present a highly relevant concept for the question whether certain goods should be provided with the help of government, or whether their provision should be better left to free market forces. Therefore, definitions for externalities such as the following can be found in every standard text book on public finance:

"*Externalities arise whenever an individual or firm undertakes an action that has an effect on another individual or firm, for which the latter does not pay or is not paid.*"[21]

Externalities can either be positive or negative. The standard case for negative external effects is pollution,[22] for example if a factory pollutes a nearby river and therefore reduces the income of local fishermen or simply reduces the quality of life for surrounding inhabitants. An example for a positive external effect are bees of a beekeeper which increase the harvest outcome of a nearby apple plantation.[23] But what makes these situations so important? This can be better explained if external effects are explained using three, not two individuals (or firms):

External effects occur if a transaction between two individuals has a positive or negative impact on an additional third party.[24]

For the case of pollution, this means that the factory owner can produce cheaper and sell more to his customers, because not he, but the fishermen have to carry the costs of his pollution. The price the factory owner bargains with his customers does not represent full costs of the product and therefore reveals wrong information for market participants: The factory owners' product is too cheap, and therefore overconsumed and overproduced, creating more pollution. And without a benefit for the factory owner in reducing his pollution, the actual demand for production methods and technology which reduce pollution is not present on the market, leading to their

[21] Stiglitz 2000, p. 216.
[22] Stiglitz 2000, p. 215; Blankart 2007, p. 492.
[23] Blankart 2007, p. 23.
[24] Ibid.

underproduction. This consequence of external effects is highly relevant, because in public finance, there is a strong tradition which assumes that under perfect conditions, free negotiations on a market lead to an efficient equilibrium of production volume, prices and cost distribution.[25] Here, government intervention is regarded as a legitimate reaction in situations where markets fail to reach this efficient state of equilibrium. And as our example of pollution shows, externalities are an important reason for markets to fail.[26] Depending on the type of externality, this market failure can come in one of the following two variants:[27]

1. Overproduction of goods generating negative externalities

2. Underproduction of goods generating positive externalities

What types of reaction are possible for public authorities? In the case of pollution, governments can simply forbid substances like CFC, enact emission standards to enforce a reduction of emissions, or initiate a market for emission certificates to internalize the formerly external costs of pollution into the price of a product. Thus, to counter externalities, public authorities can abolish a market, set standards, or directly influence the price levels with certificates or taxes. All these methods can decrease the production level of a good with negative externalities.

But what about goods with positive externalities? Unsurprisingly, new knowledge as the central product of basic research is a good with positive externalities, which will be closer described in section 2.1.1, p. 15 and section 2.3.3, p. 25. Since knowledge cannot be consumed and is easily distributed due to its immaterial form, positive externalities occur when third parties can profit from knowledge which was developed and paid for by a first and second party. Here we can see that positive externalities in the production of knowledge are a central justification of the public provision of intellectual property rights as a means to internalize the wider positive impact the production of new (technological) knowledge. Just as emission certificates create a market on which negative externalities can be internalized into the production cost and consumer price, IP law creates a market on which producers of knowledge can internalize the positive externalities of their developments. Other governmental reactions to positive externalities are innovation subsidies as an equivalent to taxes on pollution and public provision of knowledge as an equivalent

[25] Stiglitz 2000, p. 56.
[26] Blankart 2007, p. 493.
[27] Stiglitz 2000, p. 216.

to banning very harmful substances or practices. Of course, public basic research is an example of the last case.

So far, it was described what external effects are, why they decrease the efficiency of markets and how governmental intervention can be justified as means to improve or correct the market result. But to understand the full importance of external effects for the relation of markets and public authorities, one has to acknowledge the role of external effects for two further concepts which are used to justify governmental action. These concepts are *public goods* and *merit goods*.

1.3.2 external effects and public goods

Again, an introductory definition of public goods can be found in standard text books like Stiglitz (2000):

> "Pure public goods have the properties of perfectly non-rival consumption and non-excludability.
> With non-rival consumption, it is not desirable to exclude anyone from the benefits. With private provision, there will be underconsumption and/or undersupply.
> With non-excludability, it is not feasible to exclude anyone from the benefits, with private provision, there will be underconsumption and/or undersupply."[28]

Again, goods which show these properties can hardly be sufficiently provided by free markets. A classical text-book example for a public good is national defense:[29] When borders are protected, it is impossible to exclude anyone inside these borders from this protection. Likewise, there is no rivalry in consumption, because the costs of border protection do not change even when the number of people inside the borders is doubled. In consequence, national defense is provided more efficiently by public authorities.

For this thesis, it is crucial that also knowledge shows these properties of a public good. For knowledge, there is no general rivalry in consumption: if two people share an apple, each one only gets half an apple. But if both share the knowledge of how to plant an apple tree, this knowledge is not consumed in any way. Due to the fact that it is in principle possible, but most of the time very difficult to exclude others from knowledge, knowledge can be regarded as an *impure* public good. Stiglitz (ibid.) puts it this way:

[28] Ibid., p. 132.
[29] Sandmo 2008, p. 3.

> "Knowledge is, to a large extent, a public good. Through patent protection (or other forms of intellectual property rights) inventors can appropriate some of the returns to their inventive activity. Still, there are likely to be externalities. Moreover, the appropriation interferes with the efficient diffusion and utilization of knowledge. This provides the rationale for government support. It is particularly cogent for basic research."[30]

Here, the close relationship of external effects and public goods becomes visible. This relationship is not only important in the case of knowledge, but for public goods in general: "[...] *public goods can be regarded as an extreme form of externalities.*"[31]

1.3.3 external effects and merit goods

A second, somewhat less canonical concept in public finance which explains the economic role of governmental intervention is that of "merit goods". There is no universally agreed definition of the term, but "[...] *most interpretations relate to situations where evaluation of a good (its merit or demerit) derives not simply from the norm of consumer sovereignty but involves an alternative norm.*"[32] This means that merit (or demerit) goods are goods which are undervalued and underconsumed (or overvalued and overconsumed) by individuals. A good example for a merit good is education: Its value being underestimated by children and parents resulted in laws for compulsory school attendance. A demerit good can be exemplified by alcoholism and other types of drug consumption. While individual consumer preferences may regard this type of consumption as most valuable, charity organizations and public programs for income redistribution tend to distribute in kind, even if from the recipients point of view, a pure cash transfer spend on drugs would have more utility than receiving food stamps or subsidized housing.[33] In both situations, governmental preferences are imposed over individual preferences in order to make both sides better of: While not going to school or taking drugs increases individual well-being in the short run, in the long run it reduces individual opportunities and increases costs for public welfare programs. Here, the involvement of externalities becomes visible: certain individual decisions such as taking drugs or lacking education have external effects on the community, therefore the community may have an interest to influence or even override individual decisions. Additionally, the paternalistic idea that individuals can be made better off by changing their consumption of merit

[30] Stiglitz 2000, p. 349.
[31] Ibid., p. 136.
[32] Musgrave 2008, p. 1.
[33] Ibid., p. 3.

or demerit goods includes an intertemporal, but not interpersonal form of externalities: If the benefits of schooling only become accessible after finishing years of schooling, the positive effects of education can be unknown or underestimated by a pupil, and thus "external" to his momentary evaluation of his situation. Parents, or public authorities who know about these positive effects thus try to use this knowledge to make the pupil better off by imposing a decision which has internalized the positive effects of schooling.

But the concept of merit goods does not necessarily imply governmental paternalism in distribution as presented in the given examples. Merit goods also describe a situation in which "[...] *individuals, as members of the community, accept certain community values or preferences, even though their personal preferences might differ.*"[34] In this notion, merit goods can be concern for maintenance of historical sites, respect for holidays or support for the arts, while drug addiction and its consequences or prostitution as offences to human dignity can be regarded as demerit goods.[35] Where do these community values come from? "[...] *common values may be taken to reflect the outcome of a historical process of interaction among individuals, leading to the formation of common values or preferences which are transmitted thereafter* [...]."[36] An important influence on stabilizing certain values is their ability in supporting behavior with positive externalities and suppressing behavior with negative externalities. In this notion, an individual may willingly contribute to public support of museums, philharmonic orchestras or ancient sites not because he prefers to visit them, but because he respects the interest of other, including unborn individuals who may have an interest in these things. Here, common values and community preferences allow for intergenerational awareness and exchange such as the preservation of historical sites or the environment. In other words: common, historically grown values can incorporate and transmit the knowledge about relevant, but time-delayed, even intergenerational externalities and influence individual behavior towards anticipating them.[37]

To summarize, merit goods describe situations where the evaluation of a good from an individual point of view differs from the evaluation from a second, wider point of view. An important reason for this can be externalities which are unknown

[34] Ibid., pp. 3,4.
[35] Ibid., p. 2.
[36] Ibid., p. 3.
[37] It has to be pointed out that the concept of merit goods does not depend on common values as a means to deal with externalities; every stable normative position, either rooted in religious believes, ethical considerations and/or expressed by majority voting is a sufficient base for the merit of merit goods.

for an individual or momentarily appear to be irrelevant, but are better known by others and/or are more relevant from a societal point of view, where possible impacts on future generations are taken into account. This idea can be used to justify public intervention into markets.

But how does this relate to public basic research? Like in the case of education, the term "merit goods" points at an individual lack of information about benefits of investments in basic science and indicate a paternalistic reaction to correct this lack of information. Here, externalities are future economic possibilities for the wider society. In the non-paternalistic notion, a community preference for basic science as a merit good allows for investments which will only be beneficial for future members of this society, such as projects on fusion like ITER. A very famous argument for public funding of basic research is based on the concept of merit goods as a pure representation of community values, without referring to any economic externalities. When R.R. Wilson was asked in the Congress about the (military) value of Fermilabs' first accelerator, he answered:

> "It only has to do with the respect with which we regard one another, the dignity of men, our love of culture [...], it has to do with: Are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. In that sense, this new knowledge has all to do with honor and country but it has nothing to do directly with defending our country except to help make it worth defending"[38]

1.3.4 Summary: Implications of external effects

The ambition of this section was to show that the occurrence of external effects not only present an important justification for public intervention into markets on their own. Moreover, they are at the heart of public goods as a second concept, and can play an important role for merit goods as a third concept used to justify public action. So the crucial implication here is that if we talk about external effects of basic research, we also discuss its character as a public good and as a merit good. All three concepts present reasons for market failure,[39] which will be at the core of the justification of public funding of science as presented in section 2.1.

[38] Fermilab 2013, http://history.fnal.gov/testimony.html.
[39] Stiglitz 2000, pp. 79,80,85.

2 Justifications for public funding of science

The question for the reasons of public funding for science comes twofold in a political and in an economic dimension: In the political dimension it is asked about the motives of public authorities and their expected benefits from science. These can be divided into two types of research policies. Mission-oriented research policy aims at specific scientific outcomes which are beneficial for national interests like defense, public health or new sources of energy. Diffusion-oriented research policy on the other side aims at the general technological innovations and economic benefits which scientific research can provide to society. The latter includes the contribution of science to economic growth and national welfare as a public motive. This aspect was highlighted by Romer's and Lucas' endogenous growth theory, which described the long-term economic growth as a function of the stock of knowledge and human capital.[1]

This leads to the economic dimension of this chapter's central question. Economics can contribute to analyse why public funding of basic research is an efficient or even necessary policy tool for either mission- or diffusion-oriented research policy. Two main narratives have dominated the discussion in the last decades: The market failure argument and the system failure argument. Both are mainly developed for general innovation policy, but will be presented with a focus on large research infrastructure.

2.1 The market failure argument

This classic argument describes how perfect market competition fails to provide the optimal resource allocation for technological and scientific innovation activities because of an individual marginal utility of R&D investments below its social marginal utility. Its static version goes back to Nelson (1959) and Arrow (1962), while Romer's and Lucas' endogenous growth theory extended it into a dynamic and long term perspective.[2] It is based on the assumption that under ideal conditions, the market leads to an optimal resource allocation, but under certain deviations from this

[1] Romer 1990, pp. 71, 97.
[2] Romer 1990; Lucas 1988.

ideal state, markets fail to provide the incentives for individuals to provide Pareto-optimal investment levels for science and innovation.

> "It is clear that for significant advances in knowledge we must look primarily to basic research; the social gains we may expect from basic research are obvious. But basic research efforts are likely to generate substantial external economies. Private-profit opportunities alone are not likely to draw as large a quantity of resources into basic research as is socially desirable."[3]

These deviations legitimate governmental involvement if it can serve as corrective action. Causes of a market failure can be found in the properties of information as a commodity and in the properties of market participants.

2.1.1 Good-related reasons for market failure

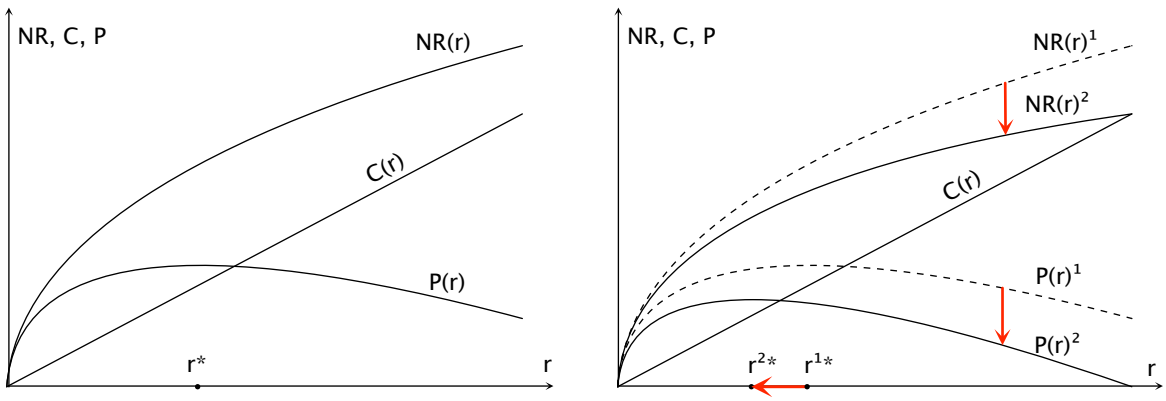
Knowledge as a public good

The economic term "public good" addresses goods which are non-excludable and non-rivalrous. Individuals cannot be effectively excluded from using them while additional users do not reduce their availability to existing users.[4] The non-excludability impedes commercial incentives to produce knowledge while its non-rivalty increases its social value. Therefore, the provision of public goods becomes a task for public authorities. Due to its immaterial nature, non-rivalry is a natural property of any knowledge. Scientific knowledge (e.g. fundamental laws or properties of matter) is also non-exclusive, because modern scientific method demands reproducibility of results, peer review and collective attempts of corroboration or falsification. Hence, there exists a fundamental conflict between the logic of scientific method and the logic of commercial resource allocation. Therefore, public provision of basic scientific knowledge becomes necessary. This is obviously true for large research infrastructure which are focused on fundamental scientific knowledge.

The possibility of reverse engineering makes technological knowledge non-excludable in principle, but intellectual property rights can serve as an institution which re-establishes market mechanisms as a tool of resource allocation. But this solution is only partially satisfying, because it comes with the downsides of hindrance of knowledge diffusion and temporal monopolies.[5]

[3] Nelson 1959, p. 302.
[4] Klodt 1995, p. 5; Graf 2012, p. 37.
[5] Graf 2012, p. 38.

External effects of research and development



a) investment calculation of an isolated inventor.

b) investment calculation in case of incomplete collection of profits

Figure 2.1: Private underinvestment in R&D due to incomplete absorption of gross revenue from innovation activities. *Legend: r= available innovation resources, r*= invested resources, NR= Net revenue, C= Costs of innovation activity, P= Profit.*[6]

Externalities are costs or benefits of a transaction which are not accounted for in the transaction and eventually affect not included parties. Technological external effects occur when other companies can profit from the R&D-Investments of a company without contributing to their costs, due to the non-excludable tendency of knowledge which leads to technological spillover-effects and incomplete protection of intellectual property rights. If profits from investments in R&D can only be partially collected, their marginal utility and consequentially their investment level is reduced (see fig. 2.1). In this case, the market fails to provide incentives for single participants to invest at a macro economical optimum. Public authorities can react to this by optimizing IP protection and by own provision of the lacking investment level.

The concept of external effects can point out why large research infrastructure can serve as a reaction to market failure. The development of RIs incorporates the development of technological research tools and the participation of industrial suppliers. During operation, RIs contribute to improved basic knowledge and to the education of graduate students. These effects are often termed as the "socio-economic impact" of RIs and can be regarded as their external effects in a wider sense. Therefore, public RIs can intentionally provide spillover-effects in terms of technological

[6]Own figure, related to ibid., p. 42.

knowledge and social capital, both effects which are unwanted by commercial enterprises.

While the public good aspect of the market-failure argument relates to more abstract scientific knowledge, external effects explain why a market failure can also occur for directly applicable technological knowledge.

Technological indivisibilities

Public funding for scientific projects becomes especially necessary if there exists a high minimal project size and cost level, which is not bearable for commercial actors, even if all long term benefits would be known and could be completely collected by the investors. Due to its scientifically necessary energy levels, the LHC is a good example for a very high minimal project size, while commercial nuclear technology or the recent appearance of civil space flight demonstrate how decades of governmental pioneering was necessary to prepare the ground for commercial parties. In terms of equilibrium theory, indivisibilities permits an efficient market equilibrium of research investment because of the lack of free adjustable marginal costs.

2.1.2 Actor-related reasons for market failure

Uncertainty and risk aversion

The success of every R&D Investment is risky and uncertain. This can lead to a market failure if the risk preferences of involved decision makers are below the social optimum.[7] Such a market failure can occur either on the product market or on the capital market: Companies can prefer low-risk investments over societally preferable high-risk investments, or banks refuse to grant a credit for a risky R&D investment. The latter case can be increased by adverse selection due to information asymmetries about the potential value and market chance between the researching company and a bank. Policy instruments like the ZIM[8] or the Helmholtz Validation Fund which provide credits or subsidies for R&D projects of small and medium-sized enterprises directly try to correct these types of market failure.

The discrepancy between social and private risk preferences can be explained by the diversification of risks: It can be beneficial for a society if its members follow the schumpeterian and knightian Ideal of an entrepreneur as a risk bearer and innovator

[7] Klodt 1995, p. 14f; Graf 2012, p. 47.

[8] Zentrales Innovationsprogramm Mittelstand = central innovation program for small and medium-sized enterprises

who provide society with technological change.[9] At the same time, a society can cope with the risk than individuals fail in this role. But risk-adverse individuals will not take these societal beneficial risks at the first place.

The provision of large research infrastructure suffers from these risk-aversion based market failures, because its final costs, its needed time frame and its scientific outcome can easily become affected by unforeseen obstacles. In the case of technological indivisibilities, the financial risks grow further, because increasing costs cannot be limited by a downscaled machine or instrument.

Time preference

"Time preference" refers to the preference for immediate utility over delayed utility.[10] A high time preference is constricting R&D investments if their results and pay-offs have to be expected for the future. A market failure occurs if the individual time preference exceeds the societal time preference, i. e. a public demand for time demanding research projects is not satisfied because individuals prefer investments which are profitable in the short run.[11] As an example of research policy motivated by time preference discrepancy, the German "High-Tech Strategy" incorporates long-run focused topics like climate change and demographic change as fields of action for research policy.[12]

The effects of a time preference discrepancy for large research infrastructure projects are twofold: Firstly, they often need more than a decade for planning and construction, and secondly, as the introductory example of the capacitive touch screen shows, the assessment of their wider socio-economic benefits again can take a decade or more.

2.1.3 Summary of the market failure argument

While these causes of market failure can be analytically separated, they practically work in conjunction and create an underinvestment in knowledge production while the price mechanism fails to reflect the external benefits of the knowledge production process and its infrastructure.[13] Endogenous growth theory implies that this static underinvestment into the knowledge base creates a suboptimal growth path

[9] Brouwer 2000, p. 149.
[10] Frederick et al. 2002, p. 352.
[11] Graf 2012, p. 48.
[12] BMBF 2010, pp. 12, 14.
[13] Gustafsson and Autio 2011, p. 821.

and therefore renders science and technology policy as an integral part of growth and welfare policy. Nelson (1959) and Arrow (1962) pointed out that governments have a superior risk-baring capacity in resource allocation to knowledge production and can more easily benefit from wider welfare economic outcomes.[14]

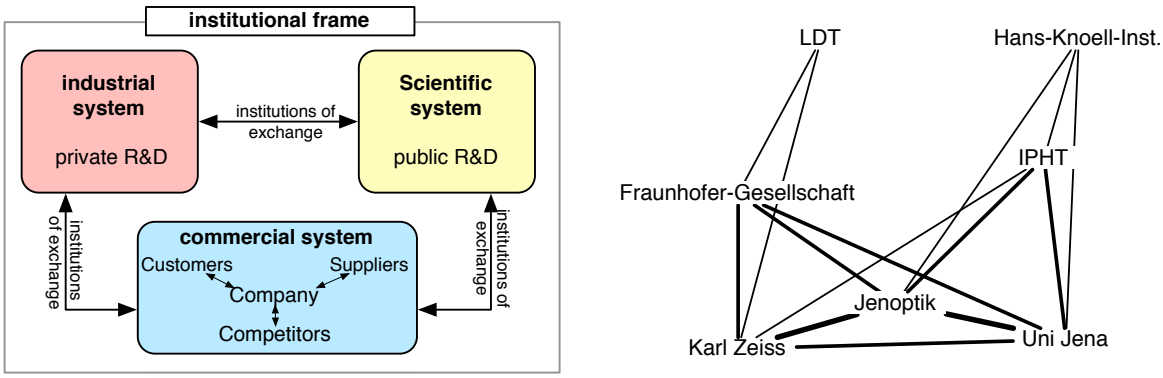
The market failure argument draws on neoclassical theory and focuses on the properties of knowledge as a commodity and the properties of market participants while assuming perfect competition and low transaction costs in a single market for knowledge and innovation. Due to the fact that the market failure is especially obvious for "Big Science" projects, this argument had created a tendency of funding choices towards this type of research projects.[15] Cases like the ITER, with steadily increasing costs and earliest expected practical use in about 2050 have provoked criticism due to missing funds for alternative, smaller and eventually more useful research projects on energy production.[16] This illustrates that the governmental intervention motivated by a perceived market failure can create investments with considerably high opportunity costs.

2.2 The system failure argument

2.2.1 From innovation systems to system failures

The system failure argument stems heavily on Lundvalls concept of *National Systems of Innovation*.[17] The main idea is that knowledge and innovation are not produced by single individuals and then brought to the market, but are a product of the interaction of individuals in cultural, political and economic systems. In consequence, different institutional arrangements with the same investment volume on R&D can produce differing outcomes in terms of learning and economic growth. The term innovation system is only heuristically defined: Innovation systems can be regarded as systems of connected institutions and protagonists which create, save and transfer knowledge, skills and artefacts which are related to new technology.[18] In short, an innovation system incorporates all factors of the creation, processing and recombination of knowledge,[19] which makes the term flexible enough to fit the particular subject matter of analysis and describe its specific institutional arrangement. In

[14]Gustafsson and Autio 2011, p. 822.
[15]Dasgupta and David 1994, p. 488.
[16]Brumfiel 2012.
[17]Lundvall 1988.
[18]Welsch 2005, p. 68.
[19]Ibid., p. 69.



a) A stylized national innovation system with its interconnected subsystems[24]

b) Jena as an example for the regional application of the innovation system concept.

Figure 2.2: The context-sensibility of the innovation system approach.

consequence, innovation systems can be "*national, regional, sectoral and technology-specific.*"[20] The development of the innovation system approach was advanced by the new growth theory by Romer and Lucas. They were pointing out the importance of knowledge production for growth, while the established concepts of neoclassical theory failed to explain the technological and economic catch up of countries like Japan and South Korea.[21] The missing theoretical concepts were taken from evolutionary and institutional economics and were used to develop new micro-level explanations for the differing macroeconomic developments.[22] As a consequence, the innovation system approach has a higher descriptive precision but a less coherent theoretical framework.[23]

Elements of the market failure argument such as public good effects, differing time preferences, risk behaviour and institutions which affect innovation externalities can also be used to explain differences in innovation system performance. But the innovation system approach differs significantly: It has no idealized concepts about the economy to orientate at, but takes the bounded rationality of its actors, changing economic frame conditions and heterogeneous markets with high transaction costs as given. In consequence, it focuses on the specific institutional framework for innovation and considers a wide array of relevant factors for technological change. Among these institutions are public education, commercial and tax law, IP

[20] Nelson 2004, p. 11.
[21] Freeman 1995, p. 11.
[22] Lundvall, Johnson, et al. 2002, p. 217.
[23] Gustafsson and Autio 2011, p. 822.
[24] Graf 2012.

regulations and much more which are controlled by public authorities. That is why public authorities and their policy considerations are an inevitable part of any innovation system. This contrasts with the neoclassical dichotomy of natural market efficiency and public intervention as a second best reaction to market failures.

Due to these differing theoretical backgrounds, speaking of "failures" in the innovation system perspective has a different meaning than speaking of neoclassical market failures. Market failures are derivations from a theoretically assumed efficient equilibrium state, partly caused by real individuals who fail to comply the theoretical assumptions made about them. The innovation system approach is independent from equilibrium theory, therefore a "failure" can only occur relative to the expectations one has about the own national innovation system performance or in comparison to other, more efficient innovation systems.

2.2.2 Types of System Failure

Because of the flexibility of the innovation system concept and its interdisciplinary community, a diverse set of classification is possible and has been developed.[25] The following classification concentrates on basic concepts of the innovation system approach and is adapted to the governmental perspective.

Systemic inefficiencies in providing technological change

A national innovation system consists of sub-systems like education, scientific research, industrial research, et cetera. Each sub-system has a differing emphasis on either the teaching, exploration or exploitation of knowledge while they are all interconnected via exchange institutions like product or labour markets, research publications or more specific policy tools. An innovation system failure exists, if the national system fails " [...] *to produce high innovation output because of deficient links between knowledge production and use and the difficulty in synchronizing activities among heterogeneous actors.*"[26] This implicates that even though the individual actors in their sub-systems perform rational and efficient, the national system level can perform inefficiently due to incommensurable institutional arrangement of exploration and exploitation of knowledge.[27]

[25] Gustafsson and Autio 2011, p. 822.
[26] Ibid., p. 823.
[27] Ibid.

Governmental intervention can change such a situation because public authorities are significantly involved in the sub-systems of education and knowledge exploration as well as general connecting institutions like the labour market. Additionally, new connecting institutions can be initiated. An example is the ZIM NEMO innovation policy program, which provides research funds for SMEs under the condition that the receiver participates in a research network or starts a collaborative R&D effort with other companies.[28]

Large research infrastructure is an integral part of the knowledge exploration system and due to its technological demands, it inherently participates in knowledge exploitation in terms of own development of operating equipment. Additionally, the involvement of industrial suppliers in the construction phase can provide a temporary but intense contact and exchange between otherwise less connected subsystems.

Systemic inefficiencies in adapting to technological change

The innovation system was developed as a sensitive analytical tool for the technological and organizational characteristics of different industry sectors and changing technologies used in these sectors. At the same time, due to the incorporation of evolutionary theory, change is regarded as a natural and inevitable element of any economy. Change can appear at multiple system levels, for example intra-sectional technological change from mobile phones to smart phones, or at the national level when established sectors like textile industry disappear and/or new sectors like electronics are established. A good performing innovation system should be able to adapt to these changes. But due to path-dependencies like technological lock-ins and organizational inertia, an innovation system can fail " [...] *to dynamically evolve to embrace new productive opportunities, even if such opportunities were known to system participants.*"[29]

A positive version of this idea can be used to explain fast catch up processes of countries; either the German "Wirtschaftswunder" or the economic catch up of Japan and South Korea: Rebuilding or newly establishing a nations industry with new sectors can give a chance to quickly develop an innovation system which tightly fits to current social, technological and scientific frame conditions without being hindered by inherited path dependencies, sunk costs and switching costs. This can

[28]http://www.zim-bmwi.de/Kooperationsnetzwerke
[29]Gustafsson and Autio 2011, p. 823.

give a strong comparative benefit towards established innovation systems in other countries.

An example for innovation policy which aim at supporting the adaptation to new technological possibilities can be found in Germany's High Tech Strategy:

> "Individual fields of technology are seen as contributions to realizing important social policy aims or as innovation drivers for other fields of technology ("key technologies"), while social change is considered to be an important prerequisite for the generation of technological knowledge."[30]

In this picture, large research infrastructure can be regarded as a tool to seed systemic adaption. This can happen by providing a basic knowledge stock due to providing scientific training in newly appearing technological fields. As a matter of fact, the ESFRI road-map lists the European XFEL as an facility to support future material sciences.[31] Additionally, large research infrastructure and its associated institutions like universities or technology parks can support the transition of regional economic clusters.

2.3 Political application of both arguments and the role of external effects

2.3.1 Market and system failure in European research policy

The market failure and the system failure argument complement one another: The market failure perspective explains why a given private investment level into R&D can be suboptimal from a societal point of view. The system failure perspective explains why the effectiveness of a given investment level depends on the institutional frame conditions of the innovation system. In terms of research policy, the market failure argument can show *why* political intervention can be necessary, while the innovation system perspective can explain *how* this intervention can be performed sufficiently.

In consequence, both arguments are incorporated in the motivation of European policy: "*Research and innovation suffer from important market and systemic failures, in particular the further one is removed from the market, justifying public intervention at the best of times.*"[32] "Horizon 2020", The current framework program for research and

[30] BMBF 2010, p. 4.
[31] ESFRI 2013, p. 28.
[32] European Commission 2011a, p. 12.

innovation policy is put in the context of the recent European debts and banking crisis and tries to outweigh it and contribute to its solution: *"The key challenge is to stabilize the financial and economic system in the short term while also taking measures to create the economic opportunities of tomorrow."*[33] The larger political framework here is "Europe 2020", the European growth strategy and successor of the Lisbon Strategy. Europe 2020 calls for adjusting the market failure in R&D investment by raising the investment rate to 3 percent of GDP. One of Europe 2020's key elements, the "Innovation Union" is targeted at initiating a pan-European innovation system layer to overcome system failures by interlinking and improving national innovation systems.[34] To achieve this, the Innovation Union-agenda targets at completing the "European Research Area" (ERA). ERA aims at improving the effectiveness of national innovation systems by creating more competition, reducing transaction costs on a European labor market by and optimizing transnational cooperation, especially for large, pan-European research infrastructures by avoiding costly fragmentation and duplication.[35]

In consequence, Horizon 2020 as the current research policy framework acts as " [...] *the financial instrument implementing the Innovation Union,* [...] *aimed at securing Europe's global competitiveness."*[36] Three general targets are defined:

1. Improving Europe's science base to secure its long-term competitiveness (Budget over six years: ca. 25 Bil. Euro),[37]
2. Improving industrial leadership to create growth (ca. 18 Billion Euro)
3. Approaching societal challenges like demographic change, climate change, food security and transportation (ca. 32 Bil. Euro),[38]

The focus in the first two targets on competitiveness, job creation and growth indicate its diffusion-oriented policy motivation which stems mainly on the system failure approach. The third target on the other side is explicitly mission-oriented and aimed at societal challenges for which market failures due to public good characteristics and time preference are apparent. In view of the embeddedness into Europe 2020 as a growth program, Horizon 2020 appears to be slightly balanced towards a diffusion-oriented policy agenda.

[33]European Commission 2011b, p. 2.
[34]European Commission 2010, p. 4.
[35]European Commission 2012, p. 3; European Commission 2010, p. 4.
[36]European Commission 2013.
[37]European Commission 2011b, p. 4; European Commission 2011c, p. 28.
[38]European Commission 2011b, p. 5.

The role of large research infrastructures in this political framework is especially considered in the European Strategy Forum on Research Infrastructures (ESFRI). ESFRI is a strategic instrument which translates the general agenda of Europe 2020 and its initiatives like the Innovation Union and ERA into specific policies for large research infrastructures, for example by the pan-European coordination of funding decisions for new research facilities in accordance with the priorities defined in the Horizon 2020.[39] ESFRI emphasizes the following benefits of RIs for the general EU policy agenda:

> "Research Infrastructures propel collaboration across borders and disciplines. They promote mobility of people and ideas. They stimulate economic spin-offs and investment. They help find solutions to our grand societal challenges of energy supply, climate change, health-care and others. And they provide a benchmark against which European research and technology can strive for excellence. They are, truly, engines to drive forward the Innovation Union."[40]

The actual scientific output is only important for the fourth of these intended functions of RIs which refers to societal challenges. This points at the importance which external effects of RIs on economic performance get in view of the Horizon 2020 framework. And it explains why empirical part of this thesis focuses on the economic impact of RIs on supplying companies. Before these relations can be further explained, a closer look on external effects is necessary.

2.3.2 External effects in the market failure and system failure arguments

Both arguments draw on external effects. While section 2.1 presented external effects analytically separated from other aspects of market failure, they are empirically interlinked. External effects which cannot be internalized by changed institutional arrangements support the public good character of scientific research. Additionally, external effects which appear time-delayed like the introductory touch-screen example can strengthen the investment-reducing effect of time preference. In the atomistic perspective on actors of the market failure perspective, external effects are a source of inefficiencies, while the holistic innovation system approach regards them as a natural and often intended relation between system participants. In the innovation system perspective, external effects between single system participants can be regarded as *internal* effects from the system perspective, which either im-

[39] ESFRI 2011, pp. 3, 7.
[40] Ibid., p. 4.

prove or reduce the system performance.[41] Whether these external effects improve or reduce performance has to be evaluated also on qualitative considerations, since they can include effects on human and social capital which can hardly be sufficiently quantified.

2.3.3 External effects of basic research

The external effects of basic research and their economic impact have been the focus of many studies. Based on a wide literature review, Salter and Martin (2001) identify six types of externalities[42] of basic research which affect economic performance:

1. *increasing the stock of useful knowledge*: Basic science undoubtedly creates new knowledge which can be further used in more applied research and product development.[43]

2. *training skilled graduates*: Public research facilities train graduates. When working afterwards in commercial sectors they bring new codified and tacit knowledge to their new organization and improve there the knowledge absorption capacity. Hence, they are an important path of knowledge transfer between basic and applied research: "*Since graduates provide a key mechanism for the benefits of public funding to be transferred to industry, it is vital that government-funded basic research and student training are conducted in the same institution.*"[44]

3. *creating new scientific instrumentation and methodologies*: Research questions and problems of basic science entails the development of research instruments and -methods, which also open up new technological possibilities for industrial purposes.[45] Examples are the medical use of X-rays or the development of transistors which became possible due to basic research on artificial crystal growing.[46]

4. *forming networks and stimulating social interaction*: Academic basic research involves the creation of new forms of network and cooperation structures with

[41] It appears that in the innovation system discourse, the term *external effect* is used for negative external effects which reduce system performance, while positive externalities tend to be called *socio-economic impact* or *spillover-effect*.
[42] Salter and Martin use the term "Spillover-effects"
[43] Salter and Martin 2001, p. 520.
[44] Ibid., p. 522.
[45] De Solla Price 1984, p. 15.
[46] Ibid., p. 14.

participants who follow different motivations than in commercial and product-oriented research. This can lead to the creation of completely new innovation network structures or increase the performance of existing network structures due to a greater heterogeneity of its participants.[47]

5. *increasing the capacity for scientific and technological problem-solving*: Due to its constant activity at the edge of the technologically feasible, basic research demands as well as fosters fundamental capacities for solving complex technological problems. These can be beneficially put to use in industry.[48]

6. *creating new firms*: Basic science provide a point of origin for new companies. These spin-offs often have a low rate of growth and success,[49] but provide an important source of technology transfer and informal networks between science and industry.[50]

Here it has to be emphasized that this list of Salter and Martin about the economic benefits of basic research reads very similar to the benefits of research infrastructures pointed out in the quote on page 27. Additionally, Salter and Martin infer that the market failure rationale for governmental funding of science is insufficient to consider this variety of impacts of basic research on the economy.[51] Now it is of interest how these literature findings on externalities of basic research connect to the central goals of current European research policy.

2.3.4 External effects of basic research infrastructure in the Europe 2020 context

Europe 2020 incorporates the market-failure oriented 3 % target of GDP invested into R&D, while Horizon 2020 uses the system failure narrative when pointing at increasing the effectiveness of this investment in terms of growth, jobs and competitiveness.[52] Section 2.3.2 showed that external effects play a central role in both argument types, and we can notice that ESFRI uses arguments similar to Salter and Martins list of external effects to embed itself into Europe 2020 and Horizon 2020. This is exemplary for research policy getting a strong diffusion-orientation when it is embedded into growth policy, because for the general growth agenda, it is of rather

[47] Salter and Martin 2001, p. 523.
[48] Salter and Martin 2001, p. 523; This aspect is corroborated by Zellner 2003.
[49] Salter and Martin 2001, p. 526.
[50] O'Shea et al. 2005, p. 995.
[51] Salter and Martin 2001, p. 527.
[52] ESFRI 2011, p. 7.

little interest what basic scientific research develops, as long as beneficial effects on economic performance occur, either by the scientific subject itself or its research technology and infrastructure.

This notion has to be qualified in view of the specific research policy in the Horizon 2020: Horizon 2020 is targeted at improving the science base and its market take-up,[53] supporting industrial performance and addressing societal challenges. While the second target is obviously diffusion-oriented and targeted at economic impact, the other two give a more ambivalent picture: The "Excellent Science" priority incorporates the focus on "future and emergent technologies" as well as excellent scientific training,[54] two elements which can also be found as No. 2 and 3 on Salter and Martins list. Additionally, the whole "Excellent Science" priority is connected to the Innovation Union initiative, and therefore gives the basic science sector a systemic function for the European Innovation system.[55]

The priority on societal challenges is the only mission-oriented target which gives science and its research infrastructures a content-sensitive direction. But due to the fact that these are *societal* challenges, external effects gain importance as carrier of results from scientific communities to the wider society. The most important societal challenge identified in Horizon 2020 is climate change. With training skilled graduates, social network creation and spin-offs, Salter and Martin identified three external effects which help to spread new knowledge, methodologies and technologies relevant for societal challenges. In consequence, even the mission-oriented *Societal Challenges* priority in Horizon 2020 supports diffusion-oriented strategies like"(...) *activities from research to market, including: R&D projects, applications of key technologies (e.g. ICT, bio, nano), pilot and demonstration projects, market uptake and replication projects, [...] as well as innovation inducement prizes.*"[56] The focus on diffusion and innovation system performance reappears in the specific agenda for research infrastructure as communicated by the ESFRI Chair:

> "RIs in Europe will serve as high-performance platforms for cooperation among universities, enterprises and research institutes. The resulting innovation ecosystem will spur new ideas, solutions and innovations of benefit to the European economy and society, as well as science. Special attention should be paid to nurturing the SMEs that supply them, collaborate with them, or spin-off from them."[57]

This special attention for supplying SMEs leads to the next chapter of this thesis.

[53] European Commission 2011b, p. 9.
[54] European Commission 2011a, p. 34.
[55] Ibid.
[56] Ibid.
[57] Rizzuto 2013, p. 4.

3 SURVEY RESULTS

The last chapter started with a historical example of the capacitive touch screen as an economically relevant side-effect of basic research, it went on with describing such an externality as relevant for both main justifications of public intervention, and ended with pointing out the importance externalities gain in view of current, diffusion and growth oriented European research policy. While Salter and Martins paper give a wide overview on previous studies on external effects of basic research in general, the survey performed for this chapter concentrates on a less extensively studied aspect:

The external effects publicly funded basic research infrastructure has on supplying companies during its construction process, exemplified by the example of the construction process of the European XFEL research facility.

This aspect gains importance due to three reasons: Firstly, for basic research infrastructure, the construction process presents the closest interaction between basic science and industry. Therefore, it is the best opportunity for fruitful exchange and cooperation, which is of importance in the innovation system performance perspective. Secondly, European research policy acknowledges its innovation-relevant public procurement activities as an important policy tool.[1] Thirdly, as the quote on page 27 pointed out, enterprises connected to RIs are regarded as the maybe most important transfer path and user of the knowledge and technology developed in RI's.

The central question behind this structure is whether research facilities provide a *stimulus* of technology development to supplying companies. There exists a vast literature on direct technology *transfer* between research (mainly universities) and industry, especially in form of patent exchange. But technology *transfer* is only limitedly suitable to assess technology and learning effects as externalities, because the possible externality is the central element of exchange, and therefore tends to be priced adequately. The term "technology stimulus" in the context of science - industry relations describes the situation in which new technological needs and money as

[1] European Commission 2011b, pp. 5, 8, 10.

well as helpful knowledge are transferred to companies, where the final technology development occurs. In this situation where the research facility is acting as a buyer of products yet to be developed, externalities can occur more easily in form of every not monetary element like knowledge and contacts which the buying research facility provides additionally. For this reason, the focus group for this survey where companies which supply custom produced and technologically demanding products. Following the concept of technology stimulus, we are not only interested in the direct effects of a science - industry cooperation, but also how these effects are put into further use.

To access the survey data from this perspective, the first section of this chapter will put the performed survey in the context of its predecessors and describe the applied methodology. Section 3.2 will analyse the composition of participating enterprises and their relation to the European XFEL project to show more detailed who the potential recipients of learning effects are. Section 3.3 focuses on the direct technological and organizational learning effects of the survey participants due to their supplying contracts, while section 3.4 will present the expected or already realized further use and impact for the company and its product portfolio. Section 3.5 will give an overview on the findings.

3.1 Methodology

3.1.1 Existing studies

The existing literature on the relationship of economic actors and basic science infrastructure has been published either by peer reviewed journals or directly by institutions of basic science. The literature of the first type, published until 2001, has been thoroughly collected and analyzed by Salter and Martin (2001). Examples of highly relevant publications are De Solla Price (1984) on the general relation of science and technology and Beise and Stahl (1999) on the impact of public (but not necessarily basic) research on industrial innovation in Germany. The growing amount of literature after 2001 incorporates corroborations of specific aspects of Salter and Martin's synthesis: Zellner (2003) for example describes the migration of scientists from academic basic research to industry as an important source of knowledge for industry, while Cohen, Nelson, et al. (2002) uses data from 1994 on industrial R&D in the US to derive the impact of public research and describe the responsible transfer path, in both aspects congruent with Salter and Martins findings. Toole (2012) focuses

on the impact of public research on pharmaceutics as a specific industrial sector, while Autio, Hameri, et al. (2004) use three case studies on single firms to describe more detailed the impact of large research infrastructure (CERN) as a specific type of public basic research. A more recent and also congruent literature review on the role of large research infrastructure has been performed by Zuijdam et al. (2011). In consequence of these corroborations, Salter and Martins' synthesis will be used as a benchmark for this survey.

While this literature points at the common consensus on the economic importance of public basic research in general,[2] the work by Autio, Hameri, et al. (2004) is a rather rare example of peer-reviewed academic work on the specific economic impact of large research infrastructures. In combination with the growing need to justify public spending after the early 1990's,[3] this lack motivated the institutional actors of big science to initiate evaluations of their own socio-economic impact. Notable examples are the already mentioned work by Zuijdam et al. (2011) which was initiated by Dutch public authorities or COST (2010) on the socio-economic impact of the international radio telescope project SKA. Additionally, the Authorities of the Øresund-region in Sweden supported the Study by Hallonsten et al. (2004) on the expected socio-economic impact of the local installation of the European Spallation Source (ESS).

This survey builds on the methodology and experiences by previous work on this topic: Autio, Bianchi-Streit, et al. (2003) analyses the technology transfer and innovation effects of CERN's procurement activity for the LHC, while Lütjens (2004) closely follows this approach and studies the impact of DESY's Procurement activity for the TESLA test facility, a prototype of the European XFEL facility. While Autio, Bianchi-Streit, et al. (2003) was the methodological guide for Lütjens (2004), Lütjens (ibid.) is the direct predecessor of my survey. It is a diploma thesis supervised by Wilhelm Pfähler, who performed and supervised several studies commissioned by DESY on the socio-economic impacts of basic science in general or on the regional impact of specific facilities of DESY, resulting in papers like Pfähler and Hoppe (1999), Pfähler and Gabriel (1999), Pfähler, Bönte, et al. (1999) and Pfähler and Hoppe (2001).

[2] Schmoch 2004, p. 718; Toole 2012, p. 1.
[3] Lundvall and Borrás 2005, p. 607.

Innovation effects of CERN's procurement activity 1997-2001

To approach the technological and organizational learning effects which CERN induced on its industrial suppliers, Autio, Bianchi-Streit, et al. (2003) performed a questionnaire-based survey on their technology-intensive suppliers. 629 companies with relevant procurement contacts between 1997 and 2001 were addressed and 178 valid questionnaires received. Their key findings included significant technological learning effects, which directly resulted in newly developed products at 38% of the companies with an estimated number of 528 new industrial products and services.[4] Organizational learning effects included an increased market knowledge and access as well as an increased international exposure, resulting in 4400 estimated new customers for CERN's technology-intensive supplier firms.[5]

Beside these results of the procurement activity, Autio, Bianchi-Streit, et al. (ibid.) identified the interaction frequency between CERN and its suppliers, the number of personnel involved in interaction and the firm's investment in its relationship to CERN as determinants for CERN's learning effects on its suppliers.[6] This combination of relevant social capital and specific technological learning indicates that technological learning effects can sometimes outweigh the monetary value of science-industry relations,[7] highlighting the importance of non-monetized relations of basic research institutions as a source of positive external effects.

Regional impact of the TESLA XFEL on supply and demand

The direct forerunner of my survey, Lütjens (2004) was interested in the expected regional impact of the installation of the European XFEL in Hamburg, based on the experiences of the suppliers of the TESLA Test Facility, a prototype of the European XFEL.[8] He reused parts of the questionnaire of Autio, Bianchi-Streit, et al. (2003) and added detailed questions on the regional impact of the procurement activity. The technological and organizational learning effects and reputation benefits found by Autio, Bianchi-Streit, et al. (ibid.) were corroborated, while the impact of the region of Hamburg appeared to be rather limited, due to the highly specialized and nationally as well as internationally distributed suppliers. 88 % of the Companies located

[4] Autio, Bianchi-Streit, et al. 2003, p. 46.
[5] Ibid.
[6] Ibid., p. 47f.
[7] Ibid., p. 50.
[8] TESLA XFEL was the former project name of the European XFEL. "TESLA" was the name of the linear accelerator technology developed by DESY.

in the region of Hamburg were mainly supplying less demanding technology and showed little learning and innovation effects.[9]

My survey mainly presents a repetition of Lütjens (2004) after a decade of progress of the European XFEL project, but with two important differences: Firstly, as a consequence of the low level of regional impact of the procurement activity, questions on this topic were dropped in favor for more detailed questions on the type of transferred knowledge and the impact on product development. Secondly, instead of supply theory as the theoretical framework, this thesis is mainly based on institutional economics.

3.1.2 Development of the questionnaire

My survey profits from the experiences of its predecessors, and uses to about 70% similar or identical questions as Lütjens (ibid.), implemented as a web-based questionnaire on the platform www.soscisurvey.de. Table 3.1, p. 32 gives an overview of the main questionnaire which is included in Appendix A.2.

Part	# q.	*Content*
-	-	Front Matter: Information about the survey and its purpose, emphasizing the institutional independence from the European XFEL GmbH and DESY.
I	3	Informations about the answering company
II	7	The relation between DESY / the European XFEL Company and its supplier
III	7	Innovation and stimulus of Technology: Which learning effects occurred and how where they triggered?
IV	11	Innovations effects and technology diffusion: Which wider effects like new products, customers or employees did these learning effects have on the company?
V	2	Investments: Does the supplying contract induce new investments?
VI	2	Reputation: Where and for which type of customer does the European XFEL functions as a valuable reference customer?
-	-	Back matter: open space for comments or additions

Table 3.1: Main structure of the questionnaire and distribution of its 32 questions.

The following changes to Lütjens questionnaire were made: The web-based interface allowed for skipping questions dependent on an introductory question an-

[9] Lütjens 2004, p. 47. It should be noted that these findings count for the regional impact of the procurement activity for the TTF, but not for the regional impact of DESY as a large research infrastructure in general.

swered negatively. Where possible, this shortens the questionnaire. Additionally, draw-bars were used instead of 6-point-scales in cases where sensible information or general tendencies were asked. In terms of content, questions on regional impact were dropped and questions on the form and type of transferred knowledge as well as the type and application of new developed products added. This modified questionnaire was pretested six times, by XFEL personnel proficient in English, by an employee of the DESY technology transfer office, and finally by three members of the target group.

3.1.3 Sample selection

In contrast to Autio, Hameri, et al. (2004) and Lütjens (2004), the list of companies was not produced by the procurement divisions of the European XFEL GmbH and DESY, but instead developed in individual interviews with the group leaders of technologically relevant work groups. This was done for two reasons: Firstly, the construction and development of elements of the European XFEL is distributed among many European partner countries and research institutes and are brought in as in-kind-contributions. Therefore, the relevant contact persons at the involved companies are better known to the scientific and engineering personnel. Secondly, the direct contact to group leaders in the ongoing development and construction process provided knowledge of relevant upcoming industry partnerships, which would appear in procurement documentation only months later. These group leaders were asked to name companies who supply "custom build" and "technologically demanding" products and to name competent contact persons at these companies.

This procedure resulted in a good coverage of companies with direct contact to personnel of DESY and the European XFEL GmbH and several companies with contact to partner institutes, while it is possible that sub-contractors of partner institutes are under-represented. The development of the detectors and the scientific instruments were mostly in an too early stage to show relevant industrial contacts. Over-represented are probably companies which supply products which are part of the MTCA.4 computer standard developed at DESY, because DESY is very active in promoting and industrializing this technology, which made the contact to these companies much easier.

3.1.4 Questionnaire distribution

The contact personnel named by the group leaders were contacted either personally on occasions where they visited the construction site or their partners at DESY / European XFEL GmbH, or via phone. Here, the general scope and motivation of this survey was explained, its institutional independence from DESY and the European XFEL GmbH highlighted and anonymity assured. The questionnaire was completed later, at a time suitable for the participant. Due to this personal approach, the respond rate came out relatively high, even though often, multiple phone contacts were necessary until the questionnaire was completed.

3.1.5 Conceptual limitations

test group:	X	O	(O)	X	O	O	X	O
control group:			(O)		(O)	O		O
	t_1	t_2	t_0	t_1	t_2	t_0	t_1	t_2
a) pre-experimental design			**b)** mixed design type			**c)** standard survey design		

Figure 3.1: Design types for surveys. X = event of interest; O = observation; (O) = estimation of counterfactual state, derived in O.

While my survey profits from the mature questionnaire of its predecessors, it also bears their methodological limitations. They do not incorporate a control group as a counterfactual,[10] which would be required for a valid, standardized evaluation design (see figure 3.1c).[11] Therefore, the survey design initially qualifies as an explorative, pre-experimental setup (see figure 3.1a). This can be advocated due to the emerging state of this special research on the impact of large research infrastructure, where explorative surveys like these are still the best available.

Additionally, the standard design types of fig. 3.1a and fig. 3.1c relate to the indirect measurement of the assumed effects of an event or intervention before and after. In contrast, Autio, Bianchi-Streit, et al. (2003), Lütjens (2004) and this survey directly ask involved parties about their *perception* of the impact of their collaboration with a large research facility. This incorporates a stimulus for the participant to compare the present state with the counterfactual, imagined state of no collaboration. In consequence, the whole survey design is a mixture of an explorative (pre-experimental)

[10] Khandker et al. 2010, p. 22.
[11] Diekmann 2006, p. 310; Schnell et al. 2011, p . 221. Schnell also uses the term "ex-post-facto design".

and a standard survey design (see fig. 3.1b). It has to be noted that this setup with an directly communicated research question increases the bias of the subjective memory of the participant and his tendency towards socially desirable answers.[12]

Furthermore, in alignment with the exploratory state of the research agenda, the general questions are *if* and *which* learning effects exist, and *how* they were induced. For these exploratory questions, the subjective perceptions of involved parties are adequate and can be used to improve more objective surveys in the future.[13] Their main limitation is that they do not directly evaluate learning and technology transfer itself, but evaluate the subjective perception of these effects. As a consequence of these limitations, and in alignment with Autio, Bianchi-Streit, et al. (2003) and Lütjens (2004), the results of my survey will be presented with methods of descriptive statistics, setting aside analytical statistics for further research. As another relevant limitation of this survey and its predecessors, their findings are valid for the context of CERN and the DESY / the European XFEL GmbH, but cannot be generalized for basic research facilities in general. For this reason, Autio, Bianchi-Streit, et al. (2003) highlight the early stage of this research agenda and its need for larger and refined surveys.

3.2 The industrial focus group and their relation to the European XFEL facility

Preliminary to analysing the learning effects triggered by the demands of basic research, it is of interest *who* the recipients are and *how* they relate to the European XFEL project. This covers the type of commissions, the origin, size and R&D density of the suppliers, previous contracts and the relevance which DESY and the European XFEL GmbH have as customers for its suppliers.

Obviously, their relation is based on their supplying contract. Fig. 3.2, p. 36 shows what these commissions generally consist of. The many answers for modified standard products as well as custom produced and custom developed supplies confirm that the initial filter for collecting contact data of potential survey participants was effective. In regard to the differentiation between technology *transfer* and

[12] Lütjens (2004) performed his survey during a time where companies could hope for further and larger contracts due to the upcoming XFEL construction, while my survey was done without such a potential influence.

[13] Babbie 2010, p. 92.

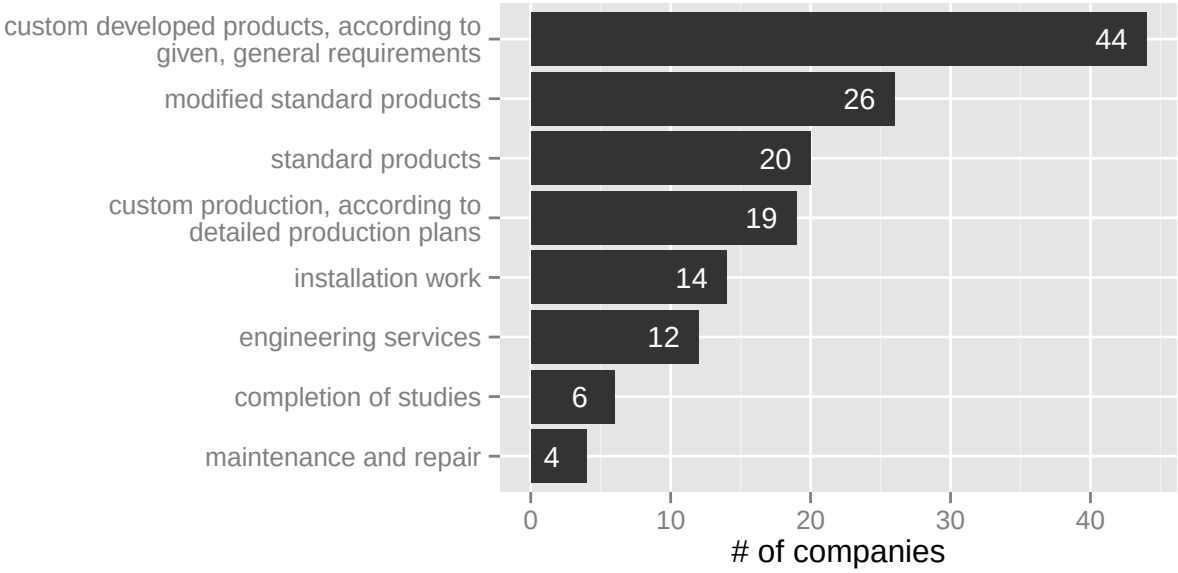
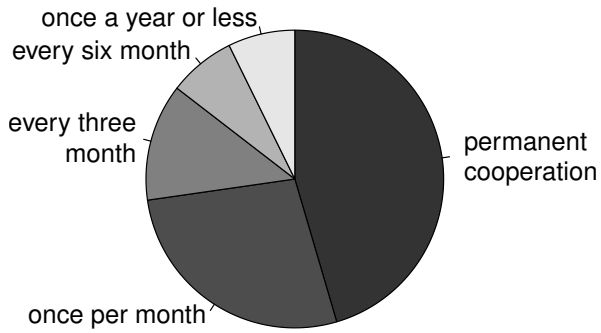


Figure 3.2: Product types supplied by survey participants (multiple answers were possible)

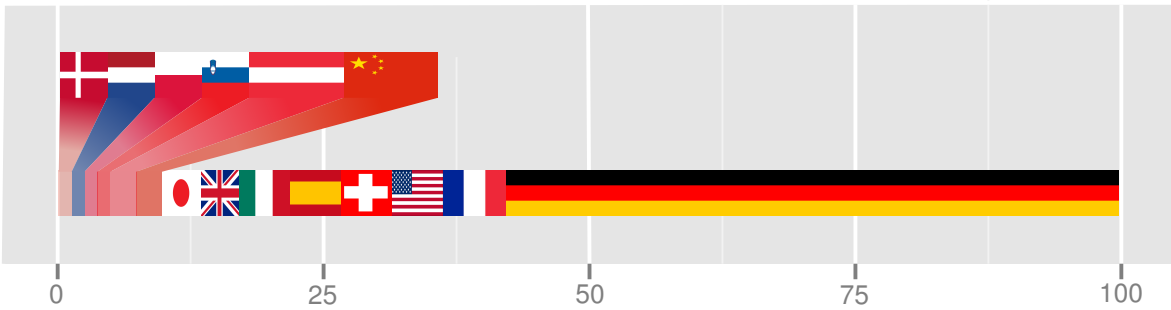
stimulus,[14] the difference between custom production and custom development of supplies has to be highlighted: The larger majority of companies are supplying custom developed products, and therefore they are in a stimulating situation for own technological learning and development. In this case, the scientists often depend on the experience and know-how of their industrial partners. Examples for this are the laser systems and linear positioner for scientific instruments, klystrons, x-ray mirrors, niobium pre-products for accelerator cavities as well as cryogenic equipment and vacuum components. Only a smaller group of companies are delivering supplies which have been developed at DESY or the European XFEL GmbH. The best examples for this classic case of technology transfer are the accelerator cavities as well as the MTCA.4 computer standard and several elements of its product range. In these cases where the size of the machine requires large quantities, technology which has been developed by DESY is transferred to industry to profit from their mass production competence.

Two things are important here: Firstly, while technology transfer from science to industry can be a fruitful type of stimulus, this stimulus does also occur without transfer. Secondly, the superior number of contracts on custom developments among the survey participants indicate that technology stimulus is the more common type of socio-economic impact. This pattern needs close interaction of both parties, and consequentially, as shown in fig. 3.3a, most survey participants are

[14] see p. 29



a) contact frequency in cooperation



b) percental share of home countries of the suppliers.

Figure 3.3

in frequent or permanent contact with their scientific partners. This close contact renders the construction process of large research infrastructure as an ideal topic to study the exchange between science and industry. Where do these companies come from? Fig. 3.3b[15] shows the percentaged distribution of the suppliers' home countries. To a certain extent, this home country distribution reflects the organizational structure and related cost distribution of the project: Germany as the host country and sponsor of about 58% of the total project budget is simultaneously home country of most of the companies of this survey's focus group. Other countries who are shareholders can contribute in-kind, either in form of contributions by local research centers and universities, or by contracting domestic companies. A good example for the last case is the scientific Instrument FXE, which is constructed by the Danish company *JJ X-Ray* and paid for by the Danish government. But due to two reasons, Germany's share in fig. 3.3b may be disproportionately high: Firstly, Russia as the second largest shareholder is missing, because most Russian contributions come from public research centers and not private enterprises. Secondly, the high return rate of the survey was accomplished by personally following the so-

[15]This plot includes also companies which were named by the scientists at DESY and the European XFEL GmbH, but which did not participate in the survey.

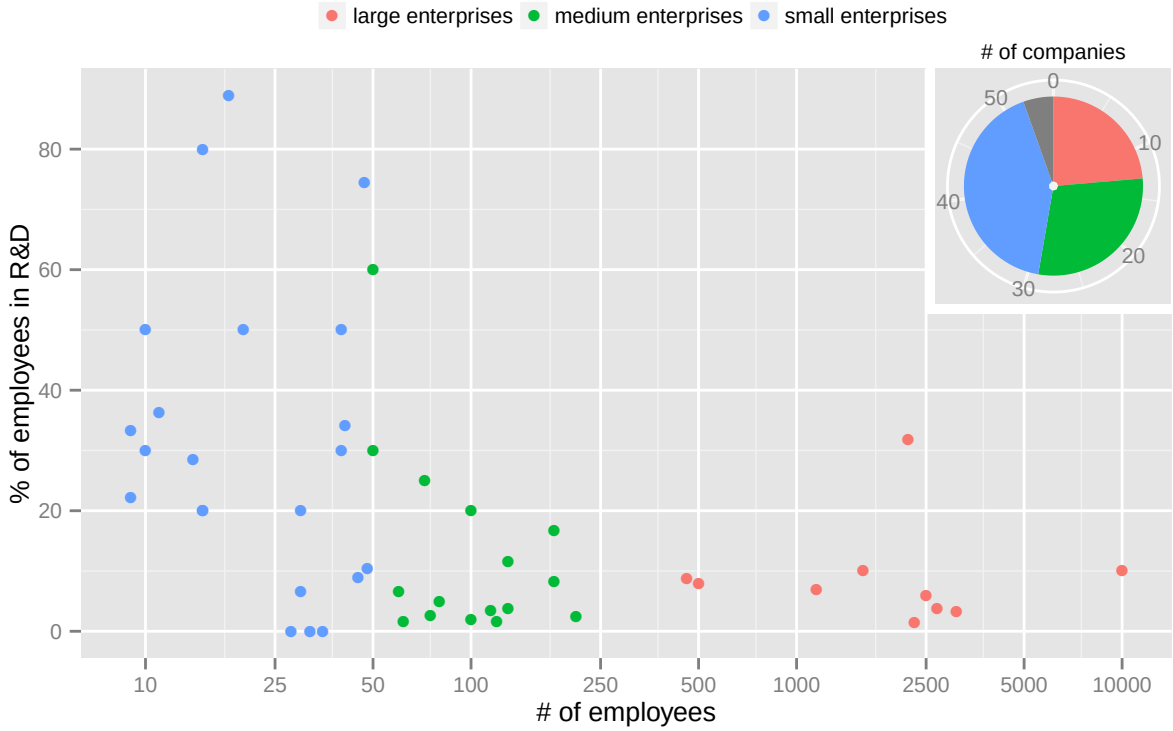


Figure 3.4: R&D density

cial contacts from scientific personnel to their industrial partners. Being located in Hamburg made it much easier to access companies with direct contact to Hamburg, while suppliers of foreign partner institutes are possibly under-represented.

As the next step in accessing the socio-economic impact of the European XFEL Project on its suppliers, fig. 3.4 plots the company size against their R&D density. This shows two relevant aspects: Firstly, small and medium enterprises (SMEs) are the dominant size class among the suppliers. Secondly, smaller companies show a high percentage of employees in R&D.

The first observation gains importance due to the political emphasis on the role of SMEs pointed out on page 27. The second observation can be explained due to the special needs of the European XFEL project: The supplied goods covered by this survey are technologically highly demanding, but in industrial dimensions in very low numbers. Consequentially, possible suppliers need a considerable technological competence for own developments and for conforming the specifications expected by the scientific partners. Also, they need the absorptive capacity to understand the preliminary work done and knowledge gained at the research facility. Additionally, the small number of supplied goods requires a high degree of flexibility to be able

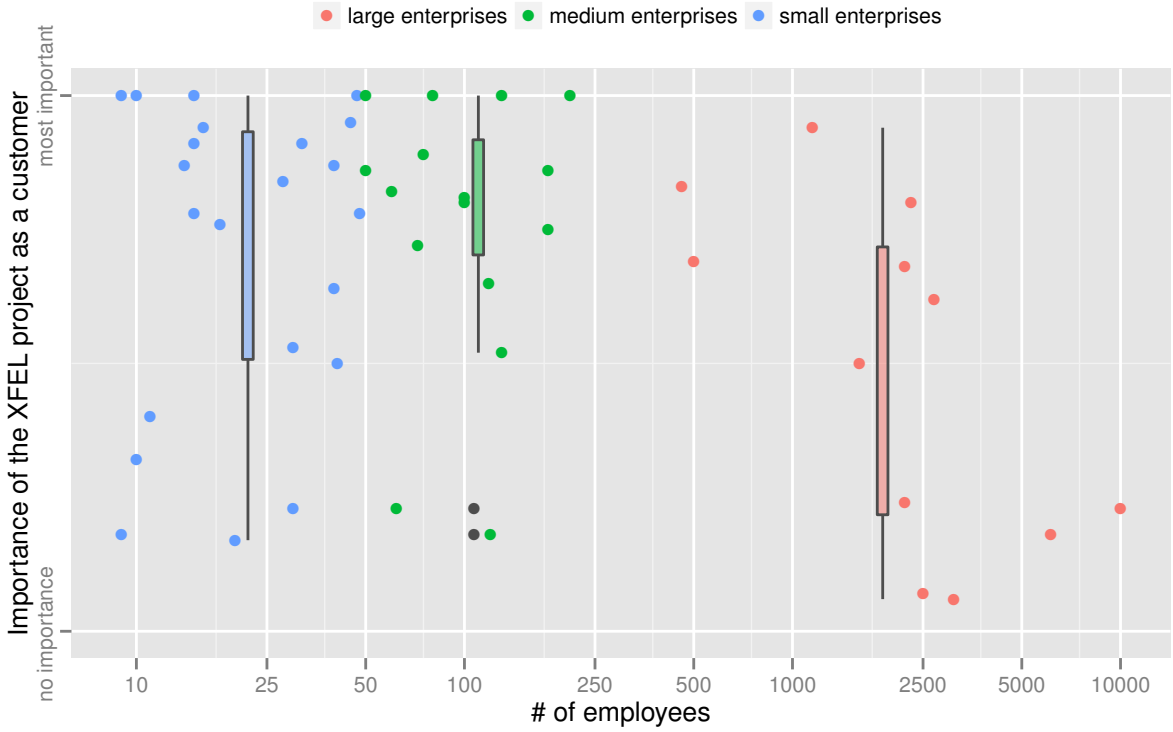
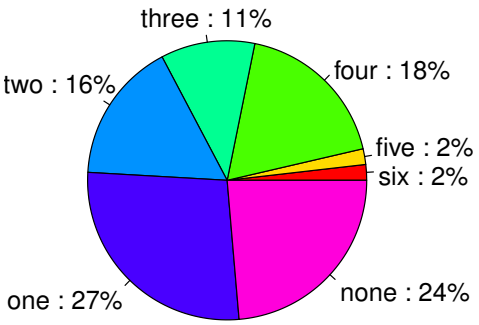


Figure 3.5: Importance of the supplying contracts and company size

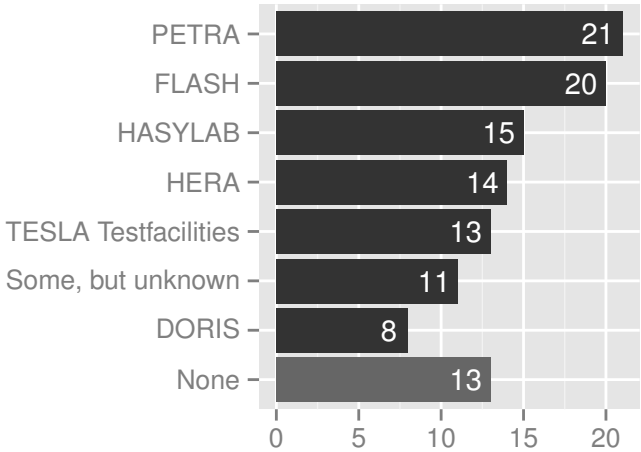
to adjust the own organization of development and production to custom specifications to keep the cooperation profitable. As a matter of fact, a small number of scientists reported problems in finding suppliers for unique, but complex items. On the other side, even the largest sizes of orders for the European XFEL like the 800 accelerator elements are rather small for industrial dimensions, and therefore supplied from companies specialized on scientific research and instrumentation, in this case companies like *Research Instruments* and its parent company *Bruker*.

This divergence between small, innovative and flexible companies suitable for custom developments and large companies suitable for cheaper production of larger series incorporates a source of frustration for smaller companies: One company complained about tenders for prototypes given to small companies, while the tender for the larger, final series are given to larger companies. In point of view of the developer, this pattern generated sunk costs for him and positive externalities at the producer of the final series.

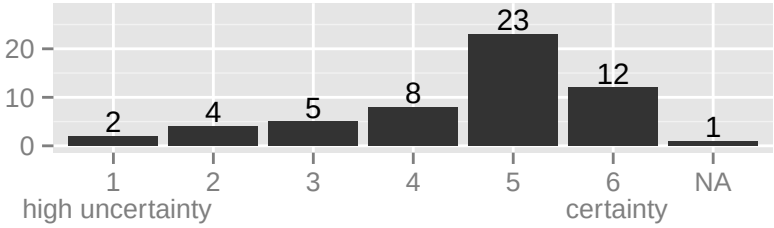
This frustration is in line with the main results from fig. 3.5: For small and medium enterprises, the European XFEL project is a much more important customer than it is for large companies. Eight SMEs even stated that the European XFEL



a) amount of older DESY facilities to which suppliers did also contribute



b) # of companies which have supplied before to these facilities at DESY



c) Expectations about further contracts.

Figure 3.6: Stability of science - industry relations

project is their most important customer. This indicates that large research infrastructures can serve as a key market for specialized SMEs. Due to its demand for new technologies, this market can serve as a nurturing environment for start-ups and spin-offs. A good historical example here is Bruker, which was founded in 1960 by a professor for experimental physics and specialized on the recently developed NMR spectroscopy technology, which started as a research instrument in physics, but is today commonly known as a medical imaging tool. Back then, Bruker profited from the political focus on "Big Science" and its demand for research instruments,[16] but is today a large corporation, selling its instruments also to pharmaceutical, chemical and medical industries as well as food, textile and metal industry. Section 3.4 will deal with the question whether this pattern of further use of research technology can be found at other companies.

Another aspect of the great importance of the XFEL project as a customer and the correspondent specialization of the companies is the stability of their relation: As

[16] Reinhardt and Steinhauser 2008, p. 83.

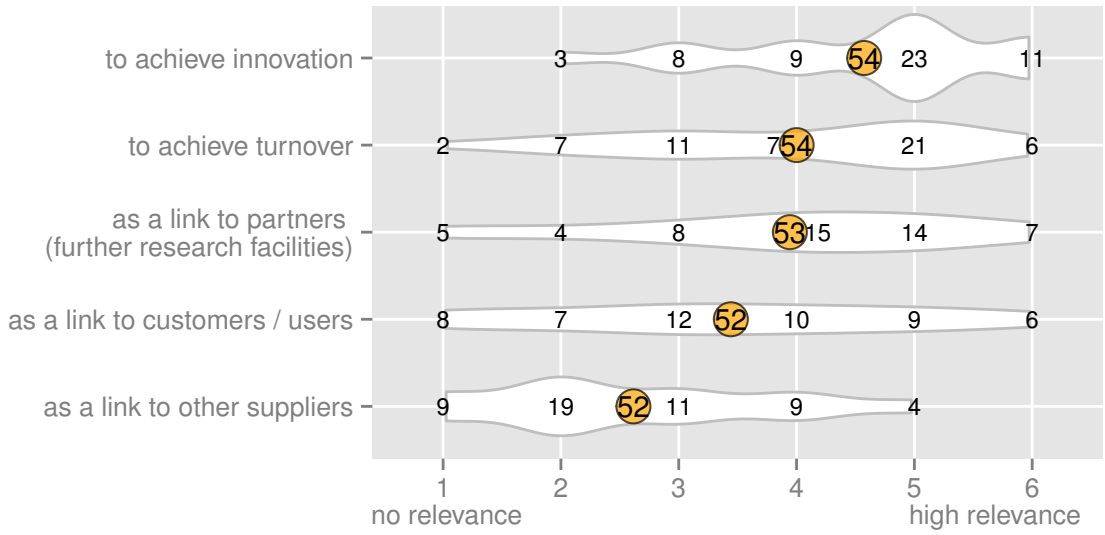


Figure 3.7: Criteria for the relevance of DESY / European XFEL as a customer. A detailed plot explanation can be found in Appendix A, p. 83

shown in figure 3.6: 76 % of the suppliers covered by this survey have been already involved in one or more construction processes or refits of older DESY facilities. While FLASH is the direct predecessor of the European XFEL and the ring accelerator PETRA has been refitted in 2009 as a storage-ring-based X-ray source, several suppliers have also been involved in older facilities like HERA, TTF and the recently decommissioned DORIS. As a consequence, most suppliers covered by this survey expect further commissions in the future (see fig. 3.6c).

What exactly makes a research facility an important customer? Fig. 3.7 differentiates between turnover, innovation effects and network effects as possible reasons and shows that the possibility to achieve innovation was rated as slightly more important than the financial attractiveness. This reflects the common pattern of technologically demanding products, supplied in small quantities. Additionally, about half of the participants regard their XFEL contribution as a relevant link to scientific partner institutes of DESY and the European XFEL GmbH, for example other large public research centres and universities. The relevance of the development and construction process of the European XFEL facility as a stimulating environment for innovation can be highlighted by taking a look at companies which see no or only little relevance in their contribution: As shown in fig. 3.8, this subset of companies gave similar ratings on innovation and network effects as the total sample.

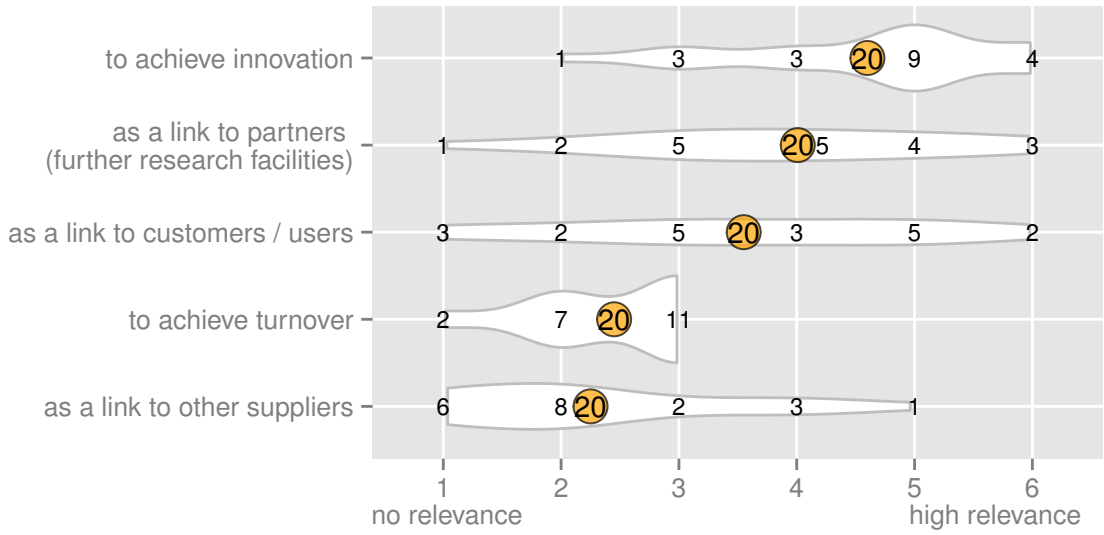
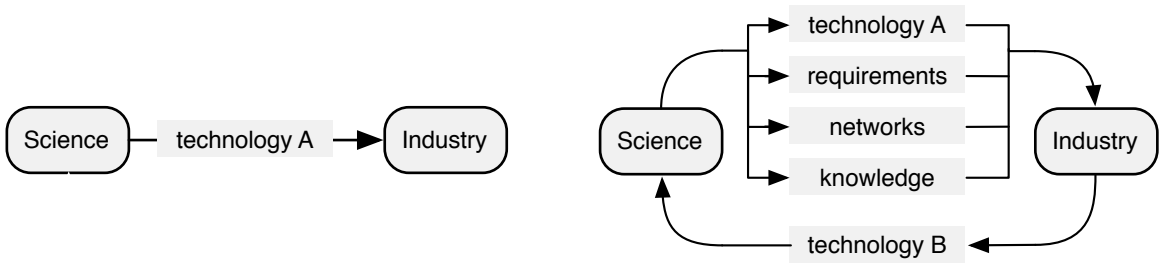


Figure 3.8: Criteria for the relevance of DESY / European XFEL as a customer (subset of companies with low ratings on the relevance of financial turnover)

short overview

The following list summarizes the findings of this section and gives an introductory view on who is profiting from possible learning effects, where they occur and how these companies relate to the European XFEL Project:

- Suppliers are internationally distributed, but the shareholder's contribution to the overall budget strongly influences this distribution and thereby the place where socioeconomic impacts occur.
- most companies in the sample do not only produce, but also develop technology, therefore the stimulating effect for developing technology is probably more important than a transfer of technology.
- the majority of companies are SME's with a large share of staff in R&D.
- Due to the specialization of companies and the mutually gained trust, the science-industry relation tends to persist over longer periods of time.
- For most SME's, DESY / the European XFEL GmbH are more important customers than they are for larger companies.
- This importance is not only based on the financial value of the science-industry-relation, but also, and partly even more, on the possibility to achieve innovation and to enter social and institutional networks of public science.



a) technology transfer **b)** technology stimulus

Figure 3.9

3.3 Direct impact on suppliers

At the beginning of this chapter, the differentiation between technology transfer and technology stimulus was introduced. As figure 3.9 shows, technology transfer is an optional, but not necessary part of technology stimulus. The transfer of technology from science to industy is a powerful stimulus for further developments. But also the transfer of scientific and social knowledge can trigger or foster commercial innovation, especially if it accompanied by scientific requirements on a new technological level and public funding which minimizes the development risk for the supplier.

Following this idea, this chapter will present the impact of the XFEL Project on its suppliers in form of technological, organizational and social learning effects. Social learning effects primarily include network effects and the associated reputation effects. To better understand how and in which form these learning effects occured, the questionnaire also included questions about the relevant contact and exchange mechanisms as well as questions about the type and form of transferred knowledge.

Beyound that, the investment effects and employment effects are presented as a "harder", more quantifiable impact. But these impacts are rather an effect of the stimulus than part of it: This is because every order which is large enough will has investment and employment effects. But a stimulating effect is based on contrasting needs, specifications and organizational frame conditions which require as well as foster technological learning and organizational adjustments.

3.3.1 Technological learning effects

A central question in this survey were the technological learning effects, shown in fig. 3.10. Participants could evaluate their expected or achieved learning effects in the given list of technological areas on a 6-point scale, while fig. 3.10 ignores the first level on the scale to focus on reported innovations.[17] The plot tries to point out the *quantity* and *quality* of innovation effects: The quantity is displayed by the order of technological sectors on the y-axis, while the quality of innovations in each sector is displayed by their mean answer level on the scale.

The first information to be gained here is the considerable amount of perceived learning possibilities: The 55 participants responded 186 times in the range from 4 to 6 on the scale, thus reporting 186 at least fair product or process innovations due to their European XFEL project contribution. Among these, there are 32 answers for "very important innovation" with at least one case in 12 out of 15 technological sectors. This indicates that the technological needs for the development of new large research facilities either offers or triggers learning processes, and that in multiple technological sectors.

What can be learned from the distribution of answers over sectors? In pure quantity, most innovations are reported for mechanical engineering and production processes, which both are sectors which naturally affect most supplied products. Comparable high ratings were given for measurement and diagnostics as well as precision engineering. The high quantity of innovations for these four sectors can be seen as the consequence of the rigorous requirements by the XFEL facility on precision and quality.

"Scaling of production" is actually a mixture of technological and organizational aspects, but was added due to suggestions from company representatives during the pretest. The demands for the XFEL facility and the availability of appropriate suppliers leads to changed production scales in both directions: Small companies focused on development can face the opportunity to deliver an uncommonly large quantity, while large companies may have contracted for an uncommonly small supply. Accordingly, the highest ratings were mainly given by suppliers for the MTCA.4-based control infrastructure as well as LINAC-focused technology like cavities and vacuum pumps. At the current state of development, the accelerator in general and the MTCA.4 infrastructure in special are XFEL elements for which the strongest industrialization efforts are done, which corresponds to the high ratings for HF and control engineering as well as electronics.

[17] Note that every company could evaluate for every technological sectors, even though most companies are only active in a fraction of them, thus answering "no innovation achieved" for most fields of technology.

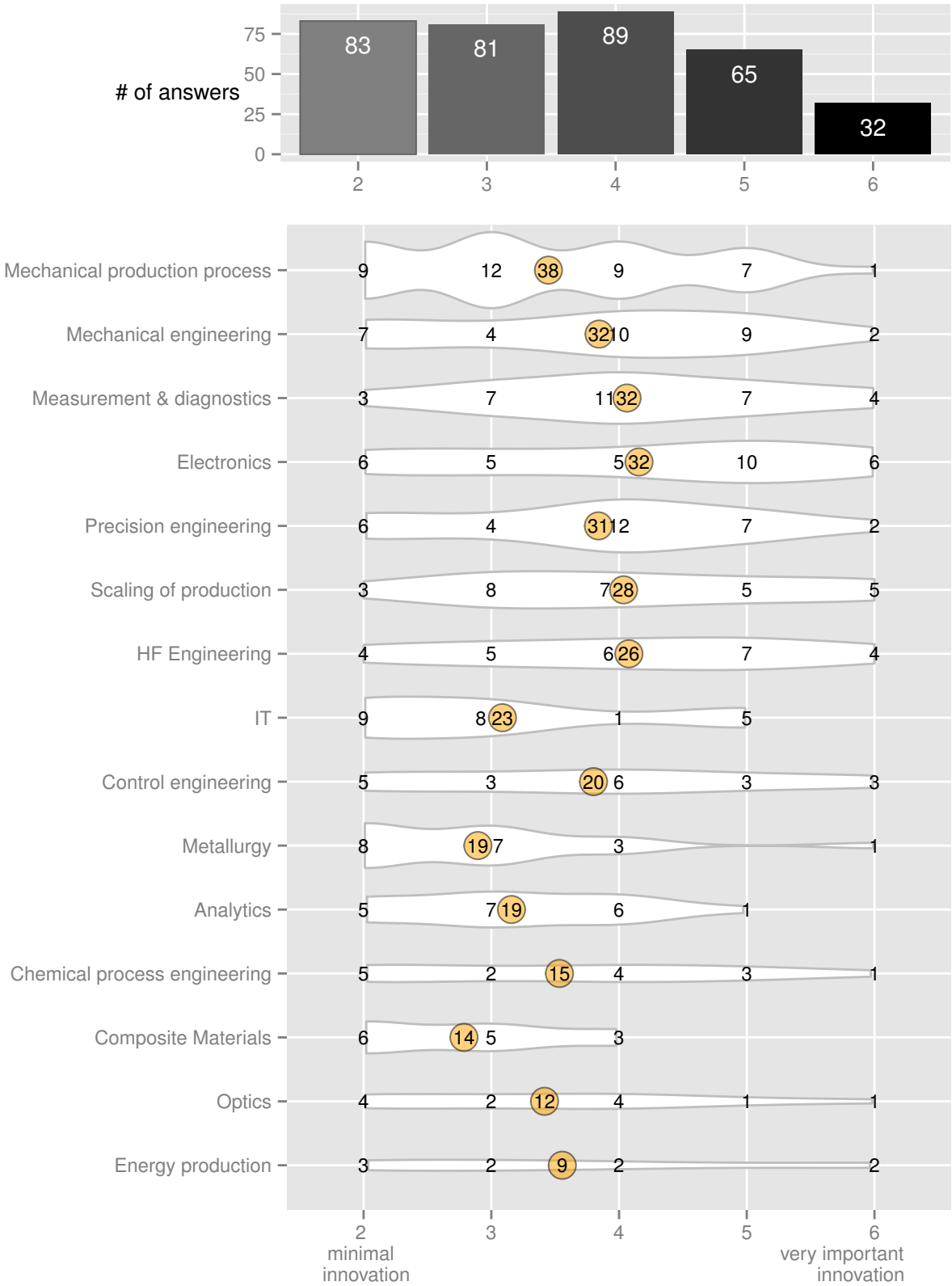


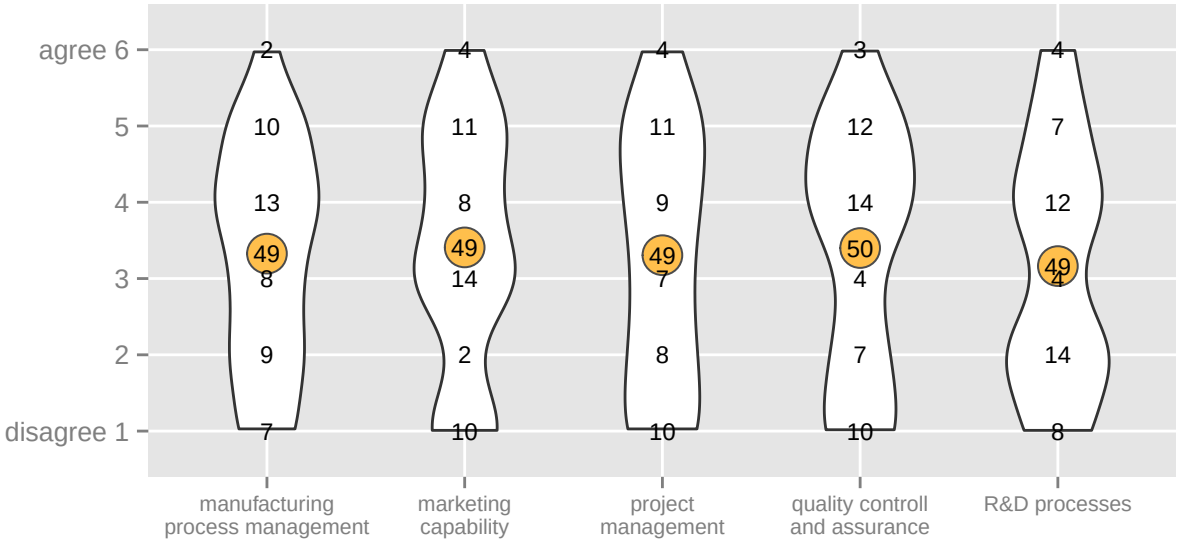
Figure 3.10: Technological learning effects

3.3.2 Organizational learning effects

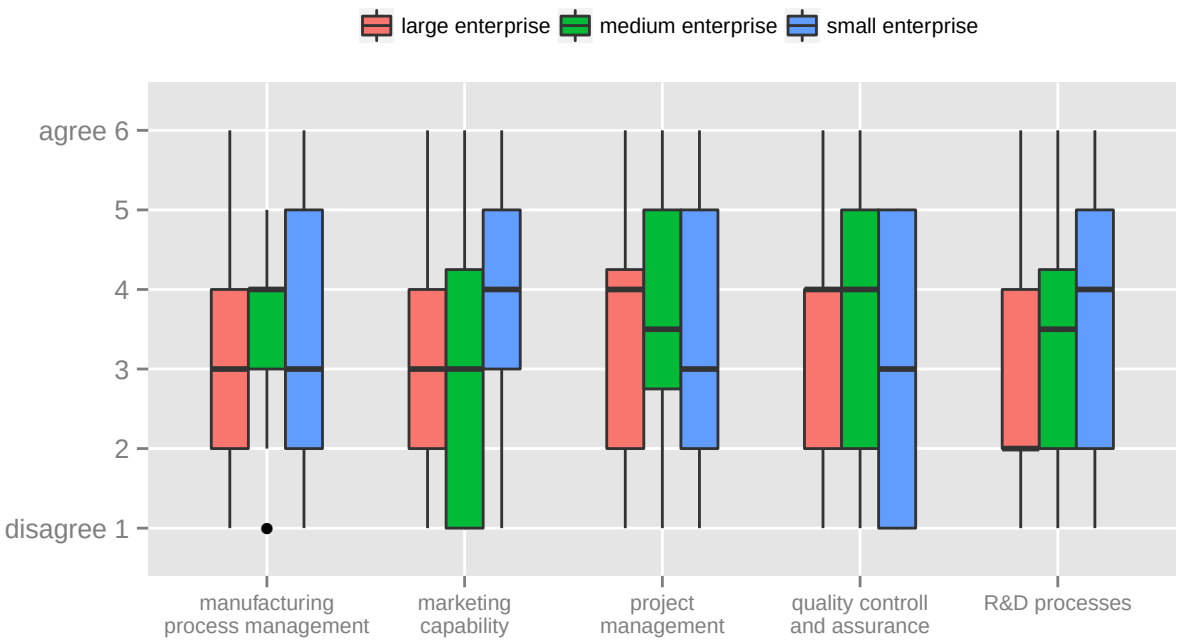
While basic research has unique technological demands and therefore can possibly offer unique technological learning opportunities, its organizational learning effects will be different in principle than those triggered by other customers. Nevertheless, every complex technological innovation needs a supporting organizational structure and capacity which has to be able to be improved and to adapt to new circumstances.

Fig. 3.11a shows the responds of the survey participants on organizational learning effects due to their XFEL project participation. While the majority of participants reported reasonable learning effects for all given organizational aspects, they are very similar in their average and without striking differences in distribution. Noteworthy is the difference between marketing capability and R&D processes on the lower end of the scale: 22 companies regarded their learning in R&D processes as not or only minimally important, while only 13 companies used this rating for their learning effects in marketing capability. This is in accordance with the fact that being strong in R&D appears to be a precondition to be among the suppliers for technologically demanding and / or custom developed supplies. On the other side, marketing capabilities where triggered in two ways: Companies which are new to the market of public science had to adjust to this market. And, as will be shown in section 3.3.3 (p. 51), companies who successfully cooperate with a project like the European XFEL gain experience with the scientific community as well as a valuable reference customer.

Fig. 3.11b reveals that this difference can be explained by significant differences in the distribution of answers by small and large enterprises. For both organizational aspects, small companies (which are the majority among the participants) gave higher ratings than large companies. In case of marketing capability, 50 % of the ratings around the median by small companies are between 3 and 5 on the scale, while the same quartile for large companies ranges from 2 to 4. For R&D processes, the median for large companies is located at 2 on the scale, causing the large total number of ratings on the lower end. For all aspects, the top quartile of small companies goes from 6 to 5, while the same quartile for large companies mostly goes from 6 to 4. This can be interpreted as a general tendency towards larger organizational learning effects for small companies, which would be in line with statements by scientists who accentuated the higher organizational flexibility of small companies.



a) Overview on organizational learning effects



b) Organizational learning effects, differentiated by company size

Figure 3.11: Organizational learning effects

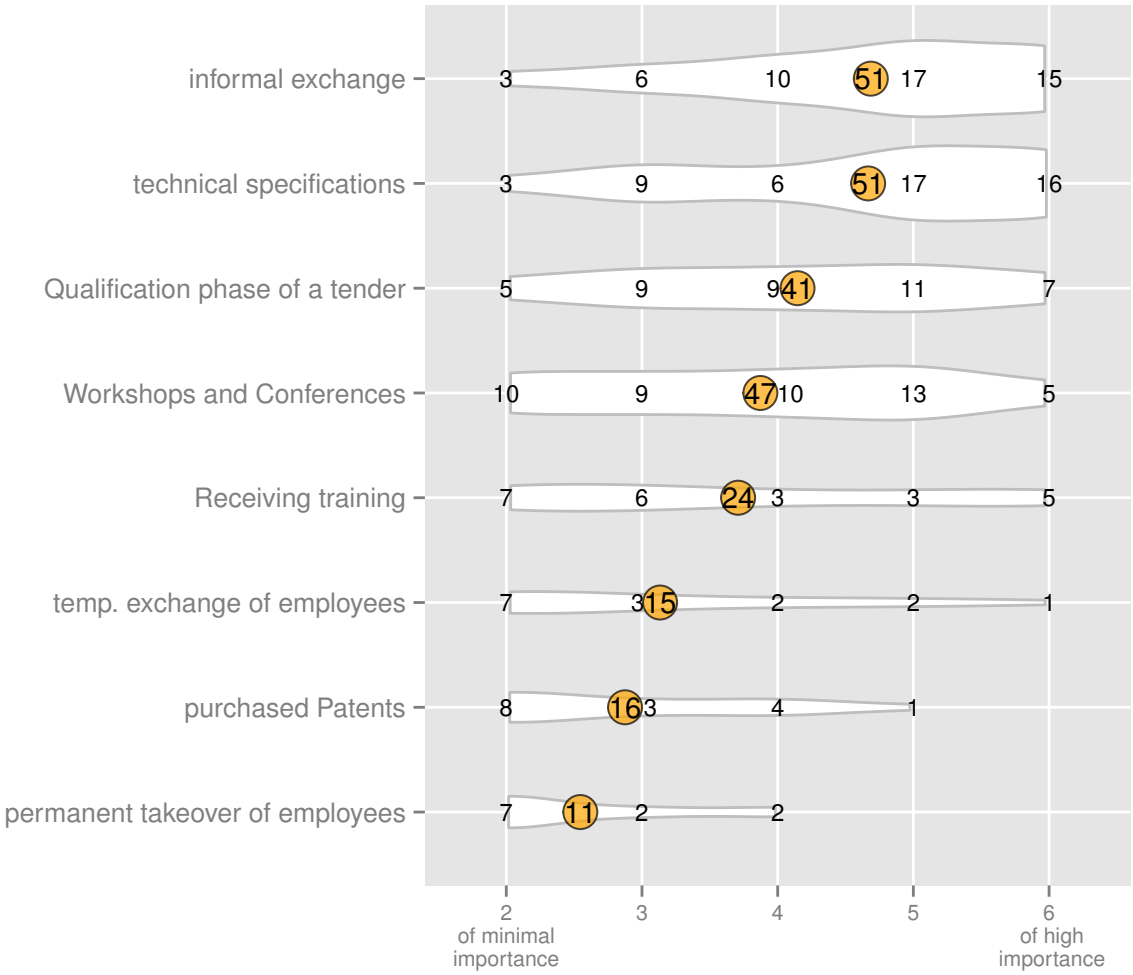
3.3.3 Path, form and type of knowledge transfer

Which types of interaction supported the learning effects shown in the last two sections? As shown in Fig. 3.12a, most important where the informal exchange during cooperation and the exchange of codified technical specifications. The high ratings for informal exchange have to be highlighted, because an important advantage of science-industry cooperation is their differing assessment of technology: In the public basic science context, technology is a necessary means for producing new knowledge, while in the industrial context, both knowledge and technology are assets deserving protection from competitors. Exchange is much eased if one side lack this need of protection. As fig. 3.2 (p. 36) showed, most participants are delivering custom developments, therefore this informal exchange includes not only transfer of technological knowledge but also learning stimulus in form of cooperative problem-solving and development. Part of this more open communication culture typical for public research are workshops and conferences on their scientific goals and technological needs, which were a highly anticipated platform for exchange. One participant reported that exchange was hindered because one of his own suppliers required non-disclosure agreements which were in conflict with the more open exchange with their scientific partners.

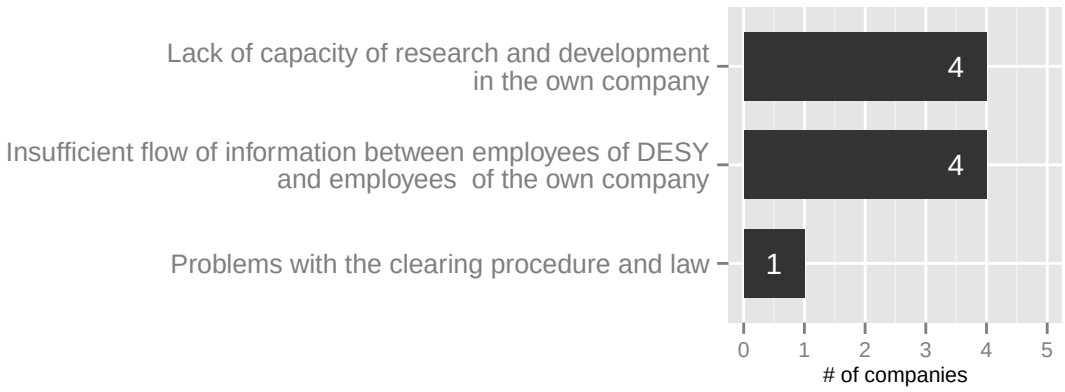
Another important exchange path of publicly funded science is the qualification phase of a tender: Being bound to public purchasing law, larger supplies have to be invited as tenders. These come twofold: In case of tenders for the production of supplies which have been developed at DESY / European XFEL GmbH, the qualification phase of the tender includes intense technology transfer including training and exchange of personnel. For crucial elements like the accelerator cavities, multiple suppliers are trained to avoid dependence on self-created monopolies. In contrast, the qualification phase of tenders for supplies to be developed at the companies strictly prohibits exchange between the research institute and the companies. One participant reported that in his view, this regulation causes unnecessary and redundant development work.

Fig. 3.12a also confirms the mobility of trained scientists as either a path of knowledge transfer or a source for absorptive capacity for companies by hiring scientists formerly employed in basic research.[18] Fig. 3.12b shows complementary that at 4 suppliers, a lack of R&D capacity was complicating the exchange, which is in line with Cohen and Levinthal (1990) who describe internal R&D as a central factor for a company's absorptive capacity.[19]

[18] Zellner 2003, p. 1893; Salter and Martin 2001, pp. 521, 528.
[19] Cohen and Levinthal 1990, p. 128.



a) Paths of exchange



b) occurred impediments for exchange

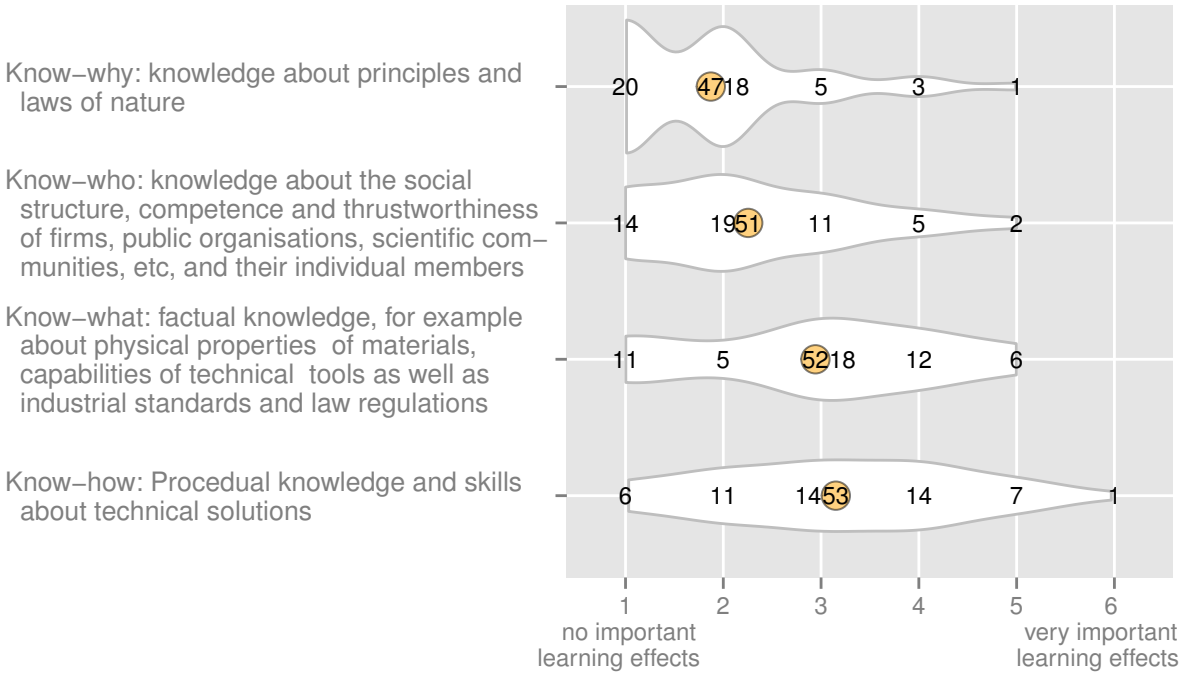
Figure 3.12: Paths of transfer and stimulus between the European XFEL project and its suppliers.

Since the emergence of "the knowledge-based economy"[20] as a theoretical concept for innovation processes and their economic value, a vast body of literature has dealt with the economic effects of knowledge. In view of knowledge transfer as an externality of basic research and a form of technological stimulus, this survey utilized the works by Carud (1997) and Lam (2000) and asked for the types of new knowledge[21] and the form in which it has been stored at the companies (see fig. 3.13a).[22] These two questions were newly developed for this questionnaire.

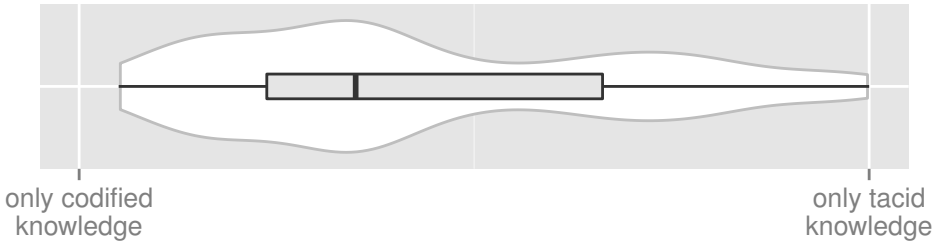
Fig. 3.13a) shows that beside of the expected importance of know-how and know-what, also learning effects on social and purely scientific knowledge was for some companies of importance. Due to two observations in personal contacts to participants, the informative value of these answers is limited: Firstly, a recurrent reaction to this question was that the participant did not feel competent to answer this question for his company. In some, but not all in cases, the questionnaire or parts of it where given to another organizational level. The fact that most companies where approached via technical staff named by DESY and European XFEL GmbH personnel, knowledge types like social knowledge which is of greater importance for sales and the managerial level can be underrepresented. Secondly, in one case, a longer discussion on the meaning of "know-who" revealed that the most important learning effects actually occurred here, in form of a better understanding of the cultural characteristics of a foreign partner company. If this is not a singular case, the description of the question was too short and learning effects on social, cultural and organizational characteristics were of greater importance than reported in the questionnaire. Additionally, for this more abstract type of question, interviews are more suitable than questionnaires.

Fig. 3.13b displays the answers on the question whether learning effects resulted in new tacit or codified knowledge. This question passed the pretest and got positive remarks for using a drawbar, but the final dataset includes hints that a certain group of unknown size understood the scale differently than intended, resulting in inverted answers. As a consequence, the shown distribution can *not* securely tell which the major form of knowledge was, but it *can* tell us that knew knowledge was most of the time stored in both forms, and there are companies for both forms of knowledge reporting it to be mainly used.

[20] Foray and Lundvall 1996.
[21] Carud 1997.
[22] Lam 2000, p. 490.



a) types of knowledge which have been stimulated at the companies



b) forms of knowledge in which new knowledge gained during the XFEL project cooperation has been stored.

Figure 3.13: Form and types of knowledge

In view of the stimulus and transfer of technology, the distinction between tacit and codified knowledge gains importance due to the following considerations: Firstly, the transfer of some types of tacit knowledge, especially know-how and know-who is sometimes more easily or even necessarily transferred in personal contact, without codification as an intermediate step. An example here is clean room behavior needed for production and assembly of accelerator cavities and modules. And inter-cultural or inter-organizational cooperation profits strongly from mutual social knowledge gained through personal contact. Secondly, tacid knowledge appears more suitable as a stimulus for development, because it is stored in the active elements of an organization, it does not need to be looked up and therefore is more easily used for other applications.

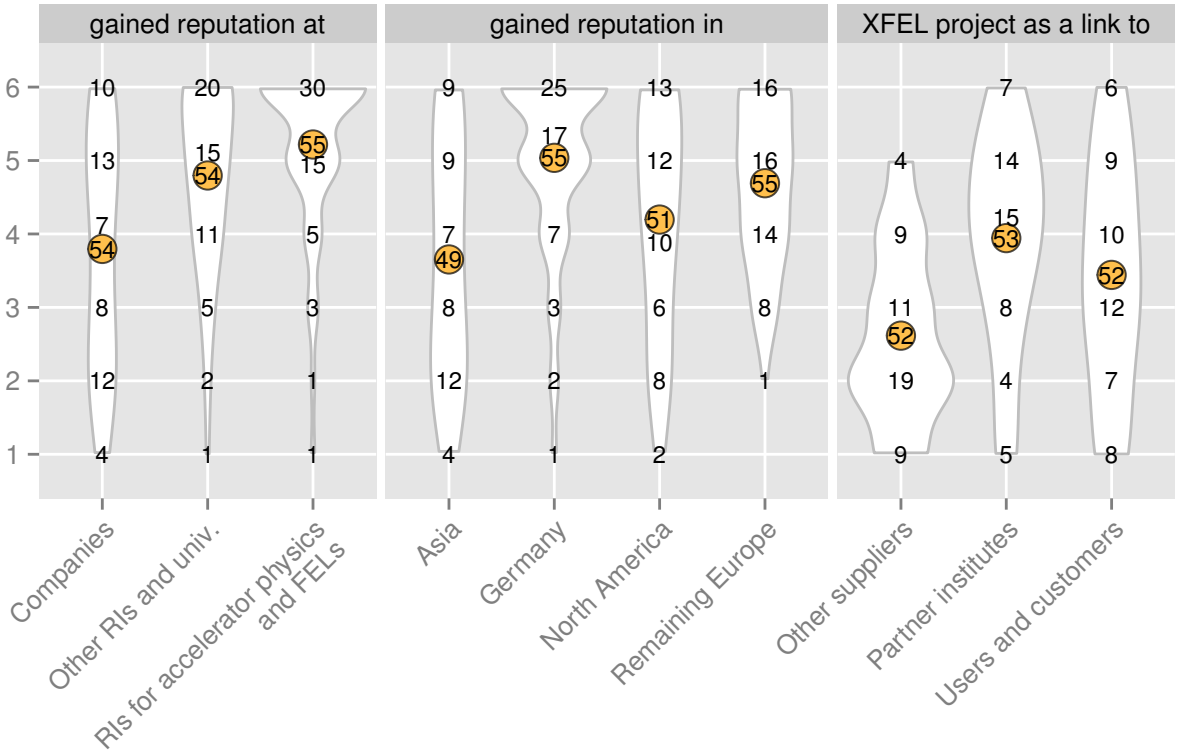


Figure 3.14: Reputation and new contacts as positive effects for suppliers. 1 = of no importance; 6 = of high importance.

3.3.4 Network effects

As fig. 3.14 shows, network effects play an important role for the suppliers: Since large research facilities and their scientific communities are internationally and personally interlinked, suppliers can profit in three ways: Firstly, they can more easily learn about other scientific projects with similar technological needs and gain knowledge on the market for scientific supplies. Secondly, if they fulfill the high demands on quality and performance which are usual for scientific applications, they gain an important reference customer, and expect that this reputation possibly spreads in the scientific community. While it is no surprise that this reputation effect is especially strong in the scientific community and in Europe, it should be pointed out that for several participants, these reputation effects were also important for dealing with other companies and in relations to Asia and North America. Thirdly, the role as a supplier for academic research incorporates incentives to participate in scientific networks and social events like conferences and therefore connects industrial and scientific networks. As thoroughly analyzed by Salter and Martin (2001),[23] this effect fosters the mutual enrichment through shared instrumentation described by De Solla Price (1984).

[23]Salter and Martin 2001, p. 523.

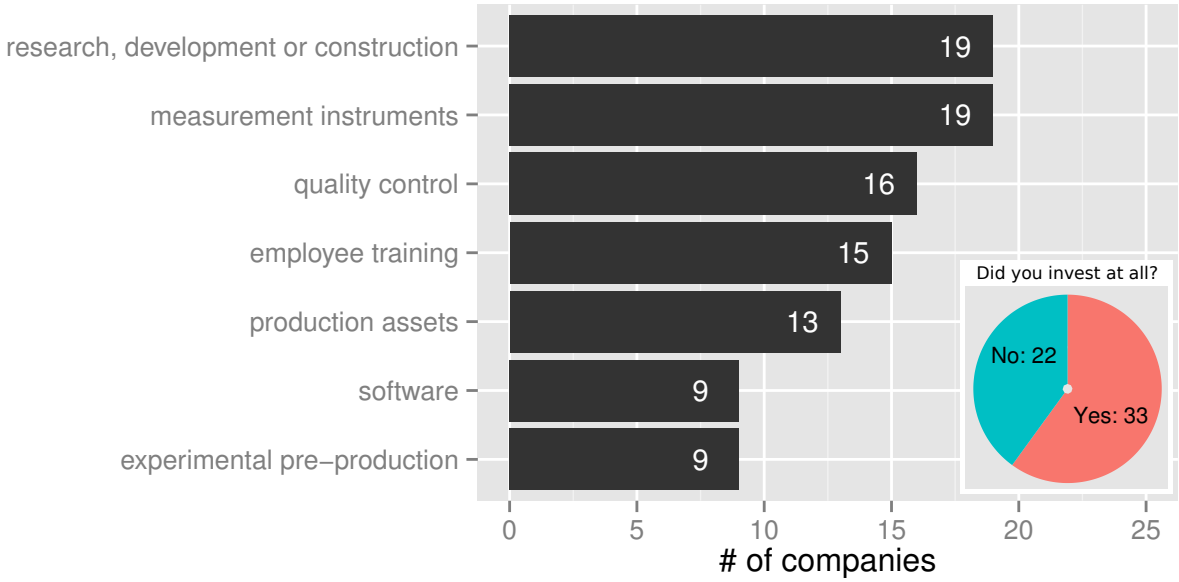
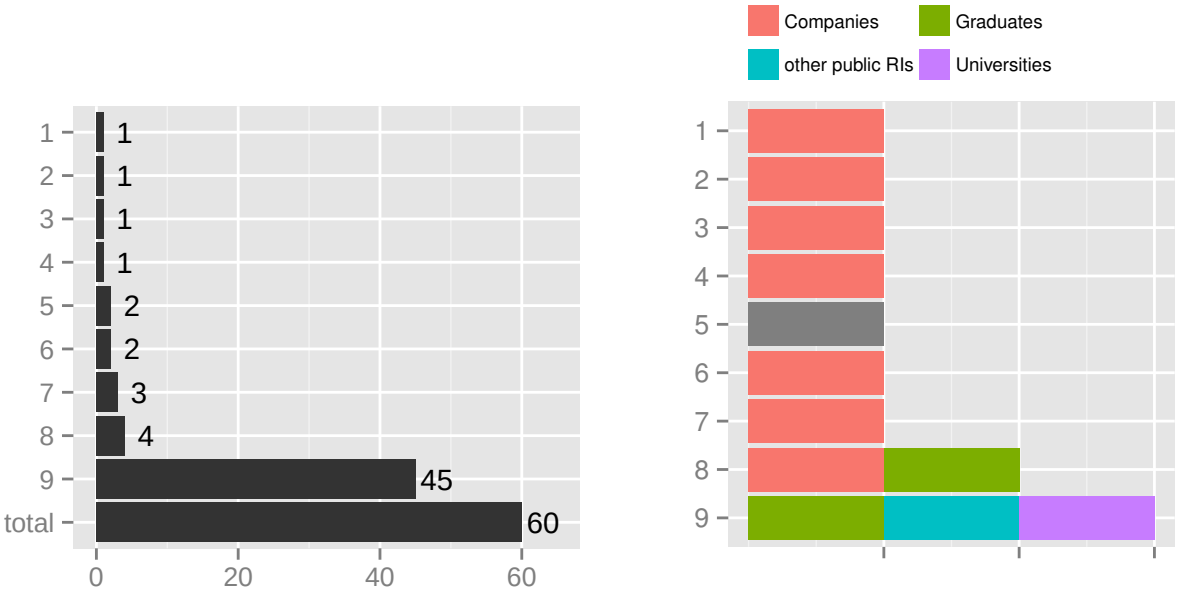


Figure 3.15

3.3.5 Investment effects

The investment effects shown in fig. 3.15 indicate that the learning effects described in the previous sections are accompanied by more "physical" impacts such as new equipment and facilities as well as intentional and specific staff training. The high ratings for measurement instruments and quality control indicate that the high demands on precision and quality are new for several companies and need specific investments to be reached. Just as new knowledge, these investments are not only applicable for science-only applications, but present another indirect path of science-industry exchange and influence. All in all, 60% of the companies did new investments due to their XFEL-project contribution.

Entries from the open input field on the questionnaires mention investments in cleaning equipment, document management systems, extended production facilities, exhibitions as well as certification under the standard DIN EN ISO 3834-2 for wielding quality. Exhibitions being mentioned as investments indicate that public relations and network participation would be a good additional investment category for the questionnaire. The mentioned standardization is a good example for investments in quality control.



a) Amount of new employees due to XFEL-project contribution, reported by 9 companies.

b) Sources of new employees named by the participants.

Figure 3.16: Employment effects

3.3.6 Employment effects

Beside of learning and investment effects, the procurement activities for the European XFEL project also have an impact on the employment structure of its suppliers: Fig. 3.16a shows that among the participants, 9 companies reported a total of 60 new jobs. The majority of 45 new employees became necessary at a producer for accelerator cavities, while the other 8 companies for example supply cryogenic equipment, power supplies, undulators, waveguides, monochromators and cables.

Fig. 3.16b shows that the majority of 7 participants named other companies as the source of these new employees, while for the cavity-producer, public research and education was the most important source of employees. No company did report hiring of staff formerly employed at DESY or the European XFEL GmbH, but the personal interviews which accompanied the questionnaire distribution revealed that there exist cases in which there is at least an interest to do so. Additionally, fig. 3.12a on page 49 showed that 11 companies mentioned the permanent takeover of staff as a source of technology transfer. Possible explanations for this discrepancy are a reservation or reluctance in dealing with this topic, which is in the focus of fig.3.16b but only a secondary aspect of fig. 3.12a.

3.3.7 Summary

A central hypothesis for this thesis was the assumption that due to the differing motivations and technological needs in basic research and its infrastructure, knowledge spillovers can occur between science and industry and present an external effect of public spending for science on industrial suppliers. The survey performed for this thesis led to the following observations:

- For 12 fields of technology, the 55 participants reported 32 "very important" achieved innovations as part of their XFEL project participation. For 15 fields (including the previous 12), they reported 154 reasonable, but less important innovations.
- These technological learning effects were accompanied by organizational learning effects: For every given type of learning effect such as marketing capability, quality control of R&D processes, more than 20 participants reported positive learning effects.
- These learning effects occurred through informal exchange and the transfer of codified technical specifications. These often happened through channels which are rather specific for public science, such as workshops and conferences or qualification phases of tenders. "traditional" exchange via patent exchange played a minor role.
- beside of achieving procedural and factual knowledge as done by the majority of participants, a minority of companies also reported important learning effects on social knowledge or abstract scientific knowledge.
- Most suppliers gained an important reference customer with positive international reputation affects, mostly among other public research facilities but also with importance for industrial customers. For several participants, DESY or the European XFEL GmbH serve as a link to other members of scientific networks.
- for 60% of the participants, the XFEL project participation included investments in assets needed for production, research and quality as well precision improvements.
- the participants reported 60 jobs created due to the procurement activity. Most of them (45) occurred at a supplier for accelerator cavities.

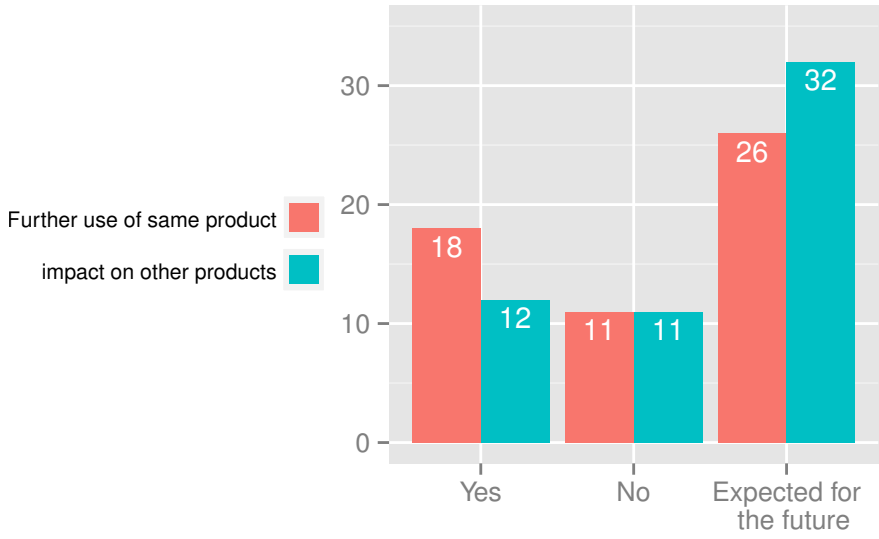


Figure 3.17

3.4 How are these learning effects put into use by the companies?

While the previous chapter section was focused on direct learning effects, this chapter focuses on the question which further impact these learning effects can have for the suppliers. The survey participants were asked whether they could find more customers for products which were initially developed for the XFEL project, or whether the knowledge gained during these contracts could be put into further use and influence existing products or initiate the developments of new products, as shown in figure 3.17.

This aspect of the questionnaire relates to a larger and representative survey by Beise and Stahl (1999): They found that " ... *less than one-tenth of product- or process-innovating firms introduced innovations between 1993 and 1995 that would not have been developed without public research.*"[24] These new products amount to approximately 5% of all new product sales. Universities were reported as the most important source, while big science laboratories were almost invisible.[25]

While not being as representative as Beise and Stahl (ibid.), this survey and its predecessors take a closer and more qualitative look on this almost invisible aspect of big science laboratories. Additionally, the question arises if a direct impact on commercial product development is covered by point 3 of Salter and Martins' list (new instrumentation) or whether it is worth a minor extension of their list.

[24] Beise and Stahl 1999, p. 397.
[25] Ibid.

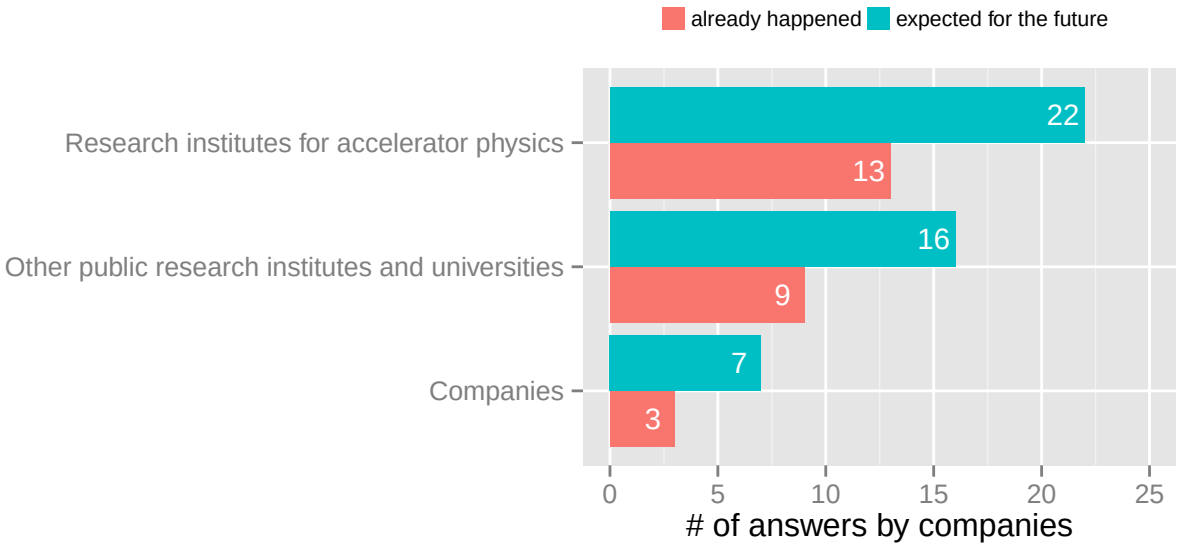


Figure 3.18: Further use of products developed according to the XFEL requirements

3.4.1 Further use of specific products

Most supplies of the survey participants were custom developed or produced for the European XFEL project. But as shown in fig. 3.18, in many cases they can also be of interest for other customers. Due to the ongoing state of development of the XFEL facility and its components, it was differentiated between already found new users of these products and the expectations for the future. Not surprisingly, there have already been several more applications found in the research community. But of more interest for this thesis are the actual and possible applications of initially science-specific supplies among commercial customers. These cases present direct technological spillover-effects between the scientific and the commercial sector.

Fig. 3.19 shows the developments for which the suppliers already found or expect further customers among commercial users. Electroplating and laser technology represent two technological fields were the European XFEL project required surface treatment processes and performance of laser systems which were not available or achieved before. In case of the RF systems used for the accelerator, the innovations were more incremental, but the needed industrial production for the 2km long accelerator helps the producer to shift his production and price level towards a more affordable level. MTCA.4 as a sub-standard for computer hardware, initialized by DESY-scientists has many potential industrial applications, while its commercialization receives concerted promotion.[26]

[26] A detailed analysis of MTCA.4 and its commercialization process can be found in Neumann (2013)

already happened

technology	specific example	possible markets
automation and control	drive technology	industrial automation
surface treatment	electroplating	vacuum technology
X-Ray instrumentation	radiation sensors	(no specific industry mentioned)

expected for the future

technology	specific example	possible further applications
laser	improved Pockels cells and BBO crystal packaging	general users of Pockels cells
electronics	electromagnetics for nano-particle orientation	nanomaterials
MTCA.4	medical imaging	medical
	medical surgeon systems, high speed data processing	medical
	machine control	industrial automation
	high speed pattern recognition	safety applications
	power supplies	telecommunication
RF engineering	production innovations for increased capacity and reduced costs caused by the large volumes of items purchased for the XFEL.	
	new pressure/vacuum window design approach will be scaled up and down for other frequencies.	science, military and industrial heating.
surface treatment	electroplating of further materials like aluminium alloys, copper or Inconel-materials.	optics, semiconductor industry, vacuum technology, Aerospace and special purpose machinery manufacture.

Figure 3.19: Further use of products developed for the European XFEL

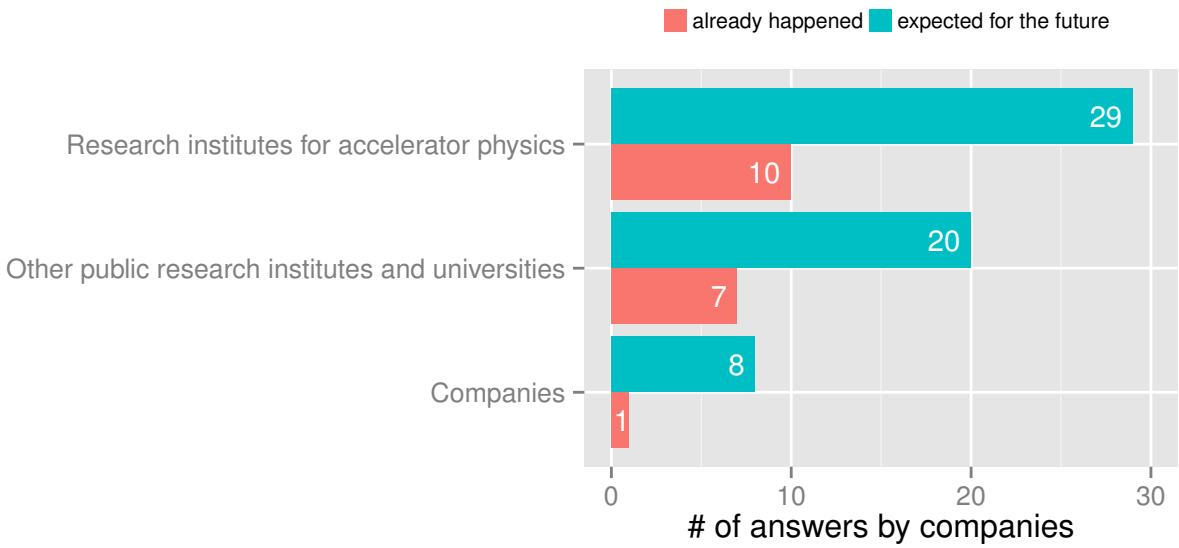


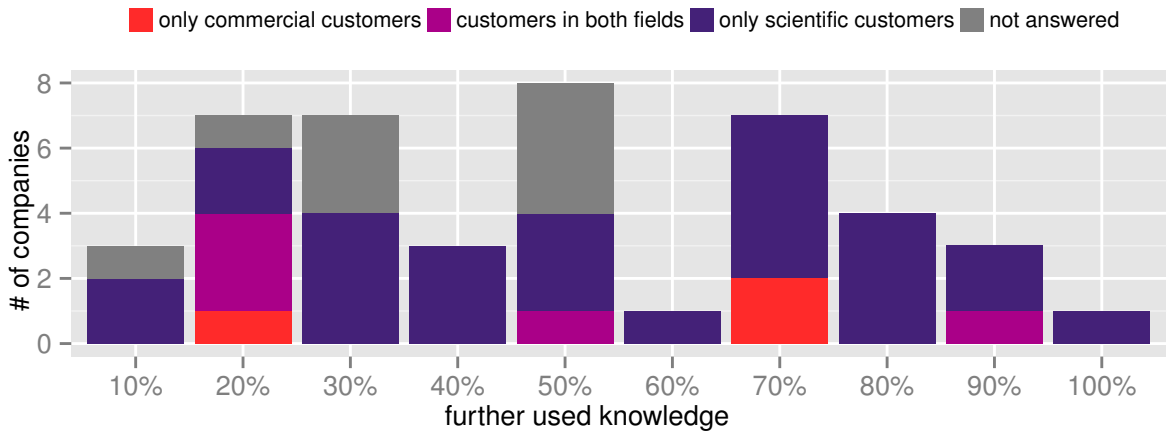
Figure 3.20

3.4.2 Improved or newly developed products

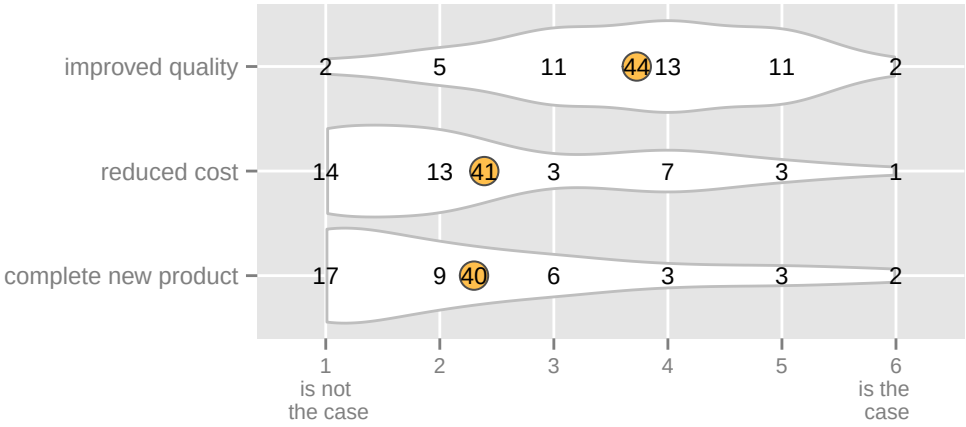
As shown in fig. 3.20, the learning effects during the development of elements for the European XFEL had also an impact on the further product portfolio of the suppliers. As in the previous section, the developments and learning effects of the procurement activity for the XFEL can easily flow into further scientific applications. This comprises most accelerator-related technologies like cryogenics, RF systems, power couplers, niobium metallurgy and surface treatment, control systems, et cetera.

The cases in which the participants also reported an expected impact on their products for the commercial sector present good examples of technological stimulus, which can occur here in two senses: Firstly, as in the case of the previous section, companies have been stimulated to either adapt to, or directly develop technology according to the special demands of scientific research. Secondly, they were stimulated to put newly acquired knowledge and skills into further use for changing existing products or develop entirely new ones. This aspect exceeds last sections' aspect of transferring XFEL-related products into new markets. A more detailed description of the extend and the effects of further used knowledge is given in the following figures:

Fig. 3.21a shows the amount of knowledge learned during the XFEL project participation which can be used for other or new products and services. Important



a) Percentage of knowledge gained due to contributing to the XFEL project and further used for other products and services.



b) Effects of XFEL-related experience on other and new products

Figure 3.21

here is the fact that the full scale was used by the participants, indicating that in principal, knowledge spillovers can be quite substantial for some suppliers. This tendency even can be found for those suppliers who reported spillover effects into commercial sectors. Half of these reported rates of reusing knowledge of 50 % or more. As presented in fig. 3.21b, the dominating effect on other products is the improvement of their quality, while a minority of suppliers also reported significant cost reductions or the development of completely new products. This is in line with the reported organizational learning effects and investments into quality control and assurance.[27]

Fig. 3.22 summarizes the participants' case-specific expectations about the impact of their XFEL-related learning effects on their product portfolio.

[27] see fig. 3.16b on p. 54 and fig. 3.11b on p. 47

Technology	Example	Possible further applications
MTCA.4	Remote management tools for embedded computers	Telecom and control applications
	FPGAs on MTCA -boards	Computer vision and medial imaging
	MTCA.4 digitizers	VME-digitizers, homeland security, spectroscopy
RF engineering	Harmonic filter design	Will be scaled for other industries
	RF amplifiers	Magnetic resonance imaging, Radar systems
Magnetics	Permanent magnets with high homogenity	Special electric motors
	Spontaneous radiation appertures	Nano-mechanical movements
Precision engineering	Precise production techniques needed for undulators	E.g. off shore industry
Electric engineering	Phase stable cable assemblies	Test & measurement sectors
Cleaning	Particle-free cleaning of components	General users of vacuum systems
Software	Firmware for scientific control systems	Medical, non-destructice testing, radar and radio technologies,image processing

Figure 3.22: Expected impact of learning effects on other, existing or future products.

3.5 Summary

The general motivation of the survey was to find what supplying companies gain from their XFEL project participation beside of monetary revenue and thereby identify further socioeconomic impacts, especially knowledge spillovers and learning effects as possible externalities. Due to the explorative and qualitative motivation, it was of interest *if* and *how* possible spillovers occur, while a more representative and quantitative evaluation of their amount and value was not part of the research question. In consequence, only suppliers of custom developed or produced products were selected as participants to create a sample were the occurrence of such spillovers is most likely.

Section 3.2 revealed that this sample mainly consists of SMEs with multiple national backgrounds, while the funding structure of the XFEL project shows strong impact on the national shares of contributing companies. The majority of participants was not only contracted for production, but also for the development of supplies. These companies show strong capacities in R&D and anticipate the unique technological environment presented by large research infrastructures, while smaller companies regard this relation as more important than larger companies.

Section 3.3 described the various impacts of this science-industry relation for the commercial side: 32 "very important" and 154 reasonable technological innovations were reported, mostly equally triggered by codified and informal exchange and interaction, accompanied by a fair amount of organizational learning effects and investments at 60% of the companies. Investments and learning effects especially affected scaling of production as well as quality control and assurance. a minority of companies reported new employees. Of rather high importance is the gained reputation, especially in the scientific community but also in the commercial sector. of these socioeconomic impacts, most technological learning effects and the impact on general quality capabilities can be regarded as typical, partly unique effects of scientific RIs on commercial suppliers.

Section 3.4 concluded that these learning effects can be put to further use: Half of the participants expect, and about a quarter of companies already did find new applications and customers for their XFEL-related developments. This transfer is most easily possibly for the further market of scientific research, but also occurs for commercial sectors and includes both further applications of products developed for the XFEL project as well as the influence or initiation of changes of other existing products or the development of completely new products.

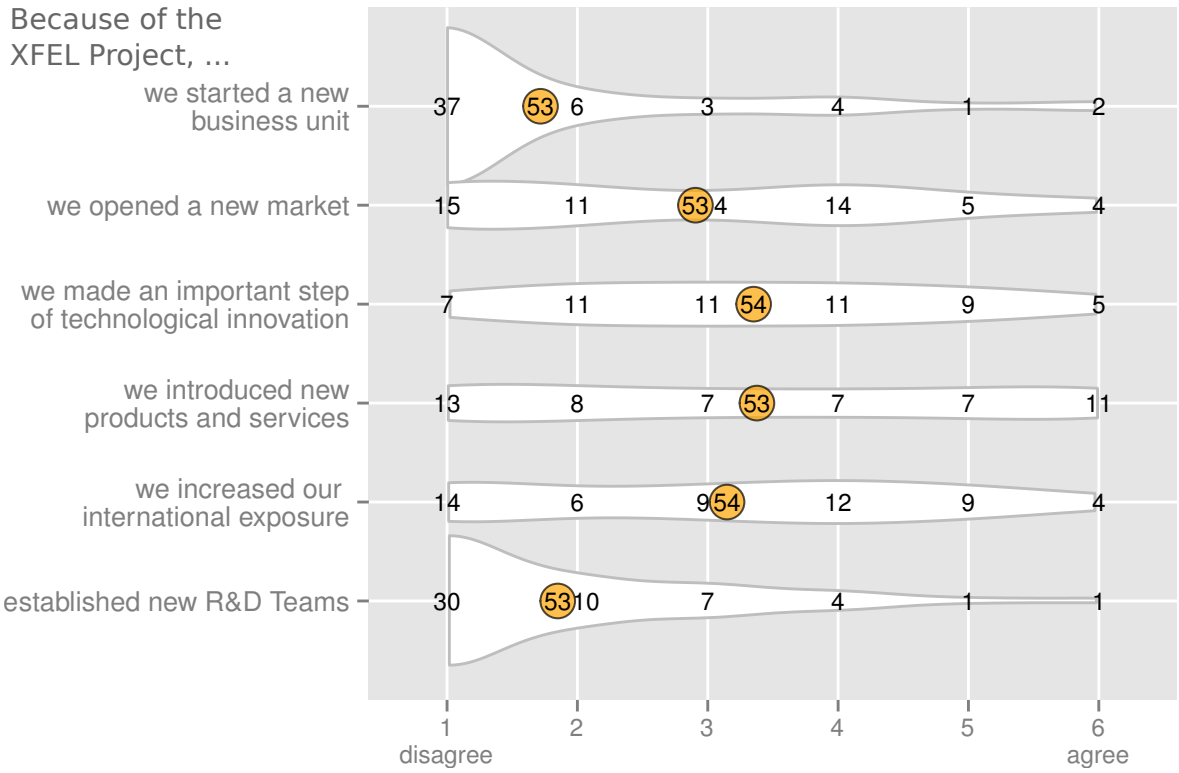


Figure 3.23

As shown in fig. 3.23, the participants were asked about the mid- or long-term effects of their contribution to the XFEL project. Their answers give a good first-hand summary of the topics of the previous sections and the reactions of the companies to the stimulus which came in form of the special requirements of the XFEL project: The technological learning effects described in section 3.3 result in important steps of technological innovation and comparably high ratings on the introduction of new products and services as described in section 3.4. The importance of network and reputation effects resulted in the high ratings for access to new markets and international exposure. The establishment of new business units or R&D teams present important organizational changes, especially for SMEs who are the majority in the sample. In consequence, the low ratings for newly established R&D teams should not be a surprise. In fact, it should be emphasized that for a small number of companies, the general impact of their XFEL contribution was large enough to trigger organizational changes of this size.

Additionally, fig. 3.23 can serve as a good illustration of the concept of technological (and organizational) stimulus, which covers significantly more than technology transfer.

4 Conclusion

This thesis started with the question for (economic) reasons and motives for public funding of basic science and its infrastructure. Chapter 2 elaborated on the market failure and system failure arguments as economic narratives underlying recent research policy. Both arguments emphasize the positive economic effects of basic research on technological change and economic performance, which have been thoroughly listed by Salter and Martin (2001). Chapter 3 then focused on the economic effects of the construction of large research infrastructure. This aspect received rather little attention in the literature before, although it presents the maybe closest interaction phase between science and industry. The analysis revealed that this phase can incorporate significant innovation and network effects as well as minor investment and employment effects. Additionally, most technological innovation effects are better understood as results of the *stimulus* of technology, which can incorporate but also exceeds the traditional concept of technology *transfer*. These results at least qualitatively correspond to the political expectations on the economic impact, as formulated by European authorities, [1] but due to the explorative research design, they do not represent a self-contained justification for evidence-based policies or funding decisions. Rather, they have to be interpreted in the context of further empirical findings like those of Salter and Martin (ibid.) and can trigger and support further theoretical considerations on the science-industry relation and its political framework. In consequence, this thesis will conclude by comparing the findings of this survey with those of Salter and Martin, put them into the context of the market failure and system failure arguments and elaborate on the meaning of technology stimulus. Finally, further research questions will be formulated focusing on the role of differing incentive structures and motives among interlinked parts of large-scale innovation systems.

[1] See p. 27

4.1 Extension to Salter and Martins' list

The meta-analysis by Salter and Martin (2001) listed the following economic benefits of publicly funded basic research:

1. useful knowledge
2. training graduates
3. instrumentation and methodologies
4. networks and interaction
5. problem-solving capacity
6. new firms

In contrast to Salter and Martin, my survey focuses on a very narrow aspect of public basic research. Now it is of interest how far this aspect corresponds to their findings: The innovation and network effects as the strongest economic impact described in chapter 3 correspond to element 1 and 4 of this list. Some innovations in surface treatment, control instrumentation or laser technology possibly correspond to element 3. Companies who reported high organizational learning effects, especially in their R&D capacity, obviously increased their problem solving capacity, in correspondence to element 5. Training graduates as an effect was not directly covered by this survey. The only hint are the low findings on graduates as new employees among the suppliers (see p. 54). The creation of new firms was also not directly covered, but one participant filled out the survey for two companies: his old employer and his own company, which was not directly founded due to the XFEL project, but received a major boost. Additionally, there are people among the personnel of DESY / the European XFEL GmbH who are interested in founding a spin off. In consequence. Thus, this survey shows minor signs that the elements 2 and 6 exist in principle.

On the other side, this survey (and its predecessors) focus on an economic benefit of publicly funded basic research which seems not to be covered by Salter and Martin. This benefit can be formulated as a 7th element on their list:

7. direct impact on commercial product development and availability.

Salter and Martin describe basic science as an important source of instruments and methodologies for the *production* of commercial products,[2] but they do not cover basic science as a potential source (or inspiration) of the products. This effect most easily occurs in cases like the construction of large basic infrastructure, in which the size of the project makes commercial partners for technology development and

[2]Salter and Martin 2001, p. 522.

industrial production processes unavoidable. This situation allows developments for basic science to be much easier passed on to commercial markets than in cases where basic science only provides basic principles and proofs of concept which need further refinement and the development of production methods which then allow marketable price levels. This impact has been described in section 3.4 based on the European XFEL. Autio, Hameri, et al. (2004) provide a more fine-grained theoretical framework, derived from three selected case studies on industrial suppliers of CERN's LHC. Their results are similar to Salter and Martin (2001) but are more detailed differentiation on technological and social learning opportunities.[3] They identify the following direct product development impacts for industrial partners:[4]

- Big-science can act as an important first customer for emerging technologies
- Big-science can be leveraged in all phase of the innovation trajectory
- Big-science centers can be leveraged for advancing development projects
- Big-science projects may not always be financially lucrative, but technological learning benefits may outweigh financial ones

The generality of this findings is constrained by its small sample and context,[5] but they support the view that Salter and Martin's list is not complete in this regard. In correspondence, Autio, Hameri, et al. (ibid.) points out that this aspect is rather underrepresented in the literature and needs further empirical support.[6] The results of this thesis confirm the findings by Autio, Hameri, et al. (ibid.) for the context of the European XFEL, and singular examples like the development of the MTCA.4 standard may give reason to regard big science centers also as active developers of emerging technologies, but this point needs a deeper analysis of the history and development processes of specific technology. Neither this thesis nor Autio, Hameri, et al. (ibid.) can judge on the efficiency or quantity of this 7th element. But the growing international cooperation on large research infrastructure which came along the end of the cold war and the further integration of the EU implicates that this impact is a growing one.

[3] Autio, Hameri, et al. 2004, p. 119 - 122.
[4] Ibid., p. 122.
[5] Ibid., p. 124.
[6] Ibid.

4.2 Stimulus of technology as an underrepresented concept

The results of my survey indicated that most learning effects among industrial suppliers were not the results of knowledge and technology transferred from science to industry. Much more, they resulted from new technological needs and problems which occur in science but are shared with or outsourced to industrial partners, were they presented fruitful and sometimes unique learning opportunities. With its own technological expertise and experience with highly complex projects and machines, large research centers can uniquely improve this learning opportunity by reducing the uncertainty and complexity of the shared tasks.[7] Moreover, the long-term and fixed objectives of big science centers in combination with their financial resources can reduce the risk inherent in innovation investments.[8] This is especially true for smaller, more specialized companies with less opportunities for cross financing.

In the introduction to chapter 3.3, this situation was conceptualized as technology stimulus, which can incorporate, but exceed the more common idea of technology transfer. At the core of technology stimulus is the transfer not of technology, but of technological needs accompanied by helpful (pre)technological as well as social knowledge which supports and enables further technological development. This highlights the importance of technology stimulus as a concept: Technology transfer in form of patents as well as job creation and turnover as indicators for financial input-output analysis are measured rather easily. But they tend to miss knowledge as an essential economic asset and as the central aim of basic science. Technological stimulus can be a helpful heuristic tool to capture the less measurable but not less important effects of basic public science on innovation and economic performance:

> "The total economic benefit resulting from such learning may greatly outweigh the monetary value of a given supplier project. In short, we believe that it is not only the financial figures that matter—in the long run, technological learning outcomes may turn out to be even more important."[9]

Beside of this comparable thought by Autio, Hameri, et al. (ibid.), the idea of technology stimulus is rather underrepresented in the literature, Very likely because it is closely connected to the equally underrepresented study of procurement activities of large RI's and its impact on industry. It is only during procurement and construction that industry gets that close to the technological infrastructure of science and

[7] Ibid., p. 121.
[8] Ibid.
[9] Ibid.

its needs and problems. For the actual time of operation of RI's, this unique relation does not exist. In this phase, elaborated and established concepts like technology transfer, training and mobility of employees suffice to capture the influence of science on industry. In correspondence, traditional activities of technology transfer offices like licensing and PR, spin-off support for employees and arrangements like technology parks gain importance again.

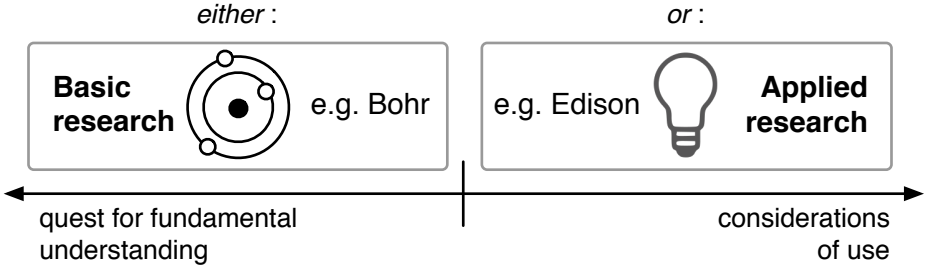


Figure 4.1: Post-war paradigm on basic and applied science

Implications for research policy analysis

The idea of technology stimulus bears consequences for concepts about the general orientation of research policy. The post-war paradigm by Bush (1945) strictly separated basic from applied research (see fig. 4.1). But following a linear model of innovation, basic science was acknowledged as a necessary source for further applied research and product development. During the cold war era, basic research was also a unique source of military advantages and a symbol of cultural supremacy. Thus, these effects of basic research created the justification for basic research funding after WWII.[10] This post-war compact for basic science between science and society was abolished after the cold war, when the integration of the world markets allowed countries to profit economically from other countries basic research proceedings without the need for own funding of comparable size.[11] Additionally, scientific progress lost its symbolic importance after a period of ideological competition.

Stokes (1997) tried to strengthen the case for basic science by showing that the relation of curiosity-driven basic research and applied research is not mutually exclusive and opposed to each other but complementary. Stokes' symbolic example for such research is the work by Pasteur, who equally improved basic understanding of microbiology as well as industrial processing for food safety. In conse-

[10]Stokes 1997, p. 90.
[11]Ibid., p. 93.

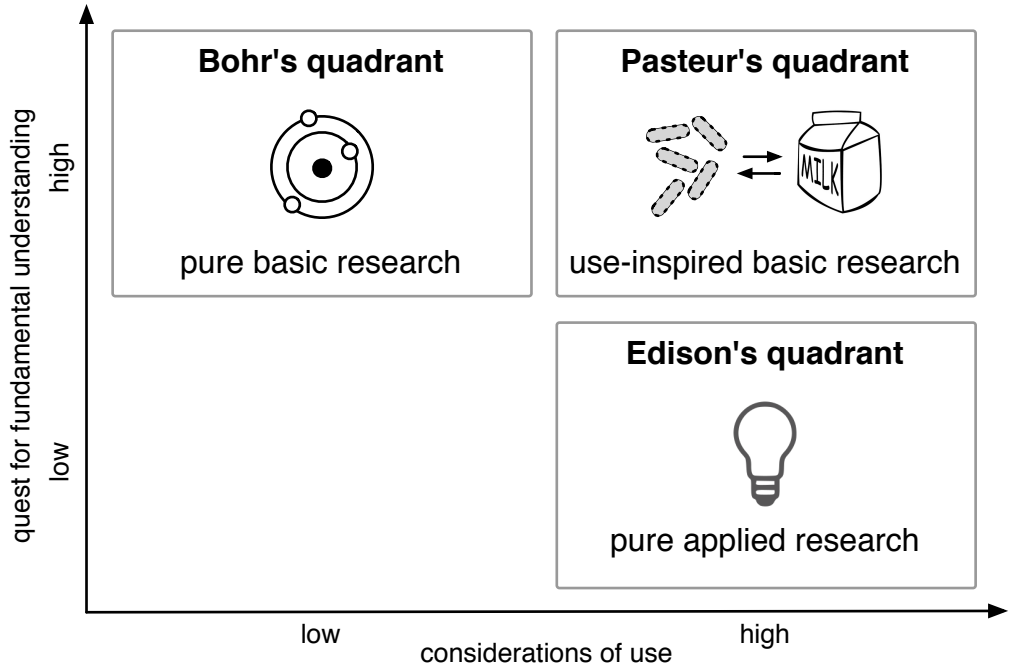


Figure 4.2: Stokes' framework for scientific motivation

quence, he proposes that public funding for basic science is especially needed and justified for research in "Pasteur's Quadrant", which is inspired by societal needs such as global warming, health and energy production. This has to be realized by " [...] *bringing together the two quite disparate kinds of judgments that shape agendas of use-inspired basic research — scientific judgments of research promise and political judgments of societal need.*"[12] In this framework, pure basic research gains its importance from its supporting role for Pasteur's quadrant: "*The societal value of use-inspired research within a scientific field strengthens the case for supporting the pure research on which the development of the field partly depends.*"[13]

But what about projects like the LHC? Its scientific purpose of corroborating the standard model of particle physics is definitely in Bohr's quadrant, and following Stoke's concept, only of secondary importance. Here the concept of technology stimulus can show that such a project with an enormous technological infrastructure can also have considerable research benefits which are relevant for commercial application. If innovation and growth are accepted as societal needs, or if a diffusion-oriented research policy is applied, a project like the LHC can also be regarded as

[12]Ibid., p. 106.
[13]Ibid., p. 104.

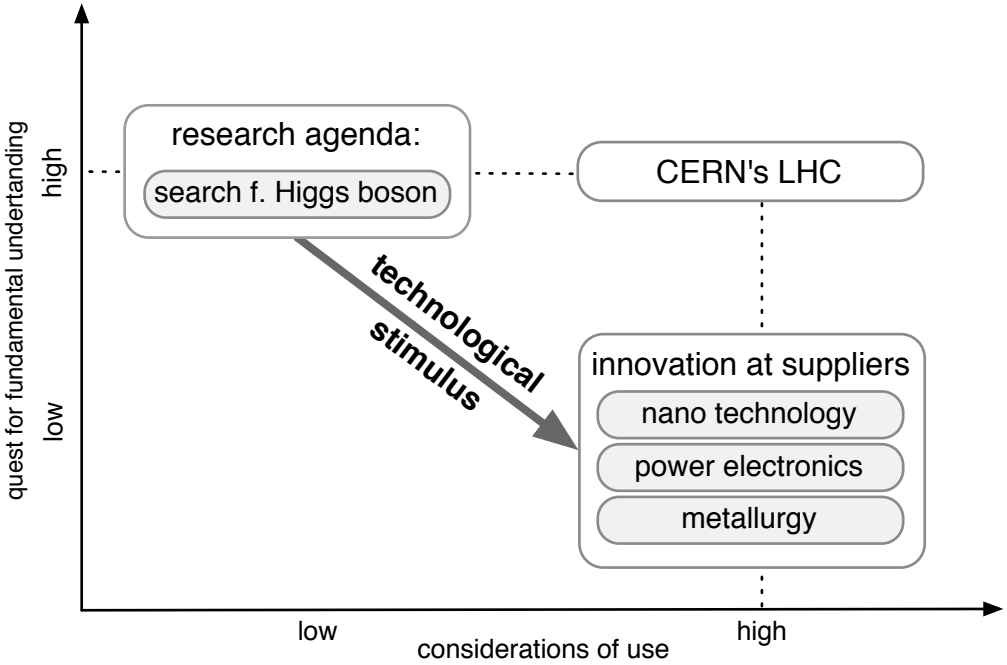


Figure 4.3: The LHC in Stokes' framework.[15]

part of Pasteur's quadrant and therefore share its legitimation for funding (see fig. 4.3).[14]

Compared to Bush's post-war paradigm, Stokes draws a new and improved picture on possible intentions of scientific projects. With technology stimulus, it shares the appreciation for curiosity and applicability as distinct, but mutually beneficial motivations for research. At the heart of technology stimulus is the idea that it can be beneficial if technology development is done in different sectors with orthogonally opposed motives and then exchange their skills and achievements. This idea can contribute to Stokes' framework by highlighting the value of unintended, but desirable side effects which research in one quadrant can have for other quadrants. Stokes also cares for *who* actually profits from basic science investments: *"The uncertainty as to who will capture the benefit in technology from new scientific knowledge is lessened when basic research is directly influenced by potential use."*[16] In correspondence, the technological stimulus among suppliers presents an easily controlled way to channel the benefits from national investments, and the results from this thesis showed that it is heavily used in the case of the European XFEL.

[14]The LHC with its pure basic science agenda is the better example than the European XFEL, which includes rather use-inspired applications such as material science, photovoltaics and biomedicine.

[15]Innovation examples for the LHC are taken from Autio, Hameri, et al. (2004)

[16]Stokes 1997, p. 106.

4.3 External effects vs. socioeconomic impact

In Chapter 2 of this thesis, the phenomena which are at the focus of this survey were described as "external effects". This economic term is theory-laden and includes a certain economic perspective and policy implications, as sketched in fig. 4.4: identified external effects indicate a suboptimal market result and may justify corrective public action to support their internalization. Being closely related to the market failure approach, the term "external effect" evaluates not only a phenomena like learning effects, but also the transaction in which it occurs: From a neoclassical point of view, external effects indicate an unbalanced utility allocation which leads to ineffective production incentives. The textbook reaction are measures to internalize the externalities by regulating the market conditions towards a balanced cost-benefit allocation via the transaction price and thereby correct the production incentives. If this is not applicable, positive external effects of a good (like basic research) can be a supportive argument for its production by public authorities.

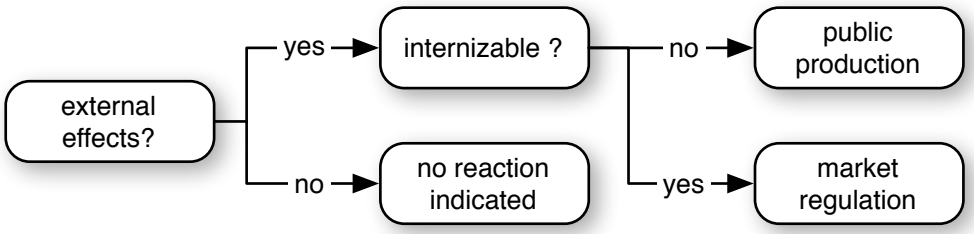
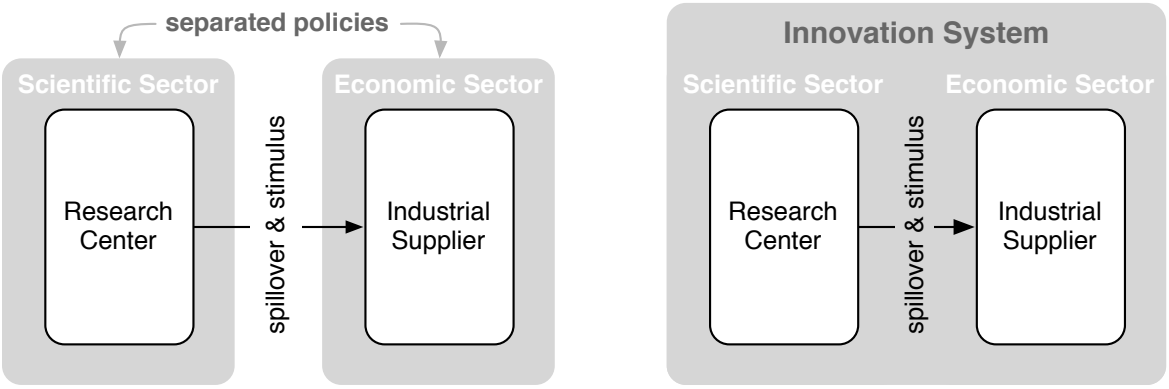


Figure 4.4: Standard policy implications of external effects

For the same phenomena, other literature offers less theory-laden terms like "socioeconomic impact", "economic benefit" or "spillover-effects". These terms do not include the connotation of an unbalanced and therefore ineffective utility allocation. In accordance with the results of this survey, the case studies by Autio, Hameri, et al. (2004) indicated that for supplying companies, learning effects can outweigh financial benefits. Assuming that these suppliers only agree to contracts which are already cost-effective without accounting the learning effects, they are a clear sign of external effects between research centers and its suppliers. Much more, technological stimulus due to social networks and confrontation with unknown needs and specifications can hardly be accounted for in any meaningful way.

But before thinking about possible policy implications of this result, the theoretical and contextual relativity of the concept of external effects should be highlighted:



a) Learning effects and technology stimulus as economic benefits are external effects of basic science if science and industry are seen as separated systems.

b) If science is part of a growth and innovation policy agenda, its positive impact on industry is still external to the scientific sector, but internal to the innovation system.

Figure 4.5

If science is put into the growth and innovation policy perspective, as it is done in current research policy, the innovation system approach has to be applied. In this perspective, the scientific and the industrial sector become sub-systems of the overall innovation system. In consequence, the relevant cost center to which an effect is external is shifted: The phenomena which was an external effect for the research institute (or the total scientific sector) becomes an internal effect of the innovation system: In the first case, learning effects can be externalities of the investments of a scientific research center. In the second case, they are internal effects for the accountancy of public authorities behind innovation policies like Horizon 2020.

The important conclusion here is that the applicability of the term "external effects" and its policy implications depends on the perceived or politically intended institutional embeddedness of actors. This means that for our case of basic research in a diffusion-oriented policy framework, a theory-laden notion of external effects is not necessary. The impacts identified by this survey still can be regarded as positive external effects. But this is only true on the level of specific organizations like DESY or the European XFEL GmbH. But on the political level as the relevant cost center, they are desirable links between two sectors of an innovation system and do not indicate any further political reaction. Following fig. 4.4, this has two consequences:

1. The notion of non-internalizable external effects cannot be used to justify public spending.

2. It cannot be used to justify market regulations which intend to internalize external effects.

The first consequence appears to be of rather little importance, because this is only a minor and supportive justification, but its loss does not affect the core of the market nor system failure argument for public spending on basic science. But there is a hidden danger, especially for science policy as part of growth and innovation policy: If the awareness for economic benefits dominates the actual scientific agenda of basic research, the case of non-internalizable external effects can be understood as an argument for public production of the external effects of basic research, but not of basic research itself. For practice, this would mean that public funding decisions on basic research are done in a way to maximize the expected economic benefit and therefore changes the incentives for the scientific agenda.

The second consequence on the contrary is of great importance: If a superior organizational level like an innovation policy framework is ignored, the policy implications of external effects can unnecessarily be called for. In practice, this can be the case on the organizational level if a research center tries to improve its financial benefits in industry contact either by lowering its willingness to pay in procurement activities[17] or by efforts to maximize its financial return of licensing activities. These measures can internalize external effects of the research institute and increase its financial return, but at the same time lower its economic impact due to the increased prices. This would thwart a diffusion and innovation agenda of the political level. Of greater impact is a regulation on the sectoral level, if measures are taken to partly refinance the scientific sector by helping him to profit from its economic impact. This can be a modification of intellectual property law and academic licensing regulations which intend to increase the financial return of knowledge as the central output of science. A heavily discussed example for this is the American Bayh-Doles act of 1980.[18] Again, such measures can change the incentives for basic research by connecting its funding sources to the economic usability and value of its results.

[17] while pointing at expected non-monetary benefits for the suppliers which were described earlier in this thesis

[18] Nelson 2001, p. 13.

4.4 Final remarks and further research questions

What can be learned from this thesis? Taking capacitive touch screens developed at CERN as an example, the introduction raised the topic of external effects of basic research. It was emphazised that because of their wide-spread and time-delayed emergence, they are hard to be completely captured. Chapter 2 pointed out that for current research policy frameworks and their theoretical foundations, these externalities are an important element for the justification of public funding. Using the construction of the European XFEL facility, Chapter 3 showed that technological and organizational learning effects at involved suppliers are significant economic benefits of the construction of basic research infrastructure which can be understood as external effects. Chapter 4 conclusively pointed out three further implications:

1. The direct impact on commercially available products is a relevant impact of basic research infrastructure which received rather little attention in previous literature such as Salter (2001). This impact is in line with the policy expectations formulated by European institutions like ESFRI. *(section 4.1)*

2. For this impact, basic science acts not necessarily as a source of technology, but also as a stimulus for its development in industry. This stimulus consists of the contact with a technological environment which has diametrically different development motivations and funding structures. Part of this contact is the exchange of experience, technological and scientific knowlege as well as access to new social networks. This stimulus and its components can be regarded as an externality of the public funds given to research centers. *(section 4.2)*

3. The theory-laden term "external effects" depends on an atomistic perception of actors and implies to take measures to internalize them if possible. With a greater awareness for complex societal structures as proposed by the innovation system approach, the term "external effects" and its policy implications become obsolete, at least for the discussion about general policy considerations regarding the public funding of science. *(section 4.3)*

Combining the results of section 4.2 and 4.3 leads us to a central implication of this thesis: The concept of technological stimulus implies that economic benefits of basic research can occur due to the fundamental differences between science and industry in terms of motives and funding structures. But the term *external effects* based on the market failure perspective implies that it would be efficient if these economic

benefits are internalized. This is achieved most practically by supporting scientific actors to receive financial benefits when they produce economic benefits. Here, a conflict occurs: Such attempts of internalization can align the incentive structure of the scientific and the commercial sector and therefore reduce the mutually stimulating effect of their relation. This can create a case where the internalization of positive effects of a good as a means to increase its production and its benefits actually reduces them. In other words: Measures to correct a perceived market failure can create a systemic failure.

For now, it remains to emphasize the prevalence of this conflict. It leads to the following research questions to be tackled in the future:

- The economic impact of basic research infrastructure is still a scarcely studied topic. This survey and its predecessors still use an explorative design, focusing on single RIs as example. Representative surveys on a larger scale are still needed do harden the empirical base for any theoretical considerations and political implications.

- This thesis named incentives derived from motives and funding structures as a crucial difference between science and industry. For an integrated innovation system perspective, it would be very helpful to further study the wider effects of complementary or competing incentive structures for interacting sectors and the overall system performance. For our case of science-industry relations, this means to analyze the effects of mixing up funding mechanisms such as commercial success.

- Science and industry share several societal institutions as well as staff, knowledge and technology. This thesis focused on a small aspect of the scientific sector and showed how the shared institutional framework allows beneficial exchange and stimulus. A different but complementary approach would be to focus on a shared institutional framework such as intellectual property law and analyze how changes made for one sector also (unintendedly) affects the other sector.

Last but not least; this thesis took an economic perspective on science and its side effects on economic performance, because this aspect plays a prominent role in the current political discourse. Two things have to be pointed out: one about science as the object of analysis and one about economics as a perspective. The latter proposes justifications for public spending for science outside of the economic perspective, and they should be more important. If a society wants to know more about the universe it lives in and the matter it consists of, this should be already reason enough to spend some money even if it does not improve smartphones or does not create innovative spin-offs and start-ups. Economic considerations bear any inherent normative implications. They can only take given preferences and goals and check whether certain measures are goal-directing. This means that this thesis took innovation and growth as given political motives and analyzed how science can contribute to them, but did not justify theses motives.

The same is true for science: Popper regards science as a method for effective human problem solving. Following him in his view we have to acknowledge that science can do two things: It can identify open questions and problems of our current understanding. And it can be applied to solve human problems. But science can not intrinsically evaluate the societal importance of identified open questions. It could not judge on its own which of the projects like the LHC, the ISS or the Human Genome Project was more urgent. In an open society, a public discourse or otherwise democratically legitimized process is needed to evaluate which of the most pressing questions and problems are to be solved by science. As Adams (1979) points out, a large and expensive research machinery can be of rather little value if society is not precise on the question to be solved.[42]

[42] Adams 1979, ch. 27

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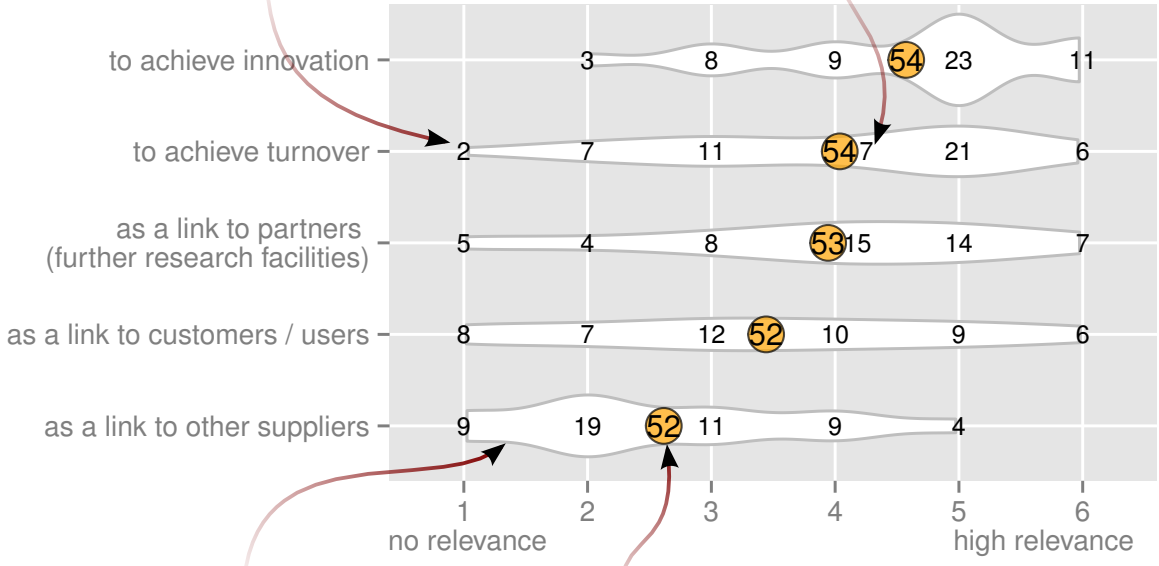
A Appendix

A.1 Plot explanation

2 = # of answers for this rating level:

2 companies stated that their XFEL project participation has no relevance for them to achieve turnover.

the 7 as # of answers at this rating level is dodged because of to spatial conflict with the 54-marker for total number and average.



The enclosing shape unites all printed answers of a question and visualizes their distribution as a violin plot.

52 = average and total amount of answers:

This plot presents 52 answers. This number is positioned at the x-coordinate of their average, in this case about 2.6 .

A.2 The Questionnaire

UNIVERSITÄT BAYREUTH

0% completed

Dear Sir or Madam,

With the help of many international partners, The European XFEL GmbH and the German Electron Synchrotron (DESY) are currently constructing a new large scientific facility, the European X-Ray Free-Electron Laser (XFEL) .

As a student at the University of Bayreuth, I am currently writing my master thesis at the chair for institutional economics of Prof. Martin Leschke. This includes a survey about learning effects for the XFEL project on supplying companies. For this purpose, I received approval and support by European XFEL GmbH. Your company has been chosen for this survey because you supply technologically demanding products for the XFEL project.

I would be very grateful if you could support me in this process by means of answering the following questionnaire.

The origin of any information given to me will be handled strongly confidential. The evaluation of the questionnaire will be carried out primarily statistically and without mentioning the company. I have signed statements of confidentiality for XFEL GmbH and would certainly agree to sign such a statement for you.

I would like to thank you in advance for your effort.

With kind regards,

Michael Neumann

Next

Michael Neumann
michael.neumann@stmail.uni-bayreuth.de
+49 (0)40 8998-6971

Notes for using this questionnaire

- You can always go backwards and forward by using the buttons labeled "back" and "next" at the bottom of this page
- When using the "back"-button, your entries for the current page will stay saved.
- The questionnaire will be finally closed and the results saved when you reach the last page.

Part 1: About your company

Please answer the questions in this part with reference to the legally independent entity of your company in which you are working.

1. Please state the main focus of the economic activity of your company. What are your central products and their main markets?

2. How many employees does your company have (approximately, full time equivalent)?

number of employees:

3. How many employees are dealing with research and development (approximately)?

Number of employees in R & D?

Part 2: Your relationship to DESY / XFEL GmbH

The main construction process of the XFEL facility is split between the XFEL GmbH and DESY as two separate legal entities. This questionnaire, however, refers to the XFEL project which comprises the cooperation of the two institutes.

4. Has your company been supplying goods or services for one of the following facilities?

check all that apply

- ☐ HERA
- ☐ DORIS
- ☐ PETRA
- ☐ HASYLAB
- ☐ TESLA Testfacility (TTF1, TTF2)
- ☐ FLASH I, II
- ☐ One or more of the above, but no classification of commisions possible
- ☐ None of the above

5. Please characterize the kind of relationship your company has to DESY / XFEL GmbH.

Several answers possible

- ☐ supply of standard products
- ☐ supply of standard products modified for DESY / XFEL GmbH
- ☐ development and production of products according to technical specifications (capacity, function, quality, etc) of DESY / XFEL)
- ☐ production of products according to detailed production requirements (design drawing, circuit diagram, bill of material, etc)
- ☐ engineer services
- ☐ completion of studies
- ☐ installation work at the DESY / XFEL GmbH grounds
- ☐ maintenance and repair at the XFEL project grounds

6. Which products or services does your company provide for the XFEL project?

7. How often is your company in contact with DESY / XFEL GmbH

- ○ Once a year or less
- ○ Every three months
- ○ Permanent cooperation
- ○ Every six months
- ○ Once per month

8. Do you expect your company to be given further commissions from DESY / XFEL GmbH?

	1	2	3	4	5	6	
high uncertainty	○	○	○	○	○	○	certainty of further commissions

9. Please state whether DESY / XFEL GmbH as customers are relevant to you considering the following criteria.

	no relevance					high relevance
	1	2	3	4	5	6
to achieve turnover	○	○	○	○	○	○
to achieve innovation	○	○	○	○	○	○
as a link to customers of DESY / XFEL GmbH	○	○	○	○	○	○
as a link to other suppliers of DESY / XFEL GmbH	○	○	○	○	○	○
as a link to cooperating partners of DESY / XFEL GmbH (further research facilities)	○	○	○	○	○	○

10. How important is DESY / XFEL GmbH as a customer to your company?

customer of no importance [ ] most important customer

Part 3: Innovation and Stimulus of Technology

In the following, "innovation" refers to innovations of products and processes.
Innovations of products include the change of use, quality, abilities, technical construction or used commodities and components of a product.
Innovations of processes refer to the use of new substantially improved methods of production.

"Stimulus of technology" includes the transfer of technology from DESY / XFEL GmbH to your company as well as the development of new technology at your company due to the technical needs of the XFEL project.

11. Please give your opinion, to what extend has your relationship to to the XFEL project induced innovations the following areas or to what extend do you expect this to happen in the future.

Should there be an important area missing in the list, please add it and likewise state the relevance of the achieved innovations.

	no innovation → very important innovation						
	1	2	3	4	5	6	I don't know
Mechanical production processes	○	○	○	○	○	○	○
Chemical process engineering	○	○	○	○	○	○	○
Analytics (Chemical, physical)	○	○	○	○	○	○	○
Metallurgy	○	○	○	○	○	○	○
Composite Material	○	○	○	○	○	○	○
Mechanical engineering	○	○	○	○	○	○	○
Precision engineering	○	○	○	○	○	○	○
Optics	○	○	○	○	○	○	○
Measurement technology, diagnosis	○	○	○	○	○	○	○
Electronics	○	○	○	○	○	○	○
Energy producing technique	○	○	○	○	○	○	○
High-frequency engineering	○	○	○	○	○	○	○
Control engineering	○	○	○	○	○	○	○
Information technology	○	○	○	○	○	○	○
Scaling of production	○	○	○	○	○	○	○

If you miss a technological area which is important for your company, please state it here and evaluate it likewise.

	no innovation → very important innovation					
	1	2	3	4	5	6
	○	○	○	○	○	○

12. Think about organizational changes which came along your cooperation with the XFEL project. How far do you agree to the following statements?

The XFEL project helps us to...	disagree 1	2	3	4	5	agree 6	I don't know
improve our manufacturing process management	○	○	○	○	○	○	○
improve our quality control and assurance systems	○	○	○	○	○	○	○
improve our R&D processes	○	○	○	○	○	○	○
strengthen our marketing capability	○	○	○	○	○	○	○
strengthen our project management capability	○	○	○	○	○	○	○

13. In your opinion, how important are the following mechanisms for the exchange and stimulus of technology and knowledge between the XFEL project and your company ?

	of no importance 1	2	3	4	5	of high importance 6	I don't know
Informal exchange of information with DESY / XFEL GmbH employees within commissions	○	○	○	○	○	○	○
Conferences, workshops of DESY / XFEL GmbH	○	○	○	○	○	○	○
Receiving technical specifications by DESY / XFEL GmbH	○	○	○	○	○	○	○
Purchase of Patents of DESY / XFEL GmbH	○	○	○	○	○	○	○
Temporally limited exchange of employees	○	○	○	○	○	○	○
Permanent takeover of employees of DESY / XFEL GmbH	○	○	○	○	○	○	○
Qualification phase of a tender	○	○	○	○	○	○	○
Receiving training from DESY / XFEL GmbH staff	○	○	○	○	○	○	○

If you are missing a mechanism which is important for your company, please state it here and evaluate likewise.

	of no importance 1	2	3	4	5	of high importance 6
	○	○	○	○	○	○

14. Has your company purchased any patents of DESY / XFEL GmbH? or do you produce products under licence of DESY / XFEL GmbH?

If no option is applicable, leave blank and proceed.

- ☐ *purchase of patents*
- ☐ *production under license*

15. Has your company employed specially qualified employees because of commissions or cooperations due to the XFEL project?

- ○ Yes
- ○ No

16. How many especially qualified employees have been hired?

Number of employees: ____

Where have these employees been employed before?

- ☐ Companies
- ☐ Universities
- ☐ DESY / XFEL GmbH
- ☐ other public research institutes
- ☐ Graduates

17. Did any of the following problems prevent an exchange and stimulus of knowledge in your cooperation with the XFEL Project?

- ☐ Lack of capacity of research and development in the own company
- ☐ Insufficient flow of information between employees of DESY and employees of the own company
- ☐ Problems with the clearing procedure and law
- ☐ Problems with intellectual property or industrial know-how issues
- ☐ Other Reason: ____

Part 4: Innovation effects and technology diffusion

This part deals with the question whether your company can use any innovations from the involvement in the XFEL project as well in further economic activities.

18. Think about any products, processes or services which you originally developed for the XFEL project. Can you sell these to other customers?

- ◯ Yes, already happened
- ◯ Yes, expected for the future
- ◯ No

19. What is the backround of these new customers of the products you originally developed for XFEL?

- ☐ research institutes for accelerator physics
- ☐ other public research institutes and Universities
- ☐ companies of the following sectors:

20. Please give examples of these products, processes or services which you originally developed for the XFEL project. In which industries and applications can they be used by other customers?

Example: cryogenic components (valves, insulation) , used for industrial gas liquefaction

21. Think about any processes, products, knowledge or services that you developed for the XFEL project. Can you use these for the development or improvement of other products or do you expect this for the future?

- ◯ Yes, already happened
- ◯ Yes, to be expected in the future
- ◯ No

22. How much of the knowledge you developed for the XFEL Project can be further used for other or new products and services?

	nothing										all
	0	10	20	30	40	50	60	70	80	90	100
% of further used knowledge											

23. In which ways can you improve other products due to the learning effects from your experiences from the XFEL project?

	is not the case					is the case
	1	2	3	4	5	6
These products, processes or services have so far not been possible	○	○	○	○	○	○
Improvement of the quality or ability of these products, processes or services	○	○	○	○	○	○
Reduction of the costs for development, manufacture or maintenance of these products, processes or services	○	○	○	○	○	○

From which fields do the customers for these new or further developed products come?

- ☐ Research institutes for accelerator physics and/or free electron lasers
- ☐ Other research institutes or universities
- ☐ Companies of the following industries:

24. Can you give examples of any other products which have been improved due to the experience you gained by supplying for the XFEL project? What are their applications, and in which industries can they be further used?

Example: permanent magnets, used in medical imaging technologies like NMR

25. Please evaluate if your employees have improved their knowledge, abilities or efficiency in the following fields of activity because of their involvement in the XFEL project.

	no difference 1	2	3	4	5	great improvement 6	I don't know
Field of manual skill							
Construction, design							
Production processes, process engineering							
Project management							
Quality assurance							
Customer relations							
other:							

26. What types of knowledge have been stimulated by the cooperation with the XFEL project?

	no important learning effects 1	2	3	4	5	very important learning effects 6	I don't know
procedural knowledge and skills about technical solutions (*know-how*)							
knowledge about the social structure, competence and thrustworthiness of firms, public organisations, scientific communities, etc and their individual members. (*know-who*)							
factual knowledge, for example about physical properties of materials, capabilities of technical tools as well as industrial standards and law regulations. (*know-what*)							
knowledge about principles and laws of nature. (*Know-why*)							

27. If your company has gained knowledge of any type during the cooperation with the XFEL project, in which form is that knowledge stored in your company?

Please select the proportion of the following forms of knowledge.

Codified knowledge refers to any information which has been written down, drawn or saved in other ways on a medium.

Tacit knowledge refers to knowledge which is only stored in the memory, capabilities and social relations of the employees of your company.

only codified knowledge — only tacit knowledge

28. Thinking about medium to long term benefits, please consider the following organisational impacts.

Because of the XFEL project...	Disagree 1	2	3	4	5	Agree 6
...we established new R&D team(s)	○	○	○	○	○	○
...we introduced new products or services	○	○	○	○	○	○
...we started a new business unit	○	○	○	○	○	○
...we opened a new market	○	○	○	○	○	○
...we increased our international exposure	○	○	○	○	○	○
...we made an important step of technological innovation	○	○	○	○	○	○

Part 5: Investments

29. Did you make additional investments for the XFEL Projects or do you plan to do so in order to be able to carry out your commission and/or to receive further commisions?

- ○ Yes
- ○ No

30. Of which kind are these Investments?

check all that apply

- ☐ research, development or construction
- ☐ pilot projects, experimental preproduction
- ☐ production assets
- ☐ employee training
- ☐ software
- ☐ measurement Instruments
- ☐ quality control
- ☐ external expertise (temporal hiring of specialists and consultants)
- ☐ other: _____

Part 6: Reputation

31. Is it important for your economic success with the following groups of customers to be able to name DESY / XFEL GmbH as a reference customer?

	of no importance					of high importance	I don't know
	1	2	3	4	5	6	
Companies	○	○	○	○	○	○	○
Research institutes for accelerator physics and FELs.	○	○	○	○	○	○	○
Other research institutes and universities	○	○	○	○	○	○	○

In which geographical regions do you expect DESY / XFEL GmbH to be an important reference customer which can improve your economic success?

	of no importance					of high importance	I don't know
	1	2	3	4	5	6	
Germany	○	○	○	○	○	○	○
remaining Europe	○	○	○	○	○	○	○
Asia	○	○	○	○	○	○	○
North America	○	○	○	○	○	○	○
other:	○	○	○	○	○	○	○

Additional Comments

The questionnaire is now finished. Did you miss any important aspect of your cooperation with the XFEL project? Do you have general Ideas how your science-industry cooperation could be improved? You can use the following blank space for general and additional comments and remarks. To finally close this survey, press "next".

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