Fraunhofer ISI

A microeconomic perspective on the impact of the Fraunhofer-Gesellschaft

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Fraunhofer Institute for Systems and Innovation Research ISI

Breslauer Straße 48

76139 Karlsruhe

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Figures

Tables

1 Executive summary

- Cooperating firms benefit from working with Fraunhofer in many ways
  - **Profit, revenue, productivity** and **employment** — effects for companies are demonstrably high.
  - **Small and medium-sized companies** (SMEs) in particular benefit from cooperating with Fraunhofer (higher EBIT, higher turnover per capita than comparable companies that did not collaborate with Fraunhofer).
- Structure of collaborating companies
  - In contract research, two thirds of the projects are in collaboration with SMEs. In publicly funded joint research projects, this figure rises to three quarters of the projects.
  - The cumulative budget of SME projects is proportionally lower than the proportion of the projects; in other words, in terms of total budget.
  - However, especially with small companies, a Fraunhofer cooperation provides larger leverage — as compared to a Fraunhofer cooperation with a large enterprise.
- Partners are, in particular, those companies where the cooperation falls on fertile ground (with corresponding absorptive capacity)
  - Fraunhofer cooperates particularly intensively with partners from **research and knowledge-intensive industries**.
  - **R&D-intensive companies**, as well as companies with **high product complexity**, benefit from joint projects with Fraunhofer.
- Publicly-funded joint projects
  - Projects together with industry — also those in collaboration with other research institutions — have positive economic effects for the cooperating firms.
  - The nature of these projects, however, is more related to basic knowledge and technology transfer and the short-term economic effects are, therefore, lower than in contract research projects,
  - Due to the large number of projects, the absolute contribution of Fraunhofer to German industry via this collaboration channel is the most important among all non-university organizations (both in terms of number and volume).

2 Introduction

The impact of scientific institutions and organizations is of great importance for political, strategic and economic decisions. Clients, partners and the public sector have an interest in knowing and evaluating the impact of the tax money invested. Decision-makers within the Fraunhofer-Gesellschaft are interested in being able to record the effects of Fraunhofer, in various impact dimensions, and use this information for further strategy formation.

Fraunhofer's economic and technological impact, its contribution to the qualification of young scientists and to new fields of technology was analyzed for the first time in a study in 2016. The Fraunhofer-Gesellschaft was the first major research organization in Germany and Europe to present such a comprehensive picture of its impact. In 2020, the Fraunhofer-Gesellschaft commissioned a number of studies to further analyze its impact and deepen the knowledge and understanding of the mechanisms. The quantification and analysis of its economic impact was in the focus of these studies. The report presented here is one of three reports and focuses on microdata and the micro-economic effects of collaborations of industry with Fraunhofer. Special focus is devoted to small and medium-sized enterprises (SMEs).

In its mission statement, the Fraunhofer-Gesellschaft defines itself as a research organization, which focuses on collaboration with industry for the goal of improving societal wellbeing and economic welfare: it states that "Together with industry, we turn original ideas into innovations — for the good of society and to strengthen the German and European economy."[1] It thus explicitly defines itself as a central actor in the innovation system, carrying out inter- and transdisciplinary research, offering system solutions, organizing networks and ensuring exchange with international partners for the benefit of German industry. In addition, there is an expectation in the German society and in politics ("mission orientation") that the work of research institutions must be more strongly oriented towards societal challenges and societal development goals, which Fraunhofer additionally addresses at operational level.

1 https://www.fraunhofer.de/content/dam/zv/de/ueber-fraunhofer/leitbild/fraunhofer-leitbild.pdf; own translation, original in German only.

3 Context

The science system in Germany is among the best in the world. It produces frontier knowledge, uses it to build up further knowledge and puts it into practice. Research at universities and non-university research institutions is at a high level of both quality and productivity compared with other countries worldwide (Frietsch and Schubert 2012; Stahlschmidt et al. 2019). In addition to the direct generation of knowledge and the qualification of future employees, other tasks and missions are increasingly assigned to the scientific institutions and universities. On top of scientific goals, there are, for example, expectations regarding contributions to achieving politically set economic or social goals. These range from the transfer of application-oriented knowledge to industry, via the increase of the competitiveness of the national economy as a whole (third mission), to the fulfillment of ambitious social goals such as combating widespread diseases or achieving sustainability goals (mission orientation of research and innovation policy).

The free flow of knowledge both across disciplinary boundaries (interdisciplinarity) and across national borders (internationalization) is an important part of service provision in all areas of science and research and is therefore also one of the tasks of universities and public research institutions. In addition, there are requirements with regard to increasing diversity — in the context of research organizations, this includes equal opportunities for women and men, the employment of older people as well as the employment of foreign scientists and researchers. All of these demands are increasingly made explicit in political and strategic objectives and are demanded politically and socially. In addition, the contribution of science to success or the targeted use of tax funds must be increasingly legitimized, i.e. funding providers and recipients must present the benefits for society and the impact beyond the pure output to legitimize the expenditure (European Commission 2017; Hacker et al. 2018; LERU 2018). This is accompanied by the question of the impact of science (or science systems as a whole) along these new requirements and dimensions.

Impact focuses on longer-term, overarching effects that are not directly linked to a measure, i.e. they go beyond the direct outcome. In addition to the general social impact, there are other types of impact from science or the science system, such as the scientific or economic impact. In addition, there are also perspectives such as cultural or ecological impact. Fraunhofer has committed itself to making contributions to all these dimensions.

Keeping an eye on the mission and its fulfillment — i.e. the impact of the Fraunhofer-Gesellschaft on the economy, science and society — and reviewing it regularly in order to be able to steer and plan itself, but also to provide evidence of its performance and thus its legitimacy to funding bodies, partners and clients, is a self-evident task for the Fraunhofer-Gesellschaft. At regular intervals, the various aspects of the mission are examined at several levels.

While the economic impact or economic effects in science and innovation research have been the subject of studies for several decades due to their measurability (Grupp 1998) and also due to the evaluation which has so far been primarily oriented on the innovation process (OECD 2005; OECD 2018), questions of the impact as a whole and in particular of the social and political effects have only recently become the subject of scientific debate. Accordingly, a number of economic studies have been carried out, while the social impact is still primarily in the theoretical-conceptual discussion. In a results paper by a high-level group on economic impact, it is accordingly emphasized that economic impact, which is oriented towards research and innovation, represents only a part of all possible impact dimensions. "… [It] focuses solely on assessing the economic impacts of R&I. Such analysis is partial and does not take into account the full breadth of the impacts of R&I, and public R&I funding. This is particularly important as much public R&D does not focus on obtaining a direct economic return." (European Commission 2017, p. 3, original with highlights).

The evaluation approach, as it is also reflected in the Commission's approach (Bruno and Kadunc 2019), thus moves gradually from monitoring the relevant activities to tracking their dissemination and finally to a genuine assessment of the impact they have on science, society and the economy. The pathways approach refers strongly to the conceptual notion of productive interactions (Molas-Gallart and Tang 2011; Spaapen and van Donghe 2011), which stresses that in order to obtain policy-relevant information, evaluations cannot simply focus on documenting the final impact. Instead, they should be based on a theory of change that identifies those interactions that initially trigger the final impacts — even if multiple interactions intervene later. By concentrating on productive interactions, evaluations are able to observe, more or less in real time, whether a program succeeds in triggering the right types of immediate outcomes and communicating these to other actors, who will eventually translate them into results and impacts. In contrast to previous approaches, the productive interaction approach aims to link outputs, outcomes and impacts through cascades of interactions along which impact pathways are formed and become effective. In this way, the path approach allows evaluators to move beyond an unsatisfactory situation where most of the output, outcome and impact indicators collected reflect little more than a disjointed

documentation of outcomes at different points in time that cannot be placed in a solid logical or causal relationship, but only through assumptions.

Despite many years of academic debate in empirical innovation research on indicators for assessing the performance of science systems and, for example, the benefits of cooperation with public research institutions for companies, there are very few empirically grounded analyses of the impact or effects of individual research organizations within an innovation system (Mote 2016; De Fuentes and Dutrénit 2012; Busom and Fernández-Ribas 2008). One of the few studies on this topic was conducted by Fraunhofer ISI (Frietsch et al. 2016). The study assesses the economic and, in part, the technological impact of Fraunhofer on the German innovation system. It could be empirically proven that the Fraunhofer-Gesellschaft makes a massive contribution to the technological renewal of the economy, as can be demonstrated, for example, in the areas of "lasers in production", "renewable energies" and "new materials".

Further results show a close exchange between the Fraunhofer Institutes and companies and research institutions. Fraunhofer partners benefit both technologically and economically from cooperating with Fraunhofer. The effects are particularly visible for SMEs, as they achieve higher EBIT (profits after tax). Product complexity, R&D-intensive companies and companies open to cooperation benefit in particular. The satisfaction of the partners reaches a high level, which is shown by the high number of recurring cooperation partners. From an economic perspective, it can be shown that Fraunhofer generates notable macroeconomic effects beyond direct regional economic effects (jobs, purchasing power in the region). The public sector receives more than three times the basic funding made available through tax revenues. The leverage of the funds spent by Fraunhofer on the gross domestic product (GDP) is 1:18, according to the 2016 study.

On the basis of econometric models, Comin et al. (2018) were able to show that a one-percent increase in the scope of contracts with Fraunhofer leads to an increase in the growth rate of the companies' turnover by 1.3 percentage points and in the short term to an increase in the growth rate of productivity by 0.8 percentage points. In addition, evidence of significant long-term effects, which add up to an 18 percent growth in turnover and a 12 percent growth in productivity over 15 years, was found. More detailed analyses show, among other things, that the more often companies interact with Fraunhofer, the stronger the performance effects, and that interactions aimed at generating new technology have a stronger impact than interactions aimed only at implementing existing technologies. Evidence was also found for macroeconomic productivity effects of Fraunhofer interactions on the German economy. For example, the results show that a doubling of Fraunhofer sales from industry (+€0.68 billion) would increase the overall productivity of the German economy by 0.55 percent.

Bilsen et al. (2018) calculated the economic impact of research and technology-oriented organizations in Europe on the basis of a classic input-output (I-O) calculation. Estimates of the direct economic effects resulted in 54,200 jobs in 2016, which generated a turnover of about 7.2 billion euros and added value of about 3.5 billion euros. The estimates of indirect effects showed 284,000 jobs in upstream and downstream sectors, which in turn generated sales of 35.8 billion euros and added value of 16.8 billion euros.

In the following, we extend on these lines of analyses, considering more recent data, employing additional data sources and estimating regression models based on further fine-tuned methodological considerations.

4 Methods

The aim of this study is to evaluate the effects of cooperating with Fraunhofer Institutes as well as other German public research organizations on companies' economic and innovation success. The basic methodology to reach this aim was the creation of two company-level datasets containing information on cooperation with non-university public research organizations (PRO) and universities. One of these datasets contains large-scale data and is based on the ORBIS database by Bureau van Dijk (BvD). This dataset includes basic company information, e.g. sales, employees and the information on the sector the company operates in. The ORBIS dataset thus contains only structural information; however, it covers the full universe of firms operating worldwide, with a slight bias towards larger firms. The second dataset is the representative firm survey *Modernisierung der Produktion* (German Manufacturing Survey, GMS), which is carried out by Fraunhofer ISI and represents the German part of the *European Manufacturing Survey (EMS)*. Though this dataset only covers manufacturing firms and thus has a smaller sample, i.e. it includes fewer companies overall, it contains much more in-depth information on firm behavior. Additional information from other databases is added to these two data sets. First, information on cooperation with Fraunhofer and other public research institutions (PROs) and universities were added to both datasets. For all PROs and universities, the data from the German public funding catalog ("Förderkatalog des Bundes") was matched with both company datasets. In addition, Fraunhofer internal administrative data (SIGMA) on contracts with industry were added as well — covering only Fraunhofer collaborations with industry and not by the other PROs, of course. Secondly, patent information from the European Patent Office's PATSTAT database was implemented. Third, we added variables on the financial situation like Return on Equity (RoE) from BvD AMADEUS. Based on two extended datasets, i.e. the extended GMS and ORBIS dataset, descriptive statistics, correlation analyses and multivariate models were estimated to analyze the

relationship between cooperation with research institutions and the success of the company. More detailed information about the two basic data sources and the addition of supplementary data from other datasets is provided below.

4.1 The databases

BvD Orbis

BVD's ORBIS database is large-scale company dataset with location (legally self-reliant branches) and sector information as well as ownership structures of 2.4 million companies in industry (NACE codes 10-33 and 45-82) in Germany including all firm sizes from micro companies with less than 5 employees to large companies operating with thousands of employees.[2] The ORBIS dataset forms the basis for the large-scale analyses with regards to cooperation with public research, but only contains information on the most recent available year (in our analyses mostly 2019 or 2020).

The German Manufacturing Survey (GMS)

The *Fraunhofer GMS*, on the other hand, captures the utilization of techno-organizational innovations in manufacturing at the level of individual manufacturing sites and the thereby achievable performance increases in the manufacturing sector. It is a unique firm-level survey which has addressed a large random sample of manufacturing firms every three years for more than 20 years. It covers the entire manufacturing sector in Germany and provides representative data of German manufacturing companies with at least 20 employees. For each wave, the data consists of between 1,200 and 1,500 firms, which provide a representative picture of manufacturing in Germany. In this report, the GMS data from 2012, 2015 and 2018 are used.

The Funding Catalog (Förderkatalog)

As neither BvD's ORBIS data nor GMS' data contain information about collaboration with the Fraunhofer-Gesellschaft, further data have to be matched to both datasets. In order to capture information on the cooperation with Fraunhofer as well as other public research organizations (PROs), we resort to data from the German public *Funding Catalog* that lists collaborative research (joint research projects) between companies and PROs as well as universities. In total, nearly 270,000 projects are currently listed in the Funding Catalog. About 120,000 of these projects are joint research projects.[3] The first

2 https://www.bvdinfo.com/en-gb/our-products/data/international/orbis

3 https://foerderportal.bund.de/foekat/jsp/StartAction.do?actionMode=list

project listed in the Funding Catalog started in 1968. The coverage of projects is rather complete for the six most relevant R&D funding ministries at least from the year 2000 onwards.

Fraunhofer's contract data (SIGMA)

In addition to this information on public funding, we employed Fraunhofer-internal data from *SIGMA* that provides information on contracted research projects from firms. We restrict our analyses to contracts during the period from 2010 to 2018. This information is only available for the Fraunhofer-Gesellschaft, and not for other PROs, but it allows us to separate contract research from joint research projects in our analyses.

Patent data and additional financial indicators

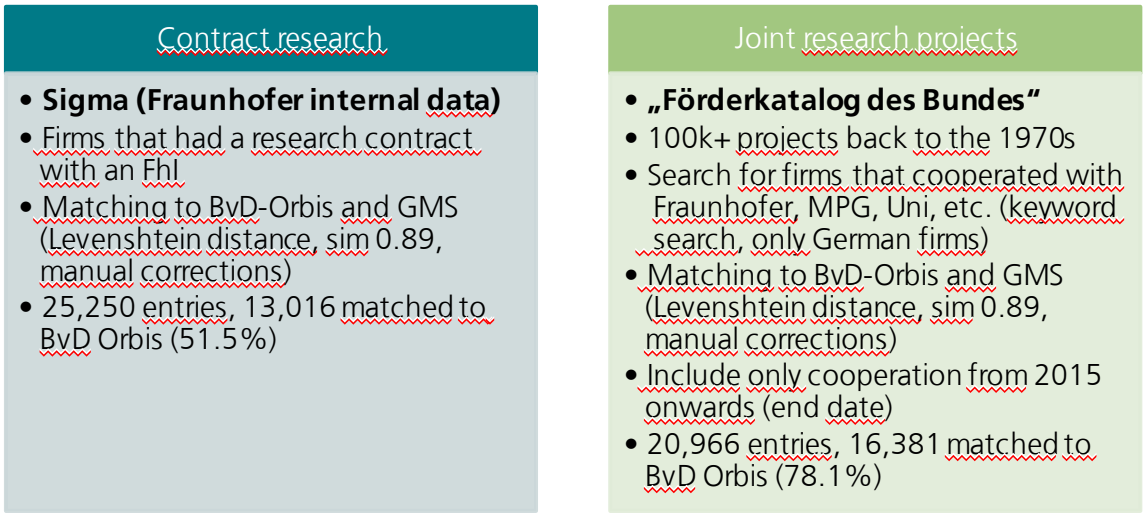
In order to get further information that goes beyond what is available in SIGMA or the funding catalog, we matched two further datasets to GMS and BvD ORBIS, namely *patent filings* (transnational patents (see Frietsch and Schmoch 2010) and filings to the German Patent and Trademark Office DPMA) and financial indicators, e.g. EBIT or Return on Equity, from Bureau van Dijk's *Amadeus database*.

4.2 The matching procedures

The information from SIGMA and the funding catalog were *matched* to the Fraunhofer GMS as well as the BvD Orbis data with the help of a string-matching algorithm based on the Levenshtein distance at the level of company names. The Levenshtein distance uses the number of edits to align two text-strings — in our case company names — as a measure. If the number of edits to align the two company names is low, the similarity between these two text-strings is high. Once a certain similarity threshold is reached, two text-strings are interpreted as a match. The similarity threshold t is set to 0.89, which has been found to be the optimal compromise for our data between an exact match (precision) and a given coverage (recall) with the help of a manually matched dataset as a gold standard. The matching procedure thus assures that companies with the same or similar names (in case of different writing styles, typographical errors and name variations) are matched together, while different names are not. We further checked when the cooperation took place as we have that information from SIGMA and the funding catalog and set a time-window of three years (five years in the case of the ORBIS dataset) to make sure that cooperations that happened several years ago do not bias our results.

An overview of the funding catalog and the SIGMA data and their matching to BvD ORBIS and GMS can be found in Figure 1. The result of the matching to the GMS is outlined in chapter 4.1 as it already shows the diffusion of cooperation among manufacturers.

Figure 1 Overview on SIGMA and German funding catalog data and matching to BvD ORBIS



For the *patent data*, we applied the same logic as described above to merge the companies from the GMS and ORBIS with the EPO Worldwide Patent Statistical Database (PATSTAT). As data from the GMS shows, around 14 to 17 percent of the manufacturers applied for at least one patent between 2010 and 2018. Regarding the following analyses, the focus lies on the share of manufacturers filing for patents during the two years prior to the measurements (12% in 2012, 13% in 2015, 10% in 2018).

As for the *financial data from Amadeus*, a slightly different approach has been used. Since the GMS uses the company database Hoppenstedt to draw a sample of the firms to be surveyed, we know the firm number of all of the surveyed firms in Hoppenstedt. On this basis, we were able to extract the VAT number of about two thirds of the GMS firms (across all waves). With the help of the VAT number, we could search for the firms in the Amadeus database to obtain further financial indicators for the firms in the sample. For firms for which a VAT number was not available, we once again applied a string-matching algorithm on the company names to obtain information from Amadeus (this was also done for the ORBIS firms). After this two-step process, we were able to assign a BvD-ID (the firm number in the databases of Bureau van Dijk) in 91 percent of the firms surveyed in 2018, 83 percent of the firms surveyed in 2012 and 86 percent of the firms surveyed in 2015. Yet, the coverage in terms of financial information, i.e. the

Return on Equity, is lower as not all information is available for all firms within Amadeus. In general, for only 35 percent of the firms this information is registered. Unfortunately, for the most recent wave this information was only available for 26 percent of the identified firms.

4.3 The resulting analytical datasets

In sum, this procedure provided us with two integrated microdata sets:

1. ~4,000 company level observations (in all waves, i.e. 2012, 2015 and 2018) with firm-specific information from the GMS survey, data on patents, firm financials and, most importantly for this analysis, information on which of these companies had cooperated with Fraunhofer or other PROs in a three-year time window.
2. ~34,000 company level observations based on BvD-Orbis including information on whether a firm has collaborated with Fraunhofer or any other PRO in the last five years.

Additionally, a "matched pair" approach was used to validate these results and to address causality in the analyses. For each collaborating company (with Fraunhofer or the other PROs, respectively), a statistical twin is identified in the GMS dataset as well as the ORBIS dataset. These twins did not collaborate in the same time period, but are very similar to their cooperating twin in terms of basic structural characteristics (e.g. industry and size for ORBIS as well as product complexity for the GMS firms). This method allows differences in innovation behavior and company performance to be compared by explicitly taking into account the methodological problem of a preceding self-selection and thus of counterfactual estimation. Moreover, the method allows various specific effects to be estimated in detail.

5 Structure and impact of collaborations with industry

5.1 Fraunhofer's collaborators and customers

The internal administrative data of Fraunhofer (Sigma) as well as the publicly available funding database (Foerderkatalog) allow the structure of the partners in these kinds of projects to be analyzed. The data has been matched to the Orbis database as well as to the German Manufacturing Survey for the years 2012, 2015 and 2018 in order to receive additional structural information on the industry partners. We restrict our analyses to German companies only — defined as companies whose contracting branch is located in Germany — as the focus of our macro-economic analyses is on

the German economy (GDP-perspective) and the analyses here should at least be compatible to them in a general way.

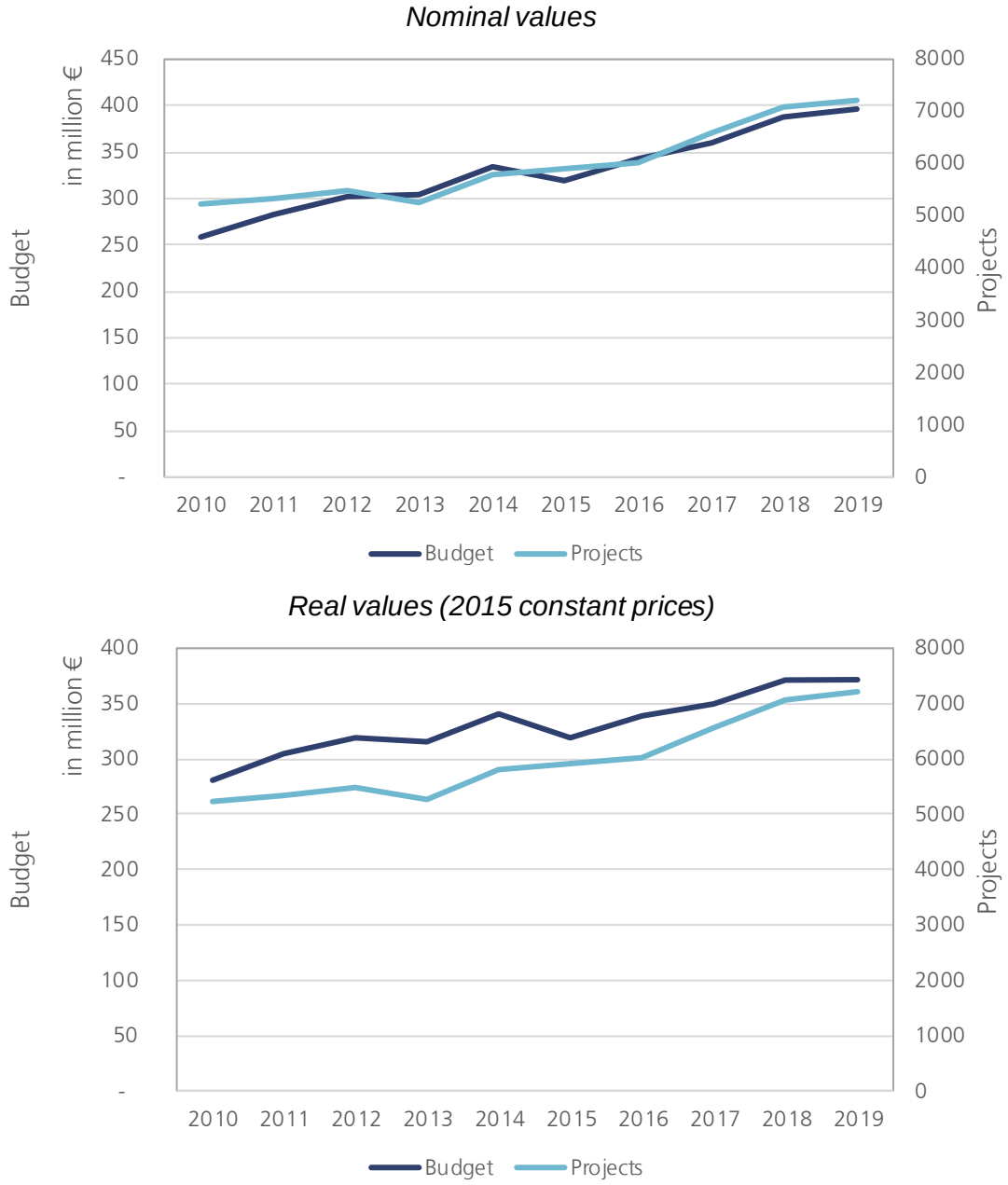
5.1.1 Direct contracts from industry

Figure 2 shows the number of projects as well as the annual budget of contract research with industry between 2010 and 2019. Both the number of projects as well as the overall budget has been increasing in most of the years. However, in the same period, the Fraunhofer-Gesellschaft has been growing in terms of employees — increasing from about 14,000 to 18,000.[4] The compound average annual growth rate of the number of projects was 3.6 percent between 2010 and 2019, while the growth rate for the nominal budget reached 4.9 percent (real: 3.2%) and the one for the employees was 3.0 percent. In nominal terms, the average size of each project has been increasing during this period at a rate of 1.2 percent, however in real terms the average project size has been slightly decreasing at a rate of -0.5 percent (see Figure 3). The average industry project budget per employee was increasing slightly at an average rate of 1.7 percent (real: 0.2%) per year, so it is essentially rather stable over time. When taken together, these trends also mean that the share of national industry contracts in Fraunhofer's total budget has been increasing in this period as well. In addition, despite its growth in terms of employment, Fraunhofer was able to keep the average budget of these contracts more or less constant. Consequently, it is justifiable to conclude that Fraunhofer has succeeded in fulfilling its mission accomplishment of doing research with and for industry.[5]

4 https://www.datenportal.bmbf.de/portal/de/K17.html.

5 Fraunhofer mission: https://www.fraunhofer.de/en/about-fraunhofer/corporate-responsibility/governance/guiding-principles.html

Figure 2: Number of projects and annual budgets of Fraunhofer contracts with industry* in nominal (upper) and real** values (2015 constant prices, lower panel)

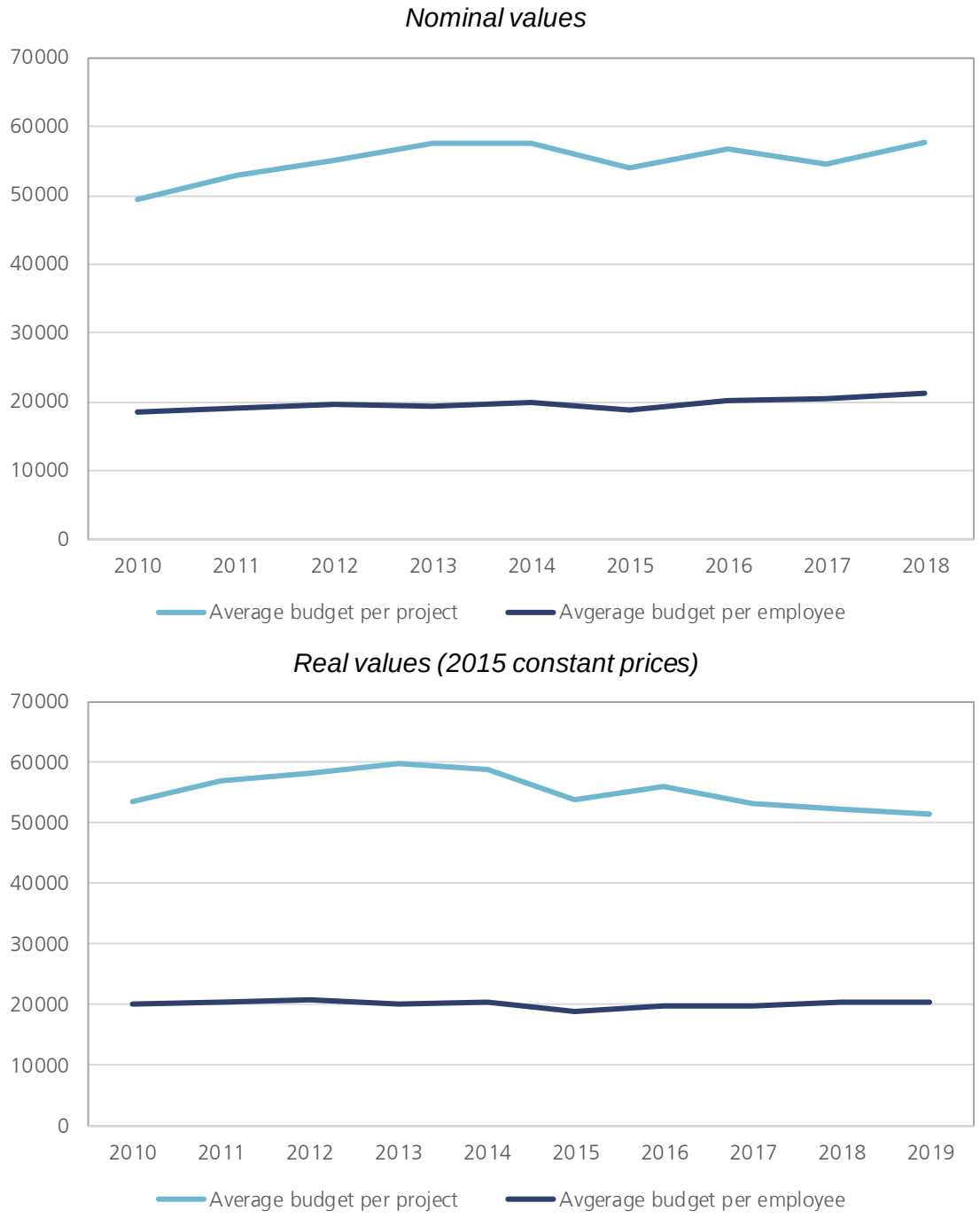


* Only considers contracts with contracting partners in Germany.

** Source for deflators is the OECD Statistics database OECD.stat, https://stats.oecd.org/

Source: Fraunhofer administrative data (SIGMA); Fraunhofer ISI calculations

Figure 3: Average size (in €) of the projects of Fraunhofer contracts with industry* in nominal (upper) and real** values (2015 constant prices, lower panel)



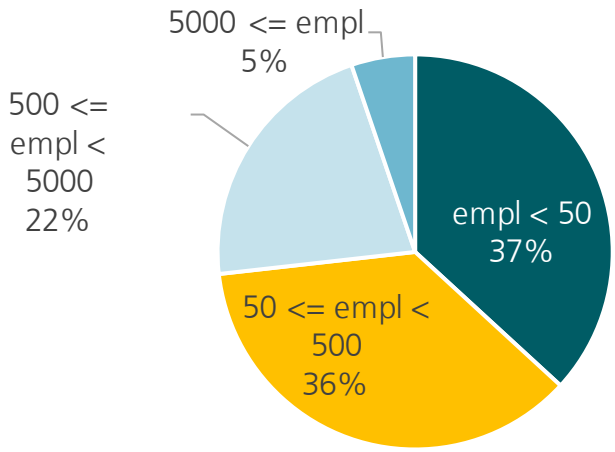
* Only considers contracts with contracting partners in Germany.

** Source for deflators is the OECD Statistics database OECD.stat, https://stats.oecd.org/

Source: Fraunhofer administrative data (SIGMA); Fraunhofer ISI calculations

The structure of these contracted projects in terms of the size of the customers is depicted in Figure 4. More than two thirds (68%) of the companies are small and medium-sized and another 20 percent belong to the broader definition of German "Mittelstand" (mid-tier-business), having less than 5,000 employees. Only 5 percent of the companies are large enterprises with more than 5,000 employees. This structure again underlines Fraunhofer's mission of collaborating with small and medium-sized companies or the "Mittelstand" in general. The aggregated budget of the projects of this latter group, however, is much higher than these 5 percent as the average size of collaboration projects with large enterprises is higher than the total average.

Figure 4: Size structure of the projects of Fraunhofer contracts with industry*, 2015–2018

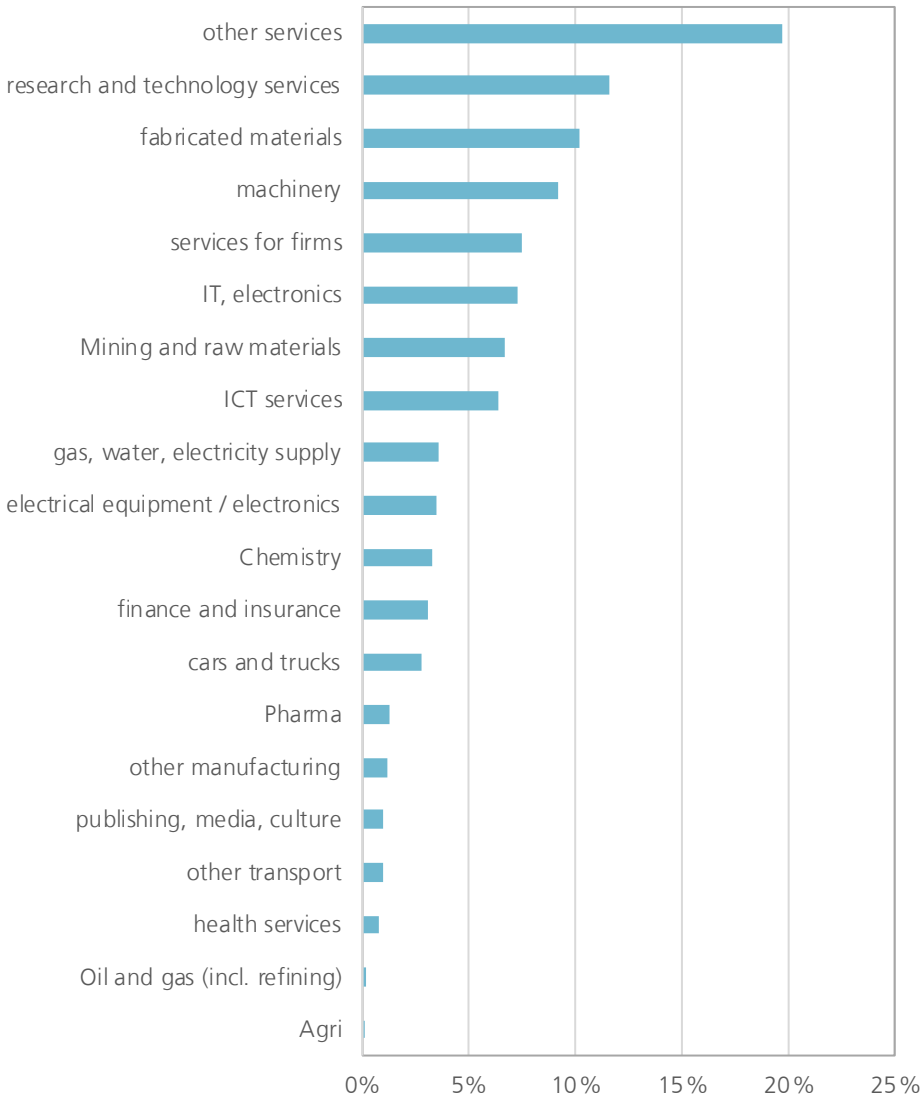


* Only considers contracts with contracting partners in Germany; this refers to 5,215 matched distinct companies.
Source: Fraunhofer administrative data (SIGMA); Fraunhofer ISI calculations

The sectors of the contracting industry partners are depicted in Figure 5. The largest share of companies of about 19 percent is with other services, which mainly include wholesale and retail companies as well as food and beverage services. The manufacturing sector is strongly represented by materials, machinery, transport (cars and trucks as well as other transport) and by chemical and pharmaceutical companies. IT and electronics as well as electrical equipment together stand for about 10 percent of the contracting companies. Services play a relevant role, especially research and technology services, but also ICT services. Energy suppliers (gas, water, electricity) and mining and raw materials providers are additional sectors where contracting partners are active.

The distribution of the budget volumes instead of the number of projects is presented in Figure 6. It can be seen that, by far, the largest budget comes from companies in the German automobile industry (cars and trucks), followed by other services, machinery industry, IT/electronics. Fabricated materials and chemistry stand for about 6 percent each, while other transport, pharmaceuticals, electrical equipment and energy suppliers account for 2–3 percent each.

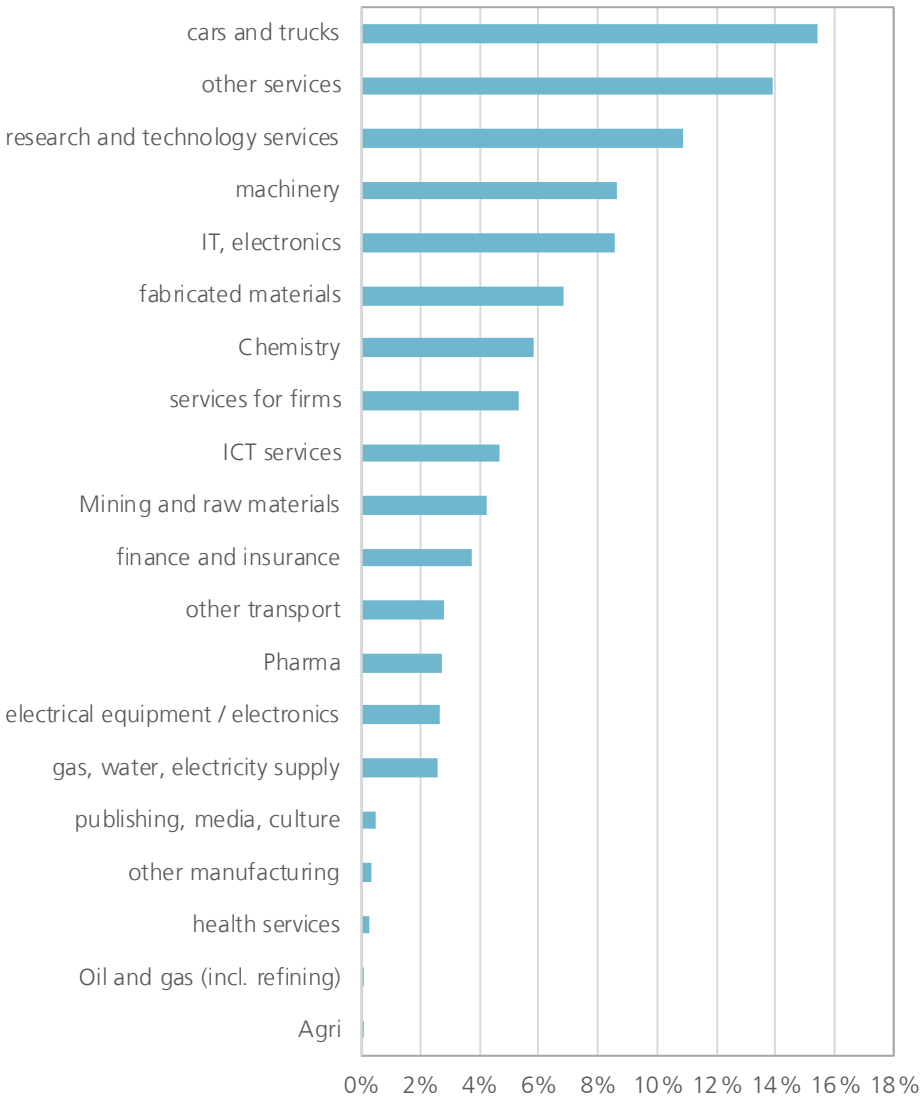
Figure 5: Projects of Fraunhofer contracts with industry* by sector in percent of total, 2010–2018



* Only considers contracts with contracting partners in Germany.

Source: Fraunhofer administrative data (SIGMA); Fraunhofer ISI calculations

Figure 6: Project volumes of Fraunhofer contracts with industry* by sector in percent of total, 2010–2018



* Only considers contracts with contracting partners in Germany.
Source: Fraunhofer administrative data (SIGMA); Fraunhofer ISI calculations

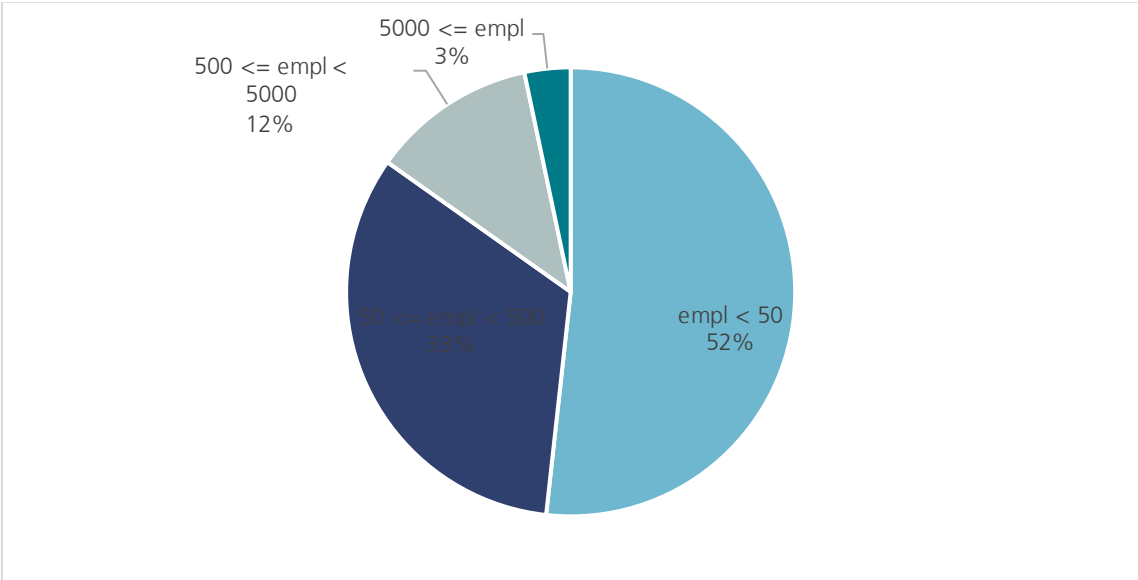
5.1.2 Publicly funded joint projects with industry

Next to direct contracts with industry, the knowledge and technology transfer also takes place in publicly funded joint projects with industry. In most cases, a number of industry partners participate in each project and more often than not other research partners are also involved in these projects. The nature of these projects is usually not development, but pre-competitive research. Consequently, from an industry's perspective these are rather basic research oriented projects addressing mid- to long-

term challenges for industry. For Fraunhofer, these projects provide the opportunity to bridge the gap between (basic) research results and potential applications in industry, which is another important aspect of the Fraunhofer-Gesellshaft's mission.

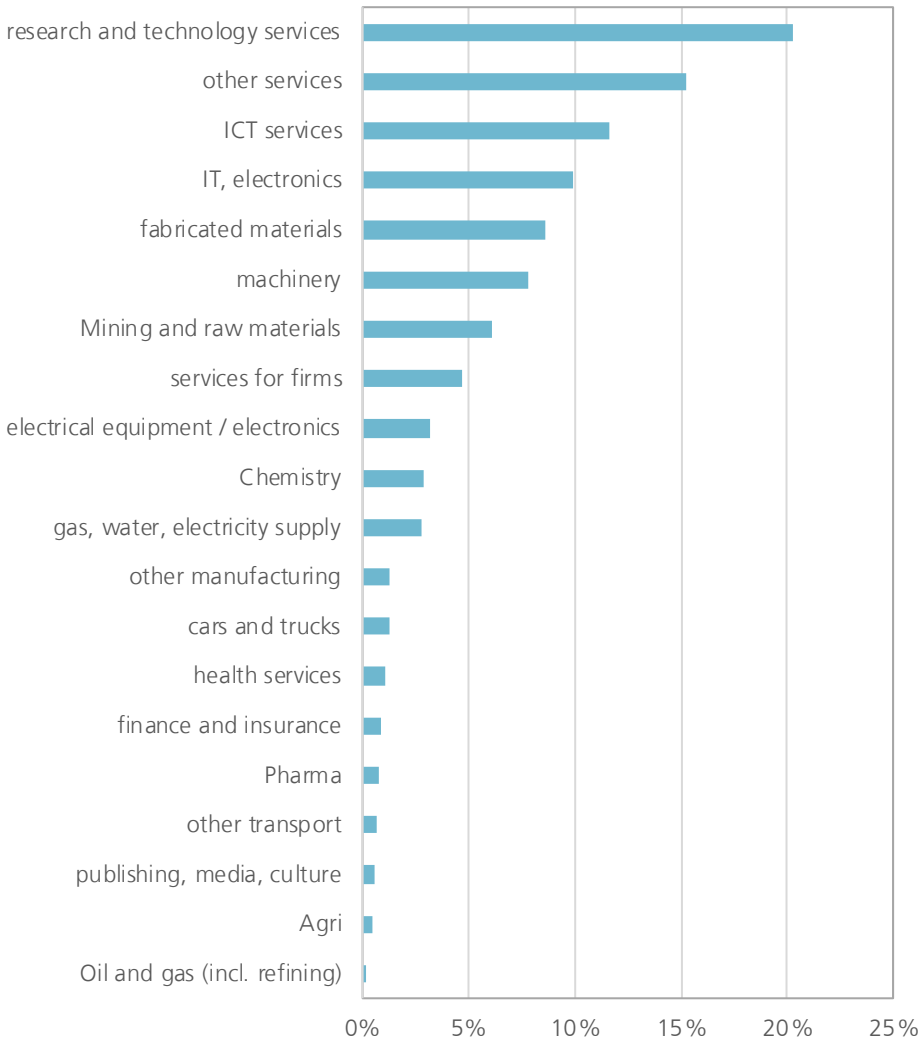
As can be seen in Figure 7, the size structure of the collaborating partners from industry is even more directed towards small and medium-sized enterprises than in the case of direct contract research. 77 percent of Fraunhofer's industry partners in publicly funded joint projects belong to the group of SMEs, another 11 percent belong to mid-tier-businesses with 500 to 5,000 employees and only 3 percent belong to the largest group. This structure stresses the opportunity of knowledge and technology transfer to enterprises in these publicly funded projects. It is often the case that companies which do not conduct regular R&D or even newcomers to innovation activities enter the scene via joint projects. From previous analyses, we know in addition that enterprises that collaborated with Fraunhofer in publicly funded projects subsequently also contracted Fraunhofer directly (Frietsch et al. 2016). Furthermore, we know that the probability of multiple collaborations with Fraunhofer is rather high once companies had collaborated once.

Figure 7: Employment structure of the partners in publicly funded joint research projects, 2015–2018



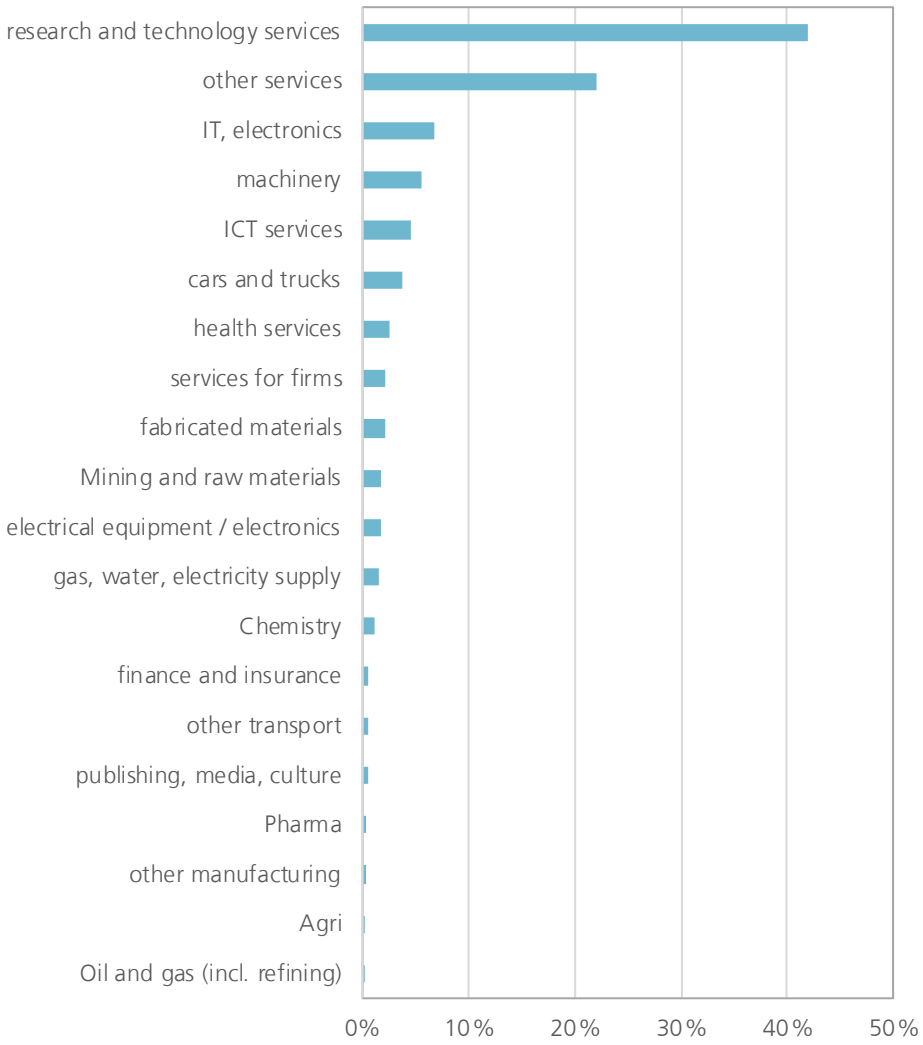
Source: Foerderkatalog; BvD - Orbis; Fraunhofer ISI calculations

Figure 8: Sectors of industry partners in publicly funded joint projects, 2015–2018



Source: Foerderkatalog; BvD - Orbis; Fraunhofer ISI calculations

Figure 9: Cumulated budget of Fraunhofer in publicly funded joint projects with industry by sectors, 2015–2018



Source: Foerderkatalog; BvD - Orbis; Fraunhofer ISI calculations

5.2 Results of the GMS analysis

As the Fraunhofer-Gesellschaft mostly cooperates with industrial firms, the following analyses only focus on manufacturing firms. The analyses are based on the matched data from the German Manufacturing Survey (GMS), which is the German part of the *European Manufacturing Survey (EMS*). The data allows a very detailed look at the research cooperation of industrial firms with the Fraunhofer-Gesellschaft or other public research organizations in Germany. Moreover, by taking self-reports of the firms into account, the matched data make it possible to differentiate between a "cooperation with Fraunhofer (contract research, and/or joint project)" and "no cooperation with Fraunhofer" as well as to identify firms that additionally cooperate with other public research organization (PROs or universities).

5.2.1 Dataset overview

In this report, data are used from 2012, 2015 and 2018. For all these survey waves, the survey samples the population very well (representativeness). In comparison with the information on the total population of manufacturing firms in Germany obtained from the German Statistical Office, the sample of GMS represents a good cross-section of manufacturing firms with at least 20 employees in terms of firm size, industry affiliation and geographic distribution. With regard to firm size, the data shows that small and medium-sized firms are particularly well captured. In terms of industry affiliation, the metal industry and mechanical engineering account for over one third of all firms — a share that corresponds with the total population (cf. Som 2012). Reference can also be made to the documentation of the survey methodology and sampling for each survey (e.g., for 2018 see Jäger/Maloca 2019). Table 1 presents exemplarily the firm size distribution of the data for all three waves; in the appendix (Table 18), the sectoral distribution is shown.

Table 1 Comparison of GMS data to Statistical office data, 2012, 2015, 2018 – referring to firm size distribution

	GMS 2012 (1)	GMS 2015 (1)	GMS 2018 (1)	Manufacturing firms in Germany (2)
Firm size classes	n	n	n	n
firms with 20 to 49 employees	41%	42%	47%	49%
firms with 50 to 499 employees	44%	44%	41%	41%
firms with 500 and more employees	15%	14%	12%	10%
Number	1594	1282	1256	45 815 (3)

Source: (1) GMS 2012, 2015, 2018; (2) The firm size distribution in all three waves closely corresponds the size distribution of the total population of manufacturing firms. See: Statistisches Bundesamt (2012, 2015, 2018), Fachserie 4, Reihe 4.1.2. (3) Exemplarily number of manufacturing firms in 2018; Fraunhofer ISI calculations

5.2.2 Cooperation with the Fraunhofer-Gesellschaft by partners from the manufacturing industry

With regard to the manufacturing firms that cooperate with Fraunhofer in the context of R&D projects, the distribution of these co-operations in the manufacturing sector in Germany is presented first. The next results shed light on the structural context of the cooperating companies. Finally, three interesting characteristics of the industrial cooperation partners are emphasized.

As Table 2 depicts, 8 percent of the manufacturers in 2018 cooperated with the Fraunhofer-Gesellschaft in the context of **contract research**. Moreover, 15 percent of all manufacturing firms participated in at least one **joint research project,** i.e. a publicly funded research and development project that includes a Fraunhofer institute. Overall, we obtained the information that, in 2018, 18 percent of the manufacturers have cooperated with Fraunhofer at least once in 2018 or the two years prior either via contract research or in the context of a publicly funded joint research project.

Table 2 Research cooperation in manufacturing, 2012–2018

	2012		2015		2018	
R&D Cooperation (Share of firms..)	n	%	n	%	n	%
R&D Cooperation with Fraunhofer-Gesellschaft (all						
with at least one contract research (SIGMA)	134	8%	119	9%	100	8%
with at least one joint research project (FKI	153	10%	172	14%	185	15%
overall cooperating with Fraunhofer-Gesellschaft	237	15%	228	18%	225	18%
R&D Cooperation in general (Self-reports)						
cooperation with any PRO's (incl. Fraunhofer)	746	49%	570	46%	515	42%
cooperation with PRO's other than Fraunhofer	538	35%	372	30%	322	27%
Inter-firm R&D cooperation						
R&D Cooperation with other firms	706	50%	622	50%	561	46%

Source: GMS 2012, 2015, 2018; Fraunhofer ISI calculations

In comparing the data for all three survey waves, we can state that the overall share of manufacturers cooperating with the Fraunhofer-Gesellschaft has been quite consistent in recent years. We can even observe a slight increase in the number of joint research projects; over the observed time period the share of manufacturers that cooperated with Fraunhofer in a publicly funded joint research project increased from 10 percent in 2012 to 15 percent in 2018. Even when allowing for major structural differences such as firm size, sector affiliation, and production characteristics as well as for R&D expenditure using a logit regression model as shown in Table 20 in the appendix, these findings remain consistent. Furthermore, it becomes clear that larger firms, producing

highly complex products and having a higher R&D intensity, are more likely to cooperate with the Fraunhofer Society.

For comparison, the cooperation in research and development with any type of research institution (RI) is also presented in the table. This share has been declining during the last decade, according to the companies' self-reports. In 2012, nearly half of the manufacturers cooperated with a research institution. In 2018, this share dropped down to 43 percent. This decline is mainly due to a steady decrease in collaborations with research institutions other than Fraunhofer institutes (like Helmholtz, Max-Planck, Leibniz or a respective organization abroad or with a university). In 2018, only 27 percent of manufacturers were cooperating with other research institutions compared to 35 percent in 2012. Finally, without any connection to a research institution, cross-company collaboration for research and development is much rarer. Only just under a quarter of these companies cooperate on R&D with other companies, be they customers, suppliers or competitors. Further analyses reveal that nearly 90 percent of manufacturers that cooperate with the Fraunhofer-Gesellschaft are also collaborating with other firms in this respect (2012: 88%, 2015, 2018: 88%). Among firms only cooperating with other research institutions, this share lies somewhat lower (2012: 87%, 2015: 74%, 2018: 73%).

Table 3 Share of manufacturers cooperating with the Fraunhofer-Gesellschaft by firm size classes, 2012–2018

	20 to 49 empl.	50 to 99 empl.	100 to 249 empl.	250 to 499 empl.	500+ empl.
Year	%	%	%	%	%
2012	9%	10%	19%	26%	48%
2015	12%	12%	21%	36%	56%
2018	12%	12%	25%	44%	55%

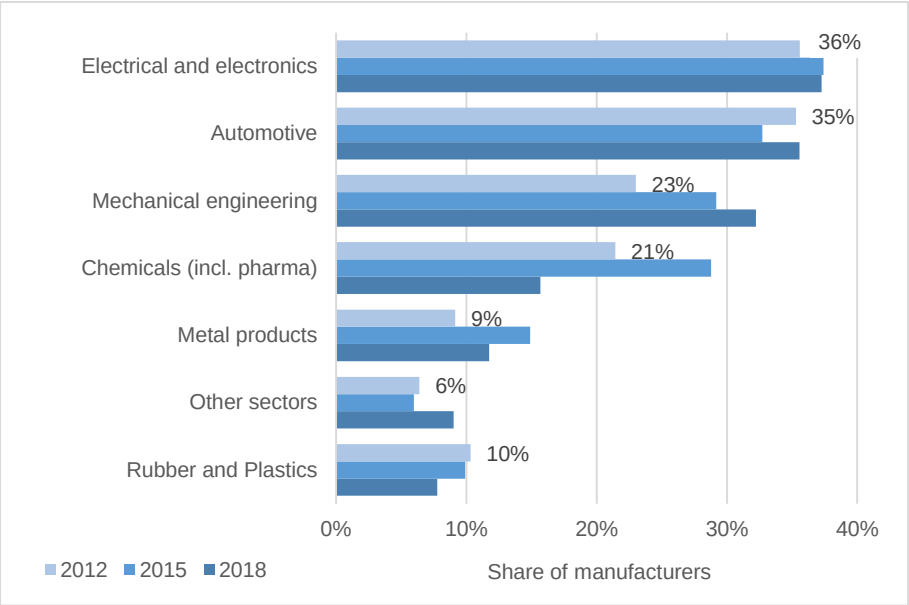
Source: GMS 2012, 2015, 2018; Fraunhofer ISI calculations

The following analyses shed more light on the R&D cooperation with Fraunhofer in any form (contract research and joint research projects) regarding firm size and sector affiliation. Firstly, as Table 3 highlights, medium-sized and large manufacturers cooperate with Fraunhofer more often. Moreover, in line with Table 2, these shares of cooperation were increasing over the observed period. In contrast, there is hardly any difference for very small firms and firms with 50 to 99 employees over time. Additional analysis demonstrates that it was possible to reach every 10th small manufacturer for cooperation. Thereby, publicly funded joint research projects with the Fraunhofer-Gesellschaft seem to be more accessible to SMEs, especially for larger SMEs, than

cooperations with Fraunhofer via contract research are. Among SMEs, the share of contract research remains very low with approx. 5% (Appendix: Table 19).

Secondly, Figure 10 illustrates the outreach of the Fraunhofer-Gesellschaft into the different manufacturing sectors: the Fraunhofer-Gesellschaft reaches a great variety of firms, however, the share of firms differs considerably among the sectors. Over one third of manufacturers of electrical or electronic products and manufacturers in the automotive sector cooperate with Fraunhofer. Approximately a quarter of mechanical engineering firms are reached. This share has been steadily increasing since 2012 due to more publicly funded projects, reaching a share of 32 percent in 2018. These key sectors are characterized by complex products and are rather digitalized. The cooperation rate of chemical firms varies the most, but it is still very considerable. Companies from other sectors, on the other hand, cooperate less frequently. Surprisingly, this also includes companies in the metal industry with a cooperation rate of only around 10 percent, although this sector continues to shape German manufacturing, as one in five manufacturers in Germany belongs to the metal industry. With predominantly medium complex products, this sector is not the core target group for Fraunhofer cooperation.

Figure 10 Share of manufacturers cooperating with the Fraunhofer-Gesellschaft by sector, 2012–2018



Source: GMS 2012, 2015, 2018; Fraunhofer ISI calculations

This size and sector focus is associated with other features of firms that cooperate with the Fraunhofer-Gesellschaft in R&D, which are summarized below based on the data from the 2018 survey. First, Table 4 demonstrates some key operating figures in detail.

Turnover and the number of employees underlines that medium-sized and larger firms are more likely to cooperate with Fraunhofer. The positive balance of cooperating enterprises in terms of value added per employee reflects the size of the enterprise; on average, larger companies achieve higher productivity. However, this advantage did not lead to higher turnover growth for cooperating firms. There are also no statistically significant differences with regard to the age of the company and the degree of internal value creation.

Table 4 Further firm characteristics, average value of co-operators and non-co-operators, 2018

Further firm characteristics	non-co-operators	co-operators	
Turnover (in million €)	23.45	123.46	***
Number of employees	104	700	***
Value added (turnover minus input per capita, in thousands €) per employee	99.1	108.9	***
Avg. annual growth of turnover (2015–2017, in %)	7.2	10.8	
Avg. annual growth of employment (2015–2017, in %)	5.8	6.2	*
In-house degree of value creation (turnover minus input over turnover)	0.59	0.61	
Age of company [years]	53.1	54.7	

Source: GMS 2018; Fraunhofer ISI calculations. A statistically significant difference between cooperating and non-cooperating manufacturing firms: *** p< 0.001, ** p<0.01 * p<0.05

Impressively, however, cooperating firms show a statistically significant higher annual employment growth, which would not be expected given the average firm size. Further analyses show that the manufacturers cooperating with the Fraunhofer-Gesellschaft employ a higher share of highly qualified employees (graduates and high skilled employees). No differences can be found in the proportion of the skilled labor force. Regarding the functional areas, the qualification profile of the employees is also reflected in a higher share of employees working primarily in R&D, but also in design and construction. This is accompanied on average by fewer people working in manufacturing and assembly.

Three further aspects should be highlighted to describe manufacturers who cooperate with institutes of the Fraunhofer-Gesellschaft on research and development topics.

1. Manufacturers who cooperate with Fraunhofer are **more innovation-oriented**.
2. Fraunhofer is collaborating with a wide range of manufacturers that are characterized by a **modern production organization**, are more likely to use new organizational concepts, technologies and produce complex products.
3. Manufacturers that **operate globally** are more likely to cooperate with the Fraunhofer-Gesellschaft.

As was also found in our previous study (see Frietsch et al. 2016), manufacturers who cooperate with the Fraunhofer-Gesellschaft are **more innovation-oriented** (Table 5). This is already evident in the qualifications of their personnel. Furthermore, 9 out of 10 of the cooperating companies invest in R&D and spend statistically significantly more than their competitors, of which only 2 out of 5 have R&D expenditures at all. Moreover, the R&D performance of the cooperating companies has increased over time (2012: 79%; 2015: 80%; 2018: 89%). In contrast, this was not the case for manufacturers not collaborating with Fraunhofer. This innovation orientation is also reflected in the higher patenting rate of Fraunhofer-collaborating companies (30% vs. 6%) as well as in a high share of firms claiming innovation as one of their two primary competitive factors (38% vs. 19%). As a result, the collaborating companies achieve significantly higher innovative business performance, both in terms of new products, market innovations and product-related service offerings. However, it should be noted that the share of product innovators has declined during the observation period. This trend can also be observed among cooperating enterprises (2012: 79 %; 2015: 83 %; 2018: 71 %) and is essentially due to the focus on process optimization and digitalization, as the following results show.

Table 5 Innovative orientation and modern production management for firms cooperating with Fraunhofer, 2018

Innovativeness	Non-co-operator %	Co-operator %	
Employees with tertiary degrees	10%	21%	***
Share of firms with R&D expenditure	39%	89%	***
Share of R&D expenditure (R&D performers)	6.0%	7.4%	***
Share of patent applicators	6%	30%	***
Share of product innovators	47%	71%	***
.. service innovators	12%	27%	***

Production management	Non-co-operator %	Co-operator %	
Automated warehouse management	25%	39%	***
Supply chain management	38%	49%	**
4 out of 5 central organizational concepts used	26%	44%	***
At least one new org. concepts introduced	30%	38%	*
At least one new technology introduced	33%	42%	*
Robots and handling systems in the production process	28%	36%	*

Source: GMS 2018, extract Germany; Fraunhofer ISI calculations. A statistically significant difference between cooperating and non-cooperating manufacturing firms: *** p< 0.001, ** p<0.01 * p<0.05

Secondly, manufacturers cooperating with the Fraunhofer-Gesellschaft are characterized by a **modernized production organization** and are more likely to use new technologies. As an example, the shares of companies that use an automated warehouse management system and supply chain management are shown in Table 5. Furthermore, it can be seen that the firms cooperating with Fraunhofer use central organizational principles more frequently: 44 percent use at least four out of the following five concepts (set-up time optimization methods, task integration, production

control according to the pull principle, quality assurance methods and standardized work instructions). Among the non-cooperating companies, this share is only one quarter (26%). Cooperating firms are also more dynamic in modernizing their production structures: in the three years prior to the survey, 38 percent had introduced a new organizational concept or 42 percent had introduced a new production technology, in contrast to the non-cooperating companies. As expected in view of the company size distribution, the cooperating companies also use classic automation technologies such as robotics more frequently. At this point, it should be noted that this orientation towards a modern production organization is linked to R&D cooperation in general and is not only promoted through cooperation specifically with the Fraunhofer-Gesellschaft.

Table 6 Index of Industry 4.0 readiness and product complexity, 2018

	Industry 4.0 readiness *				Product complexity ***		
	no digital technology used	basic user	advanced user	top user	simple	medium complex	Complex
Non-cooperating firms	15%	24%	45%	16%	22%	53%	25%
Co-operating firms	12%	16%	49%	23%	9%	43%	48%

Source: GMS 2018, extract Germany; Fraunhofer ISI calculations. A statistically significant difference between cooperating and non-cooperating manufacturing firms: *** p< 0.001, ** p<0.01 * p<0.05

Furthermore, the cooperating companies are, on average, more digitalized in terms of their production technologies (Lerch and Jäger 2020). Every 4th company of the top users cooperates with Fraunhofer according to the Industry 4.0 Index by Fraunhofer ISI. However, it is also interesting to note that every 10th firm that cooperates with the Fraunhofer-Gesellschaft does not use any of the digital technologies. This shows the strength of the Fraunhofer-Gesellschaft in addressing very different production settings of complex products: Fraunhofer collaborations not only target companies with automated high technology, but also have relevant offerings for other manufacturers of complex products. Manufacturers of complex products are the focus; just under half of all cooperation partners belong to group of complex product manufacturers (Table 6).

Table 7 Involvement in global value and knowledge chains, 2018

	Production abroad	R&D sites abroad	Share of exporters	Share of Importers
Non-cooperating firms	9%	4%	83%	84%
Co-operating firms	26%	18%	95%	92%

Source: GMS 2018, extract Germany; Fraunhofer ISI calculations

Thirdly, the Fraunhofer-Gesellschaft is associated with companies that **operate more globally** (Table 7). More than a quarter of the German manufacturers that cooperate

with the Fraunhofer-Gesellschaft have a production site abroad. Even almost every fifth cooperation partner conducts research and development abroad. In addition, Fraunhofer cooperation partners are more likely to export their products and more likely to source inputs for their production from abroad.

Even when allowing for important structural differences such as company size, industry and production characteristics, and R&D expenditures using a logit regression model, the differences in R&D locations abroad and the share of exporters remain (cf. appendix Table 20). Regardless of their firm size, manufacturers that cooperate with the Fraunhofer-Gesellschaft are more likely to sell their products abroad and are correspondingly more likely to have R&D capacities abroad in order to meet the needs of these foreign markets and customers with their products.

5.2.3 Performance effects of cooperating with Fraunhofer-Institutes for manufacturers

Besides the presented structural relations and related characteristics of manufacturers that cooperate with the Fraunhofer-Gesellschaft, this sub-chapter focuses on the firm and innovation performance. The question is whether cooperation with Fraunhofer shows an impact on the performance of the manufacturers. In order to do that, we have run a series of multivariate (OLS) regression models with several economic performance related measures as dependent variables, i.e. (1) **value added per employee**, (2) **development of employment**, (3) **development of turn-over** based on the survey data and (4) **earnings before Interest and Taxes (EBIT)** based on the Amadeus data.

Added value is defined as total turnover minus intermediate consumption based on the responses on annual turnover and services and materials procured as indication of value creation at the company level in relation to the number of employees. The **development of turnover** is measured as the percentage change in the turnover per year in the two years preceding the survey. The **development of employment** is measured as the percentage change in the number of employees per year in the two years preceding the survey. Both indicators reflect economic development from two different perspectives. For both indicators, the survey data are also used due to the higher exhaustiveness of the data. **Earnings before Interest and Taxes (EBIT)** is a measure of the profitability of the business that can be used to compare the operating results of companies without the influence of fluctuating tax rates or different interest rates on debt.

To assess the impact of the **Fraunhofer cooperation**, the **overall indicator** is used in combination with the control indicator on any cooperation with a research institution. In addition, major structural differences such as firm size, sector affiliation, and production characteristics as well as R&D expenditure are also taken into account. For firm size, we differentiate between very small firms, medium-sized SMEs and larger firms. As batch size and product complexity are determinants for the economic performance of manufacturers, both indicators are included. Regarding R&D, we take into account whether a firm is conducting R&D at all, as well as whether the firm is average in spending on R&D (less than 5%) or belongs to the top 15 with more than five percent R&D expenditure.

The survey waves were pooled to obtain a sufficiently large data set for the following estimates. The analyses are thus estimated on pooled cross-sectional data. This increases the sample size. It also leads to more accurate estimators and test statistics with higher test strength. Therefore, all models include the control variables for the survey years.

Table 8 Impact of Fraunhofer cooperation on performance, marginal effects

	Value added per employee			Develop. of turn-over			Develop. of employment			EBIT		
	dy/dx		se	dy/dx		se	dy/dx		se	dy/dx		se
Firm size, ref: 20 to 49 employees												
50 to 249 employees	6.498	*	2.649	-0.309		0.893	1.562	+	0.872	-0.404		0.683
250 and more employees	31.209	**	4.388	-3.149	*	1.373	-2.053		1.34	-0.015		0.834
Sector, ref: Food, textile, wood, others												
Chemicals incl. pharma, rubber, plastics	11.15	**	3.61	3.483	**	1.223	2.596	*	1.189	1.228		0.812
Mechanical engineering, metal products, automotive	-3.78		3.192	4.097	**	1.077	2.113	*	1.041	0.501		0.722
Electrical, electronic products	-5.685		4.612	4.268	**	1.506	2.201		1.465	1.381		1.038
Product complexity, ref: simple products												
Medium complex products	-3.063		3.25	2.007	+	1.104	0.118		1.078	0.313		0.767
Complex products	1.614		3.871	5.408	**	1.304	2.76	*	1.272	-0.282		0.873
Batch size, ref: Single unit production.												
Small/medium sized batch	5.098	+	2.899	3.123	**	0.967	1.97	*	0.943	-0.227		0.624
Large batch production	19.586	**	4.025	3.746	**	1.348	1.202		1.322	-0.319		0.874
R&D performer, vs. non R&D expenditure	6.271	*	2.886	-0.151		0.966	1.023		0.941	1.087	+	0.606
Time point of data, ref: Survey in 2012												
Survey in 2015	2.723		2.883	-7.687	**	0.967	-0.144		0.943	-1.345	*	0.577
Survey in 2018	11.387	**	2.934	-5.343	**	0.98	2.457	*	0.956	0.597		0.764
R&D cooperation with Fraunhofer	-0.097		3.806	0.953		1.228	0.37		1.194	1.537	*	0.702
R&D cooperation with any research institute	6.731	*	2.991	2.06	*	1.001	0.046		0.974	-0.107		0.634
Model fit N	2,620			3,341			3,432			804		
adj. r^2 (sig.)	0.0617	***		0.0361	***		0.0077	***		0.0176	**	

Source: GMS, German funding catalog, SIGMA, BvD AMADEUS; Fraunhofer ISI calculations.

Notes: Standard errors in parentheses, significance level *** p<0.01, ** p<0.05, * p<0.1

The estimation results of the models are shown in Table 8: According to the test of the explanatory power of the main determinants, a positive effect of R&D cooperation is generally observed on **value added per employee**. However, no additional effect is found for *R&D cooperation* specifically with the Fraunhofer-Gesellschaft. Cooperation with Fraunhofer is positively associated with this performance indicator, but no more strongly than R&D cooperation with other research institutes. This implies that cooperation with Fraunhofer is positively associated with performance, but not to a greater extent than the influence of R&D cooperation with another research institute.

As expected, other relevant influencing factors for estimating added value are firm size, batch size and R&D orientation. *Firm size* is a strong predictor for added value per employee. As often shown, larger firms have statistically significantly higher added value. In general, they are able to realize greater economies of scale within their boundaries than smaller firms given the latter's reduced and sometimes sub-critical mass in certain production and auxiliary functions. The *batch size* of the firms' production processes is also positively correlated to this performance measure. Economies of scale are easier to realize under the framework conditions of large batch size production than in small and medium sized batches. Finally, *R&D orientation* is positively related to added value per employee. On the one hand, this reflects the innovative capacity of a company. R&D-conducting companies, especially R&D-intensive companies, have a higher absorptive capacity for advanced production technologies and organizational concepts than non-R&D firms do. On the other hand, this indicator also represents the company's focus on establishing itself in the market through the innovative strength of its own product portfolio instead of merely competing on price.

The **turnover development** is estimated to be centrally determined by the sectors, the batch size and the product complexity. Here, too, a positive effect of R&D cooperation can be observed. An additional effect for the cooperation specifically with Fraunhofer cannot be determined. In addition, it is clear that the development of turnover in 2012, i.e. directly after the financial crisis in 2009, was significantly higher than in the following years. In 2018, the development was comparatively more dynamic than in 2015.

The multiple analysis of **employment development** shows no effect on R&D cooperation. Rather, the decisive factors here are the industry and the production characteristics. The positive correlation of a cooperation with Fraunhofer and the employment development in the bivariate comparison as reported above does not stand up to validation when controlling for other influencing factors. Although companies that cooperate with Fraunhofer for R&D show a more positive employment

development, this is not due to the cooperation itself, but rather to other factors that are also associated with the probability to cooperate.

The final performance indicator examined is **EBIT**. Even though the estimation model is much weaker due to the significantly lower data coverage, two interesting results emerge. The influence of cooperation with Fraunhofer is positively estimated, even if the estimator is only statistically significant at a 10 percent level. Even when taking into account the other indicators of company size, industry and production characteristics and R&D, firms that cooperate with Fraunhofer have a statistically significantly higher turnover in the following years and generate higher profits than firms that do not cooperate with Fraunhofer. In addition, the R&D orientation is another central influencing variable in this model. Companies that conduct R&D achieve a higher EBIT than companies that do not spend on R&D. For control purposes, the model was repeated without controlling for production characteristics, which led to comparable results.

In summary, it can be said that a specific effect of cooperation with Fraunhofer on economic performance can hardly be determined. However, these models did show the positive influence of R&D cooperation per se on economic performance. In order to shed more light on this connection, the following analyses focus firstly only on estimating the influence of R&D cooperation in general. On the other hand, in addition to the simple R&D orientation, the R&D intensity is also controlled for, in order to make the influence of the cooperation even clearer.

Table 9 Impact of R&D cooperation in general on performance, marginal effects

	Value added per employee			Develop. of turn-over			Develop. of employment			EBIT		
	dy/dx		se	dy/dx		se	dy/dx		se	dy/dx		se
Firm size. ref: 20 to 49 employees												
50 to 249 employees	6.967	**	2.6	-0.232		0.9	1.48	+	0.9	-0.292		0.69
250 and more employees	30.193	**	4.4	-2.925	*	1.4	-2.227		1.4	0.556		0.85
Sector. ref: Food. textile. wood. others												
Chemicals incl. pharma. rubber. plastics	11.264	**	3.6	3.535	**	1.23	2.698	*	1.2	1.358	+	0.82
Mechanical engineering. metal products. automotive	-4.303		3.2	4.057	**	1.08	2.183	*	1.1	0.596		0.73
Electrical. electronic products	-6.417		4.6	4.332	**	1.53	2.416		1.5	0.667		1.07
Product complexity. ref: simple products												
Medium complex products	-3.107		3.2	2.026	+	1.11	0.07		1.1	0.305		0.78
Complex products	-0.139		3.9	5.526	**	1.32	2.943	*	1.3	-0.531		0.9
Batch size. ref: Single unit production .												
Small/medium sized batch	4.479		2.9	2.96	**	0.98	2.051	*	1	-0.373		0.64
Large batch production	20.068	**	4.0	3.815	**	1.36	1.386		1.4	-0.495		0.89
R&D intensity. ref: no R&D expenditure												

	Value added per employee			Develop. of turn-over			Develop. of employment			EBIT		
	dy/dx		se	dy/dx		se	dy/dx		se	dy/dx		se
< 5% R&D expenditure	1.733		3.4	0.663		1.16	1.751		1.2	-0.072		0.7
5% or more R&D expenditure	9.542	**	3.4	-1.152		1.14	0.538		1.1	2.485	**	0.73
Time point of data. ref: Survey in 2012												
Survey in 2015	2.977		2.9	-7.132	**	0.98	0.021		1	-1.302	*	0.58
Survey in 2018	11.957	**	2.9	-4.777	**	0.99	2.476	*	1	0.668		0.8
R&D cooperation with any research institute	7.32	*	2.9	2.339	*	0.98	0.195		1	0.248		0.63
Model fit N	2,557			3,234			3,312			761		
adj. r^2 (sig.)	0.0625	***		0.0331	***		0.0078	***		0.0247	**	

Source: GMS, German funding catalog, SIGMA, BvD AMADEUS; Fraunhofer ISI calculations

Notes: Estimation of linear regression models. Standard errors in parentheses, significance level *** p<0.01, ** p<0.05, * p<0.1

The estimates in Table 9 show that added value per employee will be higher when firms spend more on R&D, especially when R&D spending is above average. In addition, a higher added value per employee is achieved when a firm cooperates with an R&D institution. The annual percentage change in turnover as an indicator of the firm's economic development is also higher when a company is involved in an R&D cooperation. However, there is no additional correlation with the company's R&D activity. The model for EBIT is also improved by taking into account the extent of R&D expenditure. However, R&D cooperation remains without any further additional explanatory contribution.

Against this background, we will take a closer look at the **innovation output**. Firstly, we are interested to see whether R&D cooperation is a predictor of the opportunity for product innovation or service innovation. Secondly, the question arises whether the turnover with innovations is higher for firms that cooperate with Fraunhofer. Finally, we address whether firms are more likely to apply for a patent in the three years following their cooperation with Fraunhofer than their non-cooperating counterparts.

Table 10 Innovation output, marginal effects

	Product innovator [1]		Turnover with new products [2]		Service innovator [3]		Turnover with new services [4]		Patents [5]	
	dy/dx		dy/dx		dy/dx		dy/dx		dy/dx	
Firm size, ref: 20 to 49 employees										
50 to 249 employees	**0.113**	******	**-2.525**	******	**0.034**	*****	-1.163		**0.058**	******
250 and more employees	**0.157**	******	**-3.338**	******	**0.062**	******	**-3.729**	*******	**0.172**	******
Sector, ref: Food, textile, wood, others										
Chemicals incl. pharma, rubber, plastics	-0.029		-1.067		0.025		-3.958	**	0.024	+
Mechanical engineering, metal products, automotive	-0.123	**	-0.097		0.008		-4.284	***	0.031	*
Electrical, electronic products	0.044		1.757		0.017		-3.737	**	0.047	**
Product complexity, ref: simple products										
Medium complex products	**0.065**	*****	**2.053**	**+**	**0.05**	******	1.289		-0.004	

	Product innovator [1]		Turnover with new products [2]		Service innovator [3]		Turnover with new services [4]		Patents [5]	
	dy/dx		dy/dx		dy/dx		dy/dx		dy/dx	
Complex products	**0.158**	**	**6.242**	**	**0.106**	**	1.939		-0.002	
Batch size, ref: Single unit production										
Small/medium sized batch	0.093	**	-1.842	*	0.009		-0.865		0.011	
Large batch production	0.032		-2.024	+	-0.011		0.286		0.015	
R&D intensity, ref: no R&D expenditure										
Less than 5% R&D expenditure	0.291	**	-0.114		0.031	+	-1.140		0.025	*
5% or more R&D expenditure	0.354	**	2.701	**	0.065	**	0.939		0.049	**
Time point of data, ref: Survey in 2012										
Survey in 2015	-0.037		-0.271		-0.036	*	-0.219		-0.006	
Survey in 2018	-0.074	**	0.113		-0.025	+	-0.724			
R&D cooperation with Fraunhofer	**0.062**	*	**1.591**	+	**0.012**		-0.625			**
R&D cooperation with any research institute	**0.128**	**	0.592		**0.044**	**	-0.465			**
Model fit N (sig)	3.561	***	1.888	***	3.324	***	497	***	2.504	**

Source: GMS, German funding catalog, SIGMA, BvD AMADEUS; Fraunhofer ISI calculations

Notes: Estimation of logistic (1, 2, 5) and (2, 4) regression models. Standard errors in parentheses, significance level *** p<0.01, ** p<0.05, * p<0.1

For all five measures of innovativeness, firm size is a relevant predictor as depicted in Table 10. Larger manufacturers are, on average, more innovative and achieve greater innovation output. For direct innovation output in the form of product or service innovation, there is also a correlation with the complexity of the manufactured product. Thus, product innovation is more likely to occur in companies with medium-sized series. Production and service innovators are more likely to be found in companies with complex products. Industry affiliation, on the other hand, plays a minor role. As a side note, the reported decline in the share of product innovators over time is also reflected in these pooled cross-section data. In addition, it is evident that the share of manufacturers who generate sales with service innovations is very low.

As expected, there is a positive relationship between innovation intensity and innovation output. However, the estimation for the impact of R&D cooperation differs. In addition to R&D cooperation in general, R&D cooperation with Fraunhofer has a positive impact on the odds that a firm will introduce new products, i.e. firms that cooperate with Fraunhofer are more likely to be product innovators than companies that cooperate with other research institutions. Furthermore, for the product innovators themselves, a R&D cooperation does not lead to a higher innovation output (share of turnover with new products). With regard to service innovation, the positive impact of R&D cooperation can be noted. R&D cooperating companies are more often service innovators. Here, however, cooperation with Fraunhofer shows no additional explanatory contribution. Companies that cooperate with Fraunhofer are not more likely to produce service innovations than if they collaborate with other public research organizations. Finally, the last model allows us to look at the probability that a company

applied for a patent following the cooperation. Here, industry and company size are decisive influencing variables, as well as R&D intensity. In addition, having had an R&D cooperation during the previous three years has a positive influence.

The analyses using the **matched-pair approach** support these conclusions; here, similar results are obtained as with the logit models. Thereby, the R&D cooperation with Fraunhofer was examined as the so-called treatment. Each company cooperating with Fraunhofer was assigned a statistical twin. These twins were determined by their similarity to the cooperating firm in terms of number of employees, industry affiliation, R&D status and product complexity. Furthermore, it was imperative that data from the same survey year be used. For the dichotomous output variables, the procedure known as nearest-neighbor matching is employed. For the metric output variables, the propensity score matching method is used for matching. While analyzing, a distinction is made between the estimation of the Average Treatment Effect (ATE) and the Average Treatment Effect of the Treated (ATET). The ATE measures the average effects in relation to the entire sample. In other words, the entire population of companies is considered, irrespective of whether they have cooperated with Fraunhofer or not. The ATET, on the other hand, refers only to the companies that have cooperated with Fraunhofer and reflects their influence on the respective dependent variable.

Table 11 Results of the matched-pair models on the impact of a R&D cooperation with Fraunhofer

	Average Treatment Effect (ATE)			Average Treatment Effect of the Treated (ATET)			N
	Coef.	Std. Err.		Coef.	Std. Err.		3.828
Product innovator	0.149	0.047	***	0.061	0.023	***	2.022
Turnover with new products	-0.648	1.088		1.455	1.153		3.567
Service innovator	0.033	0.031		0.014	0.026		524
Turnover with new services	-2.273	0.642	***	-0.094	0.636		2.688
Patent three years after cooperation	0.124	0.039	***	0.186	0.031	***	3.828

Source: GMS, German funding catalog, SIGMA, BvD AMADEUS; Fraunhofer ISI calculations

Notes: Estimation of logistic (1, 2, 5) and (2, 4) regression models. Standard errors in parentheses, significance level *** p<0.01, ** p<0.05, * p<0.1

Figure 11 depicts the results of the matched pair analyses on the impact of a cooperation with Fraunhofer on selected innovation indicators. The column with the estimate of the Average Treatment Effect of the Treated (ATET) is particularly relevant for the interpretation. The estimate of the impact of a Fraunhofer cooperation on the chance of product innovation and follow-up patenting corresponds to the results of the logit models presented above. A manufacturing firm that cooperates with Fraunhofer on

R&D is more likely to be a product innovator and will more likely file for a patent. However, the link to the turnover with newly innovated products is not confirmed, i.e. the extent to which new products are successfully offered on the market.

5.3 Results of the ORBIS analysis

This section describes the results of the analyses with BvD's ORBIS database. The difference to the results of the GMS data is that we are looking at the full universe of German firms that have cooperated with public research (PROs or universities), either within joint research projects or in contracted research projects[6]. However, ORBIS offers us only structural information, like the number of employees or financial measures, but no in-depth information on operational mechanisms within firms, as the GMS does. The advantage of ORBIS is a much larger coverage in terms of firms that have cooperated with Fraunhofer as well as other PROs and universities, which allows us to extend our analyses and results to a larger set of companies also beyond the manufacturing sector and to enter into a more detailed analysis of sectoral differences.

5.3.1 Dataset overview and descriptive statistics

Table 12 provides an overview of the variables in the matched ORBIS dataset. In total, the dataset consists of 34,112 observations, of which 18,179 belong to the control group, i.e. firms that did not cooperate with public research organizations in the five-year observation period (2015-2019). The remaining 15,933 firms have cooperated with a university or a PRO at least once in the last five years. Nearly all the cooperating firms in the sample have cooperated with a Fraunhofer institute at least once. However, this is an effect of sample selection as we have a large share of firms that directly contracted Fraunhofer for a research project within the sample (contract research identified in internal database SIGMA). Data on publicly funded, joint research projects, on the other hand, are available for all PROs and universities in Germany. For simplicity, we sampled these groups into one dataset, but we analyzed them separately.

In joint research projects, overlaps of collaborations with PROs or universities are possible, for example, joint research projects by industry in cooperation with a Fraunhofer Institute and a Max-Planck Institute. The second most frequent partner in publicly funded collaborative research projects — next to Fraunhofer — are universities in general. In more detail, these are technical universities TU20 (and the TU9), and in

6 The differentiation of contract research vs. joint research projects is only available for the Fraunhofer institutes.

the further ranks these are the Helmholtz-Association (HGF), the Leibniz Association (WGL) and the Max-Planck Society (MPG).

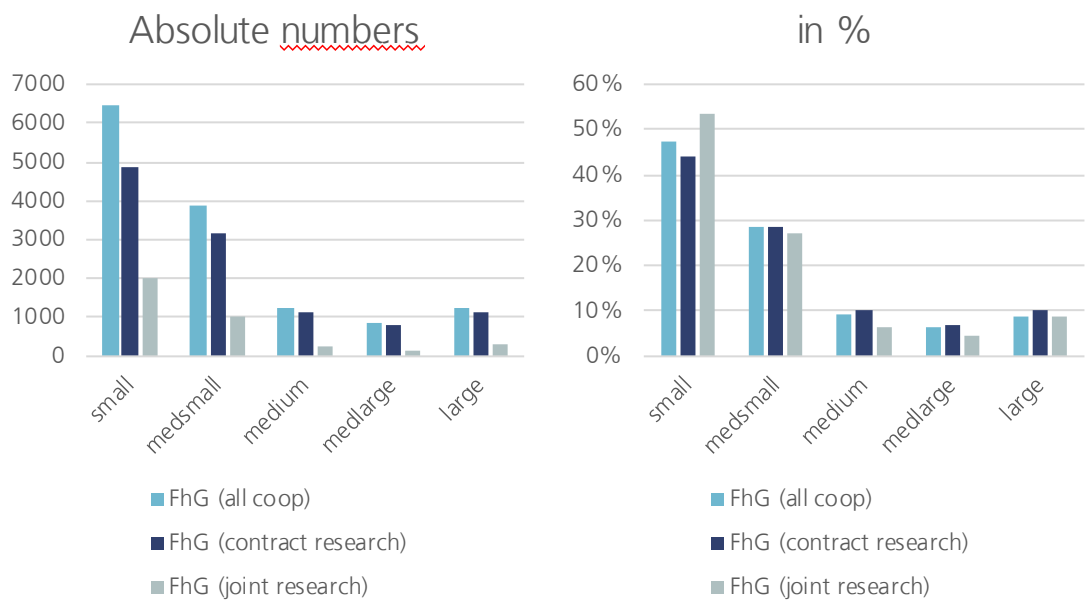
Table 12 Summary statistics

	Variable	Obs.	Obs. coded=1	Mean	Std. Dev.	Min	Max
Cooperation with…	Fraunhofer (all coop)	31623	15690	0.50	0.50	0.00	1.00
	Fraunhofer (contract research)	28776	12843	0.45	0.50	0.00	1.00
	Fraunhofer (joint research)	20131	4198	0.21	0.41	0.00	1.00
	MPG	16252	319	0.02	0.14	0.00	1.00
	HGF	18250	2317	0.13	0.33	0.00	1.00
	WGL	17064	1131	0.07	0.25	0.00	1.00
	University	22444	6511	0.29	0.45	0.00	1.00
	TU9	19250	3317	0.17	0.38	0.00	1.00
	TU20	20165	4232	0.21	0.41	0.00	1.00
	Cooperation total (0=Control group)	34112	18179	0.53	0.50	0.00	1.00
ORBIS	No. of employees	31886		677.58	8,230.00	1.00	642,292.00
	No. of employees (grouped)	31727		1.82	1.12	1.00	5.00
	SME Dummy (0=nein, 1=ja)	31886		0.90	0.30	0.00	1.00
	Operating Revenue	16796		326,926.50	3,299,499.00	0.00	231000000.00
	Operating Revenue (grouped)	16796		3.00	1.41	1.00	5.00
	Operating Revenue/Emp	16515		802.48	19,738.07	0.00	2,258,070.00
	No. of transnat. patents	34112		16.33	282.23	0.00	18,876.00
	Transnational patents dummy (0=no, 1=yes)	34112		0.14	0.35	0.00	1.00
	No. of DPMA patents	34112		14.10	317.33	0.00	34,177.00
	DPMA patents dummy (0=no, 1=yes)	34112		0.11	0.32	0.00	1.00
	NACE (2-digit)	32943		7.95	4.98	1.00	19.00
AMADEUS	ROE	7258		21.19	95.01	-919.16	911.74
	EBITDA	7522		44,799.65	708,056.50	-12,000,000.00	33,600,000.00
	EBIT Margin	4946		4.02	13.41	-98.83	100.00

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

Figure 11 shows the differentiation of firms cooperating with the Fraunhofer-Gesellschaft by size class. The majority of companies cooperating with Fraunhofer come from contract research, but Fraunhofer Institutes also cooperate within joint research projects with firms of all size classes. The largest share of cooperation, nearly 50 percent, can be observed for small companies, i.e. companies with less than 50 employees, implying that Fraunhofer Institutes are one of the major research partners especially for smaller firms, which confirms the results from the GMS analyses. The next largest group of cooperating firms are the medium-small ones, followed by medium, medium-large and large firms with similar shares. Although this distribution reflects the distribution of size groups in the total population of German companies, it can be stated that Fraunhofer Institutes often cooperate with small companies.

Figure 11 Cooperation with Fraunhofer by firm size class



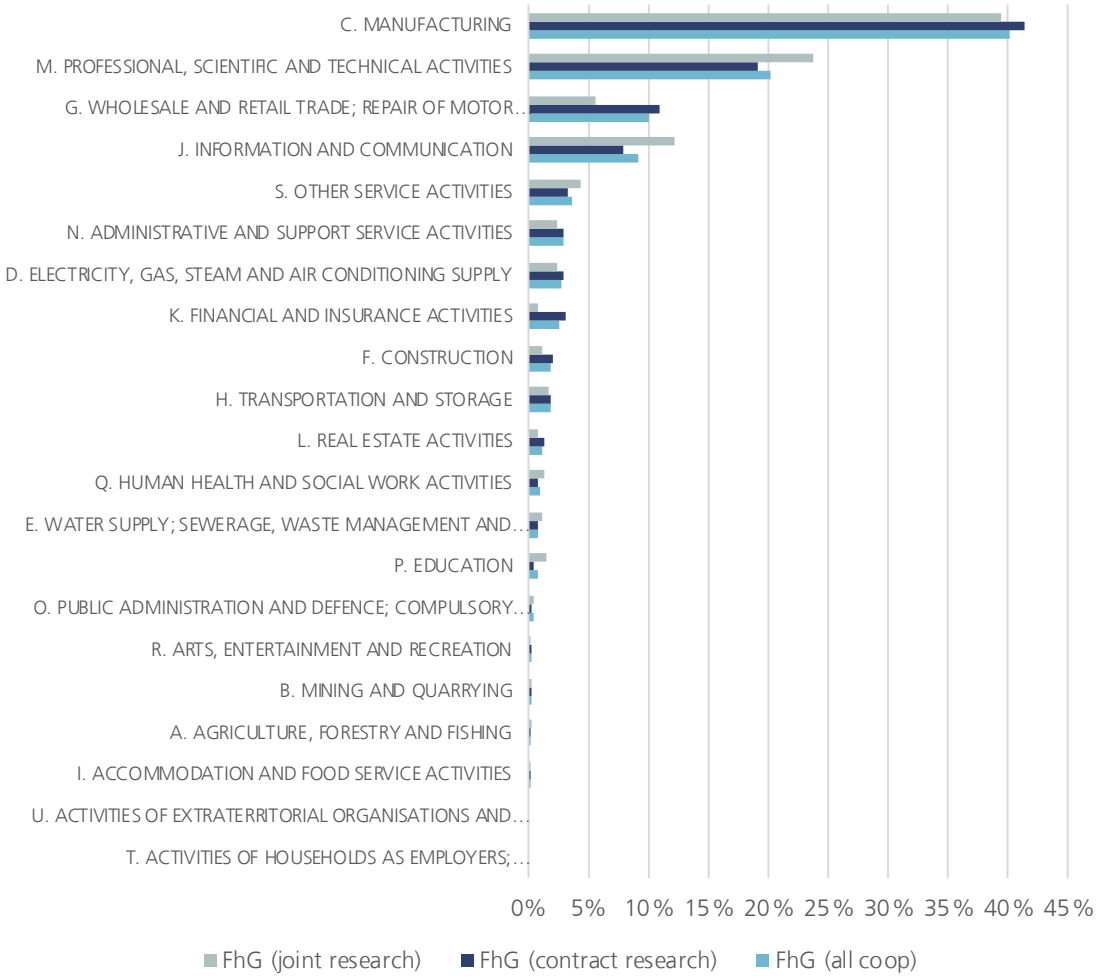
Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

Note: small: 0–49 employees, medsmall: 49–249 employees, medium: 250–499 employees, medlarge: 500–999 employees large: >1,000 employees

When looking at the differentiation by sector (Figure 12), it can be found that — independent of the type of project — the majority of firms cooperating with the Fraunhofer-Gesellschaft are located in the manufacturing sector, followed by professional, scientific and technical service providers, wholesale and retail trade[7] and information and communication services.

7 It has to be noted that some firms from the manufacturing sector are classified as belonging to the sector of wholesale and retail trade, which explains these large shares.

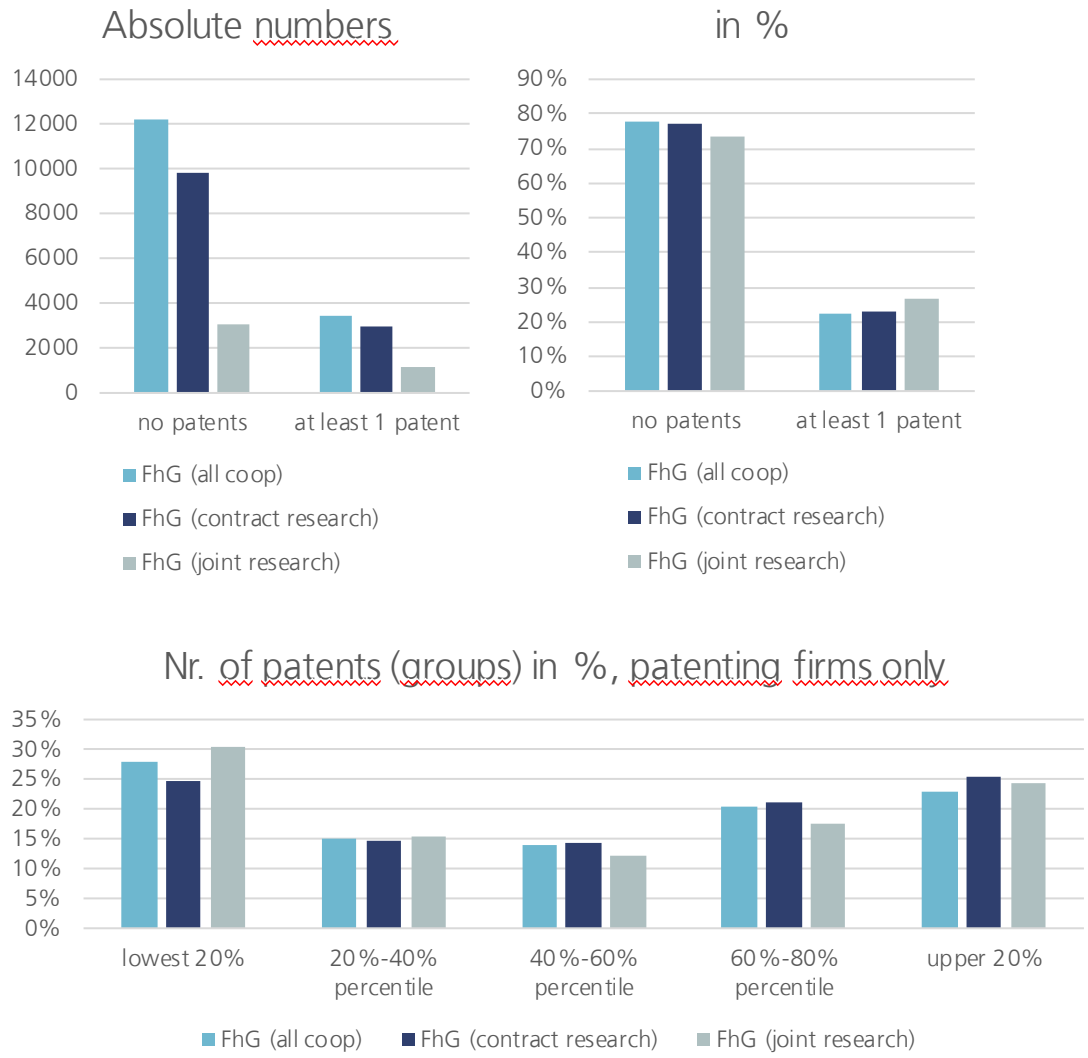
Figure 12 Cooperation with Fraunhofer by sector (NACE 1-digit), in percent



Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

Another perspective is provided by looking at the patenting activity of firms that are cooperating with Fraunhofer Institutes (Figure 13). The upper panel of the figure shows the absolute numbers and shares of patenting and non-patenting companies that have cooperated with Fraunhofer in the last five years. The majority of cooperating firms do not file patents at all. This is not surprising as few firms are active in patenting, especially when it comes to small and medium sized firms (SMEs), which make up the largest share of cooperation partners. Interesting insights, however, can be revealed from the lower panel of the figure. Here, we are only looking at patenting firms. It can be shown that, where Fraunhofer cooperates with a patenting firm, it either cooperates with firms that are in the lowest quantile (lowest 20%) of patenting firms, i.e. firms with rather small patent filing numbers, or with companies that are in the highest quantile (upper 20%), i.e. firms that have a very large number of patents.

Figure 13 Cooperation with Fraunhofer by firm patenting activity



Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

5.3.2 Performance effects of cooperation with Fraunhofer-Institutes

Besides looking at the structural effects of the cooperation with Fraunhofer, the following provides a focus on the performance related measures by asking whether a cooperation with Fraunhofer — and in the following chapter also universities and PROs in general — can be seen to impact the economic performance of the collaborating firms. In order to do that, we have run a series of multivariate (OLS) regression models with several performance-related measures as dependent variables, i.e. **operating revenue** or **revenue per employee**, and the cooperation variable as an independent

variable. In addition, we added further variables to the models to allow for the fact that firms are technology intensive. On the one hand, this is measured by a variable that captures whether a firm had filed a **transnational patent** in the last five years. On the other hand, a dummy variable for **firm size** indicating whether a company is an SME (less than 500 employees) or a large firm is introduced in the models.

The model with the operating revenue as a dependent variable is depicted in Table 13. Here, we ran three regression models, depending on the type of cooperation, i.e. **all cooperation types**, which represents a mix of **contract research** and **joint research projects**, as well as the two other types of projects in isolation. In the model, we can observe a positive relationship between cooperation with Fraunhofer Institutes and the operating revenue of companies. This relationship, however, is strongly positive for contract research projects, while a negative coefficient can be observed for joint research projects.

Table 13 The effects of Fraunhofer cooperation on operating revenue

dV: Operating Revenue	Fraunhofer (all coop)			Fraunhofer (contract research)			Fraunhofer (joint research)		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**0.414**	***	**0.027**	**0.528**	***	**0.028**	**-0.292**	***	**0.043**
Transnational patents dummy (0=no, 1=yes)	0.534	***	0.036	0.527	***	0.037	1.258	***	0.053
SME Dummy (0=no, 1=yes)	-3.243	***	0.036	-3.183	***	0.037	-3.792	***	0.052
Cons.	13.890	***	0.038	13.840	***	0.038	14.296	***	0.052
Obs.	15,562			14,317			9,989		
Pseudo R2/Adj. R2	0.029			0.029			0.037		

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

A better indicator for firm performance, however, is **operating revenue per employee,** since operating revenue as such is influenced by many different factors such as firm size or sector of activity. We interpret the operating revenue per employee as an indication of the companies' productivity. This model is shown in Table 14 and provides evidence of a generally positive correlation between a Fraunhofer cooperation and firm performance. However, there is still a difference depending on the type of research projects: for contract research, the coefficient is larger than for joint research projects, implying a stronger relationship between cooperation and firm performance in the case of contract research. This finding is not surprising for two reasons. Firstly, one can assume that collaborative projects initiated and funded by the collaborating firm are of

more direct relevance to their operating business. Secondly, publicly funded projects demand generalizability and are also used for other companies. In consequence, the nature of these projects is, more often than not, rather basic research or pre-competitive research so that the effects for revenue or other market performance indicators are usually indirect or with a longer time perspective.

Table 14 The effects of a Fraunhofer cooperation on operating revenue per employee

dV: Operating Revenue/Emp	Fraunhofer (all coop)			Fraunhofer (contract research)			Fraunhofer (joint research)		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**1107.818**	*******	**335.908**	**1368.102**	*******	**371.319**	**325.749**	*******	**112.536**
Transnational patents dummy (0=no, 1=yes)	-660.436		448.013	-786.966		491.283	-52.303		140.806
SME Dummy (0=no, 1=yes)	616.454		443.809	746.145		477.939	165.886		133.289
Cons.	-135.589		463.093	-243.178		494.960	226.286	*	130.959
Obs.	15,562			14,317			9,989		
Pseudo R2/Adj. R2	0.001			0.001			0.001		

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

Another effect can be revealed by splitting the sample of cooperating firms by size class and running the models separately for large firms and SMEs (Table 15). This series of regression models shows that the relationship between a cooperation with Fraunhofer Institutes and revenues per employee are much more strongly pronounced for small firms than for large firms. This especially counts for contract research projects, i.e. the coefficient is largest when Fraunhofer is working in contract research projects for SMEs.

Again, this is not a surprising finding. The projects funded by large companies are, on average, also larger in terms of budget, but still the relative size of the projects in relation to turnover/revenue is larger for SMEs. In other words, a collaborative project is of relative higher importance for SMEs than for large enterprises and therefore also the expected effect on the economic performance is higher for SMEs. In several cases, the cooperation project is a SME's only or one of just a few R&D activities. Whereby such projects, even though they tend to be larger in scale, are one among many other internal or external R&D activities for large, multinational companies.

Table 15 The effects of a Fraunhofer cooperation on operating revenue per employee — the moderating effect of firm size

dV: Operating Revenue/Emp	Large firms								
	Fraunhofer (all coop)			Fraunhofer (contract research)			Fraunhofer (joint research)		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**239.410**	*******	**83.992**	**259.864**	*******	**87.174**	**208.667**	*******	**48.285**
Transnational patents dummy (0=no, 1=yes)	-154.137	*	81.482	-171.622	**	85.675	-64.607		50.746
Cons.	282.570	***	67.039	284.883	***	68.608	270.729	***	26.009
Obs.	2,587			2,467			1,243		
Pseudo R2/Adj. R2	0.003			0.003			0.014		
	SMEs								
Cooperation with PRO/UNI (1=yes)	**1253.394**	*******	**396.883**	**1574.348**	*******	**443.757**	**349.510**	*******	**130.646**
Transnational patents dummy (0=no, 1=yes)	-804.375		575.583	-971.039		639.035	-35.478		171.437
Cons.	435.225	*	260.857	445.838		273.163	386.263	***	55.234
Obs.	12,975			11,850			8,746		
Pseudo R2/Adj. R2	0.001			0.001			0.001		

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

5.3.3 Performance effects of cooperation with universities and PROs in general

In this section, we re-ran our models for cooperation with PROs and universities in general to find out whether the relationships found in the above-mentioned analyses only apply for cooperations with Fraunhofer or for cooperation with research in general. A first series of models that provide evidence in this regard is depicted in Table 16. The table shows that there is a positive and significant relationship between cooperating with public research and firm performance, as measured by a series of different firm performance measures.[8] The table shows that there is indeed a positive relationship

8 We have included some further performance measures as dependent variables from BvD AMADEUS, although the number of observations for these models are lower, which limits the generalizability of the results.

between cooperating with science and firm performance, which complements the results found in the analyses of the GMS. We do find **a negative coefficient on the return on equity measure**. However, since this is a direct measure of a firm's earnings, this negative relationship can be explained by the fact that cooperation, first of all, induces costs to a firm, which negatively affects their earnings. Potential positive effects might unfold in the future; however, these are not allowed for in the model.

As for a Fraunhofer cooperation in isolation, we re-calculated the model including a sample-split, differentiating the relationships for cooperation by large firms and SMEs (Table 17). It can be found that the more strongly pronounced relationship in the case of cooperation with SMEs that has been found in the models for the cooperation with Fraunhofer also holds true for the models looking at public research as a whole. Though a positive relationship can also be found for cooperations with large firms, the effects are much stronger when looking at cooperation with SMEs, however.

Table 16 The effects of cooperation with PROs on general and firm performance measures

	dV: Operating Revenue			dV: Operating Revenue/Emp			dV: ROE			dV: EBITDA			dV: EBIT Margin		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**0.338**	*******	**0.026**	**1,022.699**	*******	**320.033**	**-9.090**	*******	**2.371**	**17,493.410**		**17,263.410**	**-0.115**		**0.415**
Transnational patents dummy (0=no, 1=yes)	0.541	***	0.035	-626.108		428.502	-4.579	*	2.666	81,095.200	***	19,440.230	-0.720	*	0.437
SME Dummy (0=no, 1=yes)	-3.270	***	0.036	582.604		428.173	7.395	**	2.895	-176,013.400	***	21,173.780	0.664		0.429
Cons.	13.912	***	0.037	-107.600		449.222	21.890	***	3.160	156,332.000	***	23,038.970	3.790	***	0.482
Obs.	16,515			16,515			7,210			7,473			4,898		
Pseudo R2/Adj. R2	0.029			0.001			0.004			0.014			0.001		

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

Table 17 The effects of cooperation with PROs on general and firm performance measures — the moderating effect of firm size

	Large firms														
	dV: Operating Revenue			dV: Operating Revenue/Emp			dV: ROE			dV: EBITDA			dV: EBIT Margin		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**-0.089**		**0.071**	**225.709**	******	**81.493**	**-9.123**	*****	**5.457**	**82,437.250**		**103,544.90**	**0.814**		**0.699**
Transnational patents dummy (0=no, 1=yes)	0.551	***	0.069	-142.128	*	78.568	4.891		4.838	322,878.300	***	92,883.230	1.284	**	0.612
Cons.	14.187	***	0.054	280.982	***	65.862	18.319	***	4.554	17,231.560		86,178.530	2.313	***	0.589
Obs.	2,682			2,682			1,377			1,413			1,397		
Pseudo R2/Adj. R2	0.001			0.003			0.001			0.010			0.004		
-	**SME**														
	dV: Operating Revenue			dV: Operating Revenue/Emp			dV: ROE			dV: EBITDA			dV: EBIT Margin		
	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.	Coef.	P>z	Std. Err.
Cooperation with PRO/UNI (1=yes)	**0.415**	*******	**0.029**	**1,149.317**	*******	**375.844**	**-9.155**	*******	**2.634**	**4,545.972**	*******	**1,629.78**	**-0.420**		**0.503**
Transnational patents dummy (0=no, 1=yes)	0.611	***	0.042	-761.962		546.443	-7.608	**	3.136	2,515.756		1,938.018	-1.802	***	0.571
Cons.	10.595	***	0.021	432.524	*	256.961	29.995	***	1.989	5,231.755	***	1,229.780	4.904	***	0.395
Obs.	13,833			13,833			5,833			6,060			3,501		
Pseudo R2/Adj. R2	0.001			0.001			0.004			0.002			0.003		

Source: BvD ORBIS, German funding catalog, SIGMA, EPO - PATSTAT, BvD AMADEUS; Fraunhofer ISI calculations

6 Summarizing conclusions

The Fraunhofer-Gesellschaft is the largest applied research organization in Europe. Part of its mission is to transfer knowledge and technology to industry, especially SMEs. One way that it fulfils this task is by conducting joint research projects with industry, both through direct research contracts as well as in public joint research projects.

The empirical data of contract research shows that Fraunhofer is able to address these tasks extremely well. The number of contracts as well as the budget per project has been increasing steadily in the observation period since 2010, both in nominal and in real terms. As the Fraunhofer Gesellschaft has been growing in terms of full-time equivalents, the per capita budget of contract research was kept almost constant over time. The structure of the contracting partners from industry reveals a strong focus on small and medium-sized enterprises (SMEs). Almost three quarters of the projects are in collaboration with SMEs and, employing a definition of the German "Mittelstand" (mid-tier business) of enterprises up to 5,000 employees, approximately 95 percent of all partners belong to this group. Most of the contracting companies can be assigned to the manufacturing sector — which includes R&D-intensive fields such as transport, machinery/mechanical engineering as well as chemistry and pharmaceuticals. The service sector is also well represented among Fraunhofer's customers, in particular, knowledge intensive areas such as technical services or information and communication services.

Based on matched datasets, we have taken a closer look at the structures of firm cooperation with Fraunhofer Institutes as well as public research, i.e. universities and PROs in general. Fraunhofer’s collaboration with industry takes two forms in our analyses: direct contract research and publicly-funded joint research. We found that the numbers and volumes of both forms are increasing over time, thus Fraunhofer is reaching more and broader sets of economic actors. In sum, SMEs are the largest group of partners and there is a broad coverage of (mainly R&D-intensive) economically relevant sectors in Germany, e.g. transport, chemistry, materials, mechanical engineering and IT. Fraunhofer partners can be characterized as being medium-sized, R&D active companies with a complex product portfolio and semi-standardized production lines.

The analyses have shown that collaboration with Fraunhofer (and also universities and other PROs) has positive impacts on the performance (labor productivity, EBIT, turnover, revenue per employee) of the partner companies. This holds true for two different samples, namely the German Manufacturing survey as well as the

collaborating firms identified in BvD Orbis. SMEs benefit relatively more from cooperation, but the relationship also holds true for large firms. Specifically, for Fraunhofer it can also be stated that contract research has more direct performance effects, while joint research projects are more long-term oriented and have less direct impacts on performance. In order to warrant a high level of trust in these central results, we have made an effort to allow for two-sided selection biases resulting from the possibility that a priori higher performing companies are more likely to collaborate with Fraunhofer. We have done so by using a matched pair approach implemented by pre-regression matching procedures to homogenize the samples of treated and untreated companies. Under the condition that selection occurs in a primarily unobservable manner, this approach can appropriately correct selection-induced endogeneity issues.

7 Appendix

Table 18 Comparison of GMS data to Statistical office data, 2012, 2015, 2018 — referring to sectoral distribution

Sector classes (NACE rev. 2)	GMS 2012 (1)	GMS 2015 (1)	GMS 2018 (1)	Manufacturing firms in Germany (2)
	%	%	%	%
Metal industry	22.6%	22.9%	22.1%	20%
Mechanical engineering	16.7%	17.4%	17.0%	14%
Food and beverage industry	8.7%	8.6%	9.1%	13%
Glass, ceramics, building materials industry	6.3%	5.8%	7.8%	7%
Electronics industry	7%	6%	7.5%	4%
Rubber and plastics industry	9.8%	8.0%	7.2%	7%
Electrical industry	4%	5%	5%	5%
Chemical and pharmaceutical industry	4.5%	5.4%	4.1%	4%
Vehicle construction	3%	4%	3.6%	4%
Other sectors	17.0%	15.8%	16.9%	21%
Number of firms	1,594	1,282	1,256	45,815 (3)

Source: (1) GMS 2012,2015, 2018. (2) Manufacturing in Germany got the same distribution for all three waves. See: Statistisches Bundesamt (2012, 2015, 2018), Fachserie 4, Reihe 4.1.2. (3) Exemplarily number of manufacturing firms in 2018; Fraunhofer ISI calculations.

Table 19 Share of manufacturers cooperating with Fraunhofer, cooperating manufacturers by firm size classes and project type, 2012–2018

Year	20 to 49 empl.	50 to 99 empl.	100 to 249 empl.	250 to 499 empl.	500+ empl.
Direct cooperation					
2012	3%	5%	11%	14%	39%
2015	4%	4%	12%	25%	40%
2018	4%	4%	11%	24%	36%
Publicly funded projects					
2012	7%	6%	11%	15%	27%
2015	10%	8%	16%	22%	47%
2018	10%	10%	18%	34%	52%

Source: GMS 2018; Fraunhofer ISI calculations

Table 20 Logit regressions for different types of cooperation, average marginal effects

Indicators		Cooperation with Fraunhofer			Cooperation with any PRO			Cooperation with any PRO, but not Fraunhofer		
		dy/dx	std. err.	p-level	dy/dx	std. err.	p-level	dy/dx	std. err.	p-level
Firm size, ref: 20 to 49 employees				***			***			***
	50 to 249 employees	0.016	[0.014]		0.126	[0.018]	***	0.130	[0.018]	***
	250 and more employees	0.137	[0.023]	***	0.241	[0.029]	***	0.076	[0.027]	**
Sector, ref: Food, textile, wood, others				***			***			***
	Chemicals incl. pharma. Rubber, plastics	0.062	[0.019]	**	0.073	[0.024]	**	0.052	[0.025]	*
	Mechanical engineering. Metal products. Automotive	0.089	[0.017]	***	0.116	[0.022]	***	0.056	[0.023]	*
	Electrical, electronic products	0.172	[0.024]	***	0.117	[0.030]	***	-0.031	[0.029]	
Product complexity, ref: simple products				***			***			n.s.
	Medium complex products	0.047	[0.019]	*	0.047	[0.022]	*	0.043	[0.023]	
	Complex products	0.1	[0.022]	***	0.100	[0.026]	***	0.025	[0.027]	
Batch size, ref: Single unit production				n.s.			n.s.			***
	Small/medium sized batch	-0.003	[0.015]		0.011	[0.019]		0.002	[0.020]	
	Large batch production	-0.044	[0.021]	*	0.045	[0.026]		0.066	[0.028]	*
R&D intensity, ref: no R&D expenditure				***			***			***
	Less than 5% R&D expenditure	0.129	[0.017]	***	0.331	[0.023]	***	0.226	[0.023]	***
	5% or more R&D expenditure	0.176	[0.017]	***	0.390	[0.022]	***	0.199	[0.022]	***
At least one R&D site abroad vs. none		0.004	[0.021]		0.001	[0.034]		-0.081	[0.032]	*
Export share > 0&		0.008	[0.030]	**	0.123	[0.027]	***	0.122	[0.031]	***
Innovativeness as prio 1 or 2		0.038	[0.013]	**	0.094	[0.018]	***	0.039	[0.019]	*
Position in value chain				n.s.			***			n.s.
	Final products for other firms vs. not	0.003	[0.015]		0.014	[0.018]		0.004	[0.019]	
	Supplying to other industries vs. not	0.026	[0.015]		0.070	[0.017]	***	0.038	[0.019]	*
Time point of data, ref: Survey in 2012				n.s.			***			***
	Survey in 2015	0.026	[0.014]		-0.017	[0.018]		-0.042	[0.019]	*
	Survey in 2018	0.029	[0.015]		-0.053	[0.019]	**	-0.083	[0.020]	***
Model fit	N	2992			2943			2943		
	Pseudo R2 (sig)	0.2146		***	0.2656		***	0.1014		***

Source: GMS 2012, 2015, 2018, German funding catalog, SIGMA, BvD AMADEUS; Fraunhofer ISI calculations

Notes: Standard errors in parentheses, significance level *** p<0.01, ** p<0.05, * p<0.1

Literature

Bilsen, V.; De Voldere, I.; Van Hoed, M.; Zeqo, K. (2018): Economic Footprint of 9 European RTOs in 2015-2016, Final report, Bussels: EARTO; https://www.earto.eu/wp-content/uploads/EARTO_Economic_Footprint_Study_-_Impact_of_9_RTOs_in_2015-2016_-_Final_Report-1.pdf

Bruno, N.; Kadunc, M. (2019): Impact Pathways: Tracking and communicating the impact of the European Framework Programme for research and innovation. fteval Journal for Research and Technology Policy Evaluation (47). pp. 62-71.

Busom, I.; Fernández-Ribas, A. (2008): The impact of firm participation in R&D programmes on R&D partnerships. In: Research Policy, 37 (2), S. 240–257.

Comin, D.; Licht, G.; Pellens, M.; Schubert, T. (2018): Do Companies Benefit from Public Research Organizations? The Impact of the Fraunhofer Society in Germany. Lund, Sweden.

European Commission (2017): The Economic Rationale for Public R&I Funding and its Impact, Policy Brief Series, Brussels: European Commission.

Frietsch, R.; Lutz, J.; Neuhäusler, P.; Schubert, T.; Lerch, C.; Bethke, N.; Rothengatter, O. (2016): Beitrag der Fraunhofer-Gesellschaft zum deutschen Innovationssystem. Karlsruhe: Fraunhofer ISI.

Fuentes, C. de; Dutrénit, G. (2012): Best channels of academia–industry interaction for long-term benefit. In: Research Policy, 41 (9), S. 1666–1682.

Grupp, H. (1998): Foundations of the Economics of Innovation. Theory, Measurement and Practice. Cheltenham: Edward Elgar.

Hacker, J.; Krull, W.; Lohske, M.; Strohschneider P. (2018): Wie sich die Qualität der Auswahl verbessern lässt, Frankfurter Allgemeine Zeitung vom 12. Juli 2018; https://www.faz.net/aktuell/karriere-hochschule/auswahl-von-forschern-wie-sich-die-qualitaet-der-auswahl-verbessern-laesst-15685958.html

Jäger, A.; Maloca, S. (2019): Dokumentation der Umfrage Modernisierung der Produktion 2018, Karlsruhe: Fraunhofer ISI.

Lerch, C.; Jäger, A. (2020): Industrie 4.0 quo vadis?: Neuere Entwicklungen der vierten industriellen Revolution im Verarbeitenden Gewerbe. Mitteilungen aus der ISI-Erhebung Modernisierung der Produktion, 76. Karlsruhe: Fraunhofer ISI.

LERU (2018): Impact and the next Framework Programme for Research and Innovation (FP9); http://www.leru.org

Molas-Gallart, J.; Tang, P. (2011): Tracing 'productive interactions' to identify social impacts: an example from the social sciences. In: Research Evaluation, 20 (3), S. 219–226.

Mote, J.; Jordan, G.; Hage, J.; Hadden, W.; Clark, A. (2016): Too big to innovate? Exploring organizational size and innovation processes in scientific research. In: Science and Public Policy, 43 (3), S. 332–337.

OECD (2018): Oslo manual 2018. Guidelines for collecting, reporting and using data on innovation. Paris: OECD Publishing.

OECD; Eurostat (2005): Oslo Manual. Proposed guidelines for collecting and interpreting innovation data. Paris: OECD/Eurostat.

Som, O. (2012): Innovation without R&D. Heterogeneous Innovation Patterns on Non-R&D-Performing Firms in the German Manufacturing Industry. Wiesbaden: Gabler/Springer.

Spaapen, J.; van Drooge, L. (2011): Introducing 'productive interactions' in social impact assessment. Research Evaluation 20 (3), 211–218.

Stahlschmidt, S.; Stephen, D.; Hinze, S. (2019): Performance and structures of the German science system. Online verfügbar unter https://www.e-fi.de/fileadmin/Innovationsstudien_2019/StuDIS_05_2019.pdf.