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THE EUROPEAN AEROSPACE R&D COLLABORATION NETWORK

Daniel Guffarth
Michael J. Barber

Universität Hohenheim | Forschungszentrum Innovation und Dienstleistung
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Daniel Guffarth
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Daniel Guffarth

University of Hohenheim, Economics Institute, Innovation Economics (520 i) &
MBtech Group GmbH & Co KGaA

Michael J. Barber

Innovation Systems Department,
AIT Austrian Institute of Technology GmbH, Vienna, Austria

E-Mail: daniel.guffarth@uni-hohenheim.de, michael.barber@ait.ac.at

Abstract

We describe the development of the European aerospace R&D collaboration network from 1987 to 2013 with the help of the publicly available raw data of the European Framework Programmes and the German *Förderkatalog*. In line with the sectoral innovation system approach, we describe the evolution of the aerospace R&D network on three levels. First, based on their thematic categories, all projects are inspected and the development of technology used over time is described. Second, the composition of the aerospace R&D network concerning organization type, project composition and the special role of SMEs is analyzed. Third, the geographical distribution is shown on the technological side as well as on the actor level. A more complete view of the European funding structure is achieved by replicating the procedure on the European level to the national level, in our case Germany.

1. Introduction

Due to an increasingly knowledge-based economy, the innovation ability of an economy increasingly constitutes the central determinant of its sustainability.[2] Therefore we consider the innovation ability of an economy and in particular of a sector with respect to the existence and the quality of interplay between several actors. As the innovation system is a complex system composed out of information, knowledge creation and collective learning which is characterized by a high degree of uncertainty (Kline and Rosenberg 1986, Dosi 1988), networks combine actors, resources and activities and therefore have to be seen as systems (Casti 1995). The network of agents, institutions and their mutual relations is issued within the innovation economic literature as innovation systems. Innovation systems can be analyzed on national (Lundvall 1992) and on regional and local consideration (Asheim and Isaksen 2002) and are characterized by interdependence of agents and non-linearity of their interactions. When industry sectors are in the focus of consideration, the concept of sectoral innovation systems established by Malerba (1999) can be applied, which

[1] This paper is an outcome of the DFG-project "Innovationsnetzwerke für die Regionalentwicklung. Eine agentenbasierte Simulation" (INSPIRED) (reference number: PY 70/8-1).

[2] That knowledge plays a central role in innovation and production has been emphasized by the evolutionary economics literature (Metcalfe 1998, Dosi 1997, Nelson 1995) and by Lundvall (1992) within his work on the knowledge-based economy.

emphasizes the importance of understanding how a sector changes over time and to "disentangle the relationships between firms' learning processes, competences, organization and behavior, non-firms organizations and institutions in a sector" (Malerba 1999, pg. 3). So a sectoral innovation system is a system of firms active in developing and making a sector's products and therefore in generating and utilizing a sector's technology (Breschi and Malerba 1997, pg. 131). As Malerba (1999, pg. 5) puts it: "A sectoral system changes over time through coevolutionary processes." Thus, technology, industry and related geography mutually influence each other and change together over time. Malerba (1999, pg. 5f) denominates six points, which are in the focus of consideration within the analysis of sectoral innovation systems:

1. knowledge and its structure
2. learning, processes, competences, behavior and organization of firms
3. links and complementarities at the input,
4. and demand[3] levels
5. the role of non-firm organizations (universities, government, etc.)
6. the relationships among agents
7. the dynamics and transformation of sectoral systems.

In this article we use this framework as a starting point for getting an impression on how the European aerospace industry, and in particular its invention community, performs; we consider the case of Germany, complementing the case of the European invention system with a perspective on the national level. Our analysis is based on actual empirical results and provides a first overview concerning the R&D collaboration network in the knowledge intensive aerospace industry within Europe (and Germany) between 1987 and 2013. We use three observation levels – agents, topics and geography – to highlight the main characteristics of the technological and industrial development in the sectoral system of innovation within the large commercial aircraft (LCA) sector.

Due to the technological complexity—prevalent in aerospace since its inception, and rising exponentially with the advent of new aircraft — cooperation is a powerful tool to access, integrate and use external knowledge. External R&D-cooperations in general have a positive influence on the innovation success of companies. The interplay of internal R&D and external R&D-cooperations can be seen as most promising, as suggested by Hagedoorn and Wang (2012). According to Miotti and Sachwald (2003) a central motive to establish cooperative relationships is the access to complementary knowledge bases of the partners. The composition and structure of pan-European networks have barely been studied to date: Both on the actor level (exceptions are Roediger-Schluga and Barber 2006 and Breschi and Cusmano 2004) and on the geographical and in particular on thematic level. We find that most important actors in aerospace research — large firms (intra- and extra sectoral), research-intensive small and medium sized enterprises (SMEs), public and private research organizations and universities — participate in EU projects, which provides us with valuable information on the organization and infrastructure of European aerospace science and technology within the emerged networks. The results of our analysis afford important insights for a deepening analysis of the invention networks within the aerospace industry and their underlying technological and institutional evolution.

[3] In this article we do not specifically address the demand side, but we use developments in it to explain changes on the supply side and the invention community. As Vincenti (1990, p.11) puts it: "performance, size, and arrangement of an airplane, for example (and hence the knowledge needed to lay it out), are direct consequences of the commercial or military task it is intended to perform".

This article is organized as follows. Section 2 provides a background overview, with section 2.1 giving a short historical abstract on the aerospace industry and its industrial and technological development in general, and section 2.2 explaining the data sources. Section 3 focuses on the European aerospace invention community, describing the thematic development (3.1) and the actor level (3.2). The geographical representation is done in both subsections. Section 4 repeats the European-level analysis at the national level, considering the case of Germany. Section 5 summarizes and assesses the potential for further research.

2. Data and industry background

2.1 Historical background of the aerospace industry and technology development

In this section we give a short historical description of the evolution of the global aerospace industry from its beginning to the 1980s[4] with respect to three different layers: industrial and geographical development and the technological evolution. This history is mainly compiled out of ECORYS (2009), Tiwari (2005), Wixted (2009), European Commission (2002), Bonaccorsi and Giuri (2000), Bugos (2010) and Cook (2006).

With the beginning of the 20th century, the first flights of airplanes[5] took place, which went hand in hand with an adoption of this technology by the military. It was a time when airplanes were developed and produced by pioneers and single entrepreneurs.[6] Their goals and especially their techniques were far from being mature enough for mass production. With the outbreak of WWI, Europe took the lead in aircraft manufacturing. Governmental funding of research facilities and the establishment of aerospace engineering degrees in university education marked the first steps into establishing the aerospace industry. In the 1920s, a recovered entrepreneurial spirit led to further developments and design-driven manufacturing was prevalent. At that time, a large variety of designs combined with a small market demand was characteristic. In 1925, the first impulse for an acceleration of aircraft production was induced in the USA by the Air Mail Act, which drove the demand for planes and pilots. This went hand in hand with the establishment of a non-military customer base, where the founding of Lufthansa, British Airways and Aeropostal fostered passenger transportation. In the 1930s in the US, the civil sector grew, due to the ability for long-range operations, with competition for passengers and the formation of alliances between aircraft manufacturers and airlines; in Europe this time marks the begin of ramping up production capacities by the defense sector. In the 1940s, war production dominated, with mass production and national focus characteristic —every country drove its own program and they were far from any cooperation. The 1950s, the first after-war period, can be labeled as in-house production era. At that time in Europe market demand increased rapidly. Nevertheless in the aircraft industry there was still an ongoing focus on defense with nearly no cooperation between companies. OEMs designed and produced the aircraft completely from start to finish.[7] Also during this decade, technological and industrial complements for the first time split up into the parts of the aerospace industry known today: civil aeronautics industry, military aeronautics industry and space industry. Nevertheless until today these sectors partly overlap concerning actors and technology and mutually influence each

[4] Subsequent years are analyzed within the main chapters, since our data starts with the years 1987.
[5] Precursor works on bionics and other aviation specific researches lead to the first flights: cf. Moon (2012).
[6] An interesting social network analysis about the entrepreneur years of the aerospace industry is provided by Moon (2012).
[7] Except Germany due to restrictions imposed by the allied forces.

other. In the 1960s the era of collaboration started, as we will see below due to the technological challenges. Further, not only one aircraft program per firm was initiated, but many simultaneous programs in the US and Europe occurred, due to an increasing demand for flights over all distances. In Germany, licensing manufacturing started and the formerly leading aerospace nation began to reestablish its position. In the 1970s Europe's aerospace landscape changed drastically with the evolution of the first European Programs — the creation of Airbus, a consortia of the leading European aerospace nations. The underlying driver for consortia creation was the increasing project volumes and the need, in the view of the European politicians, to establish a counter balance to the strong US aerospace industry. In the 1980s the deregulation of the US Airline market led to increasing competition. In the following years, large international consortia were formed to spread costs and accumulate knowledge, focusing on cost efficiency, quality and performance. In the large civil aircraft sector, the competition between Airbus, as European champion, and Boeing, its American counterpart, increased. Beside the two market leaders several other OEMs have been present in the market to that time, like McDonnell Douglas and Lockheed Martin. In Europe all involved Airbus nations tried to protect and foster participation of their firms, which led to an extremely fragmented industry structure, with numerous SMEs supplying the supranational enterprise of Airbus.[8] On the industry level, the 1990s and the new century are marked by crisis, consolidation waves, industrial integration and a still ongoing global reorganization. These developments correspond directly to our data set and will be analyzed and set in relation to our results.

The technological development constitutes only a few main changes. While aircraft until the 1960s were equipped with propeller engines, jet engines have since been used on civil aircrafts. This technology, as with many others, was developed and engineered for military use in WWII. This new technology was considerably more complex and led to changes in the sector: consortia for jet engines established and formed a unique sector within the aerospace industry and many companies went bankrupt while new ones emerged. The change from propeller to jet and turbofan technology marked a technological change (Frenken and Leydesdorff 2000, Nelson and Winter 1977, Dosi 1982). Today, the industry continues to rely on this technology, but several incremental innovations have been added resulting in an extremely increased efficiency: compared to the 1960s about 70% less fuel is needed for the same range today. Since all aerospace OEMs operate near the technological frontier, technological performance was not necessarily associated with market success (Bonaccorsi et al 2001). Concerning the design, with the exception of the Concorde, aircraft didn't changed radically and no new trajectory concept is in sight. So engineers may be expected to further develop the existing designs and improve the technology by, e.g. using new materials and intelligent solutions in aerodynamics and a rise in electrification in every part or segment of the aircraft.

Before we analyze the technological, industrial and geographical developments in the European aerospace industry between the years 1987 and 2013, we first summarize the general characteristics of the aerospace industry to provide a better understanding of how the specifity of this industry is related to our findings in chapters three and four. According to Esposito and Raffa (2006) and Alfonso-Gil et al. (2007) the aerospace industry can be characterized by a high technological level

[8] Not only Airbus as the manufacturer of aircraft, but also the defense and space entities were centralized under the European holding company EADS (a consortia of the national firms Aerospatiale Matra, DASA, CASA) founded in 1998/1999. All remarks assigned to facts before that time, are dedicated to different partners building a consortium since the 1970s.

with a high R&D intensity[9], technological complexity, high and increasing development costs, long product life cycles, long break-even periods and small markets, problematic cash flow situations, high market entry barriers and a high governmental impact in form of ownership[10], regulation and as customer. The data sources and the procedures of analyzing the data are described in the following section, before our main analysis in section three is presented.

2.2 Data sources – CORDIS and *Förderkatalog*

At the European level, we use the European Framework Programmes (FPs) on Research and Technological Development (RTD). In the FPs, the European Union has funded numerous transnational, collaborative R&D projects. Project proposals are submitted by self-organized consortia (European Council 1998) and must include at least two independent legal entities established in different EU Member States or in an EU Member State and an associated State (CORDIS 1998). The proposal selection is based on several criteria including scientific excellence, added value for the European Community and the prospects for disseminating/exploiting results. The main objective has been to strengthen Europe's scientific and technological capabilities.

Since their initiation in 1984, seven FPs have been launched (compare table 1).[11] The only publicly available data source is the European Community Research and Development Information Service (CORDIS) projects database, which lists information on funded projects and project participations. However, many challenges exist in processing the raw data into a usable form, e.g. making the data consistent over time.

General statistics on the funded aerospace R&D collaboration network						
	FP2	**FP3**	**FP4**	**FP5**	**FP6**	**FP7**
European Framework Programmes	1987 - 1991	1990 - 1994	1994 - 1998	1998 - 2002	2002 - 2006	2007 - 2013
Number of projects	390	714	241	196	255	217
Number of participants	2171	4066	2301	2385	3899	2791
Average number of participants per project	5,6	5,7	9,5	12,2	15,3	12,9
German *Förderkatalog* all projects that started between	1987 - 1990	1991 - 1994	1995 - 1998	1999 - 2002	2003 - 2006	2007 - 2013
Number of projects	24	12	38	25	72	115
Number of participants	64	43	142	83	295	350
Average number of participants per project	2,6	3,6	3,7	3,3	4,1	3,0

Table 1: time dimension and general statistics on FPs and FK

Our core data set to capture collaborative activities in Europe is the EUPRO database[12], comprising data on funded research projects of the EU FPs and all participating organizations. It contains systematic information on project objectives and achievements, indicators of project subjects,

[9] Between 10% and 18% of revenue are re-invested in R&D.

[10] On the European OEM-level this changed in 2013, as the French government and the German Daimler AG withdrew at least in a direct manner from EADS.

[11] We did not include FP1, since FP1 has no distinct aerospace category.

[12] The EUPRO database is constructed and maintained by the AIT Innovation Systems Department by substantially standardizing raw data on EU FP research collaborations obtained from the CORDIS database (see Roediger-Schluga and Barber 2008).

project costs, project funding and contract type as well as on the participating organizations including the full name, the full address and the type of the organization. From EUPRO, we identify aerospace-related projects as collaborative projects that have been assigned the standardized subject indices *Aerospace Technology*[13] or (standard only in FP7) *Space & satellite research*. We take aerospace-related organizations as organizations taking part in at least one aerospace project.

For the analysis of the German aerospace invention community, we use data about publicly funded projects summarized in the electronically available database of the German *Förderkatalog* (FK). The funded projects are subsidized by five German federal ministries[14], with aerospace relevant projects funded by the Federal Ministry of education and Research (BMBF) and the Federal Ministry of Economics and Technology (BMWi).[15] In order to participate, organizations must agree to a number of regulations that facilitate mutual knowledge exchange and provide incentives to innovate (Broekel and Graf 2011, pg. 6). For the mutual temporal comparison possibility we aggregated the German data comprised in the "Förderkatalog" into to the European time ranges of the FPs (compare table 1). The two databases enabled us to analyze the European aerospace R&D collaboration network in a sectoral innovation system framework. In the following chapter we start with the focus on the European level and assign afterwards our procedure to the national level for the case of the German aerospace industry.

3. The European Aerospace invention community

The European aerospace industry has, as described above, a long history with significant changes on the industry and the technology side as well as on the demand side. The following sections analyze, with a focus on innovation and knowledge-based perspective, the developments in the R&D collaboration network with respect to three levels in the time range from 1987 to 2013. Section 3.1 broaches the issue on the technology and the thematic developments as well as on the underlying knowledge bases within the funded Framework Programs (FPs). Section 3.2 centers the actors and their role in the established networks and gives a first impression of how the networks are embellished over the mentioned time range.

3.1 Thematic developments and knowledge bases within EUFP-projects

The technology embedded in the industry is the key factor and driving force for development. We inspected all 2013 projects dedicated to the aerospace sector and classified each of them to one or more of 25 thematic categories. Those categories are developed based on International Patent Classes (IPCs) and the German DIN-Norm (compare table 2).[16] In figure 1 the development of the topics over time is depicted as a percentage in each FP, i.e. every point indicates what fraction of the projects within a time period can be allocated to the different categories. Conspicuous is that in early FPs a more uniform distribution over the categories appeared. With FP4 four categories developed to

[13] Projects in the FP4 subprogram *FP4-BRITE/EURAM 3* originally were all assigned the *Aerospace Technology* subject index, but these were eliminated in a later revision of CORDIS. We have included these projects for consideration as aerospace projects. No projects in FP1 were assigned the *Aerospace Technology* subject index; we have excluded FP1 from consideration.

[14] www.foerderkatalog.de.

[15] We identified all aerospace relevant projects with the help of the *Leistungsplansystematik* ("activity systematics").

[16] We do not make use of the standardized subject indices from CORDIS—they provide a broad categorization of all FP projects, but are not specific enough for categorizing the aerospace projects.

an outstanding position until FP7: SAT (satellite and space topics), RSY (quality and safety systems, non-destructive detection and repair systems, maintenance and their facilities), OMP (optimization of manufacturing processes and supply chains, existing product improvements) and SIM (simulation, numerical models, computer-aided systems, e.g. for air traffic management or aerodynamic application). All other categories show a shrinking share within the FPs. Categories ranging between 5-15% application over the FPs are the following: AER (aerodynamics and flow streams), ELE (electric and electronics (including cables and conductors), electromagnetics and magnetics), LSO (lasers, sensors and optics), REC (recycling and pollution avoidance mechanisms) and OMA (other materials: rubber, leather, resins, wood, etc.).

Thematic Categories	
Code	**Thematic explanation**
AER	Aerodynamic, flows and aero thermic
ALO	Alloys and coatings, glazed materials and paints
CEG	(technical) ceramic and glasses
CHE	Chemical processing (incl. petrochemicals)
COM	Composite materials
ELE	Electric and electronic (incl. cables and conductors)
FCH	Fuel cells, batteries, liquid hydrogen, cathodes and membranes
FOR	Forming, moulding, winding, sintering and grinding
LIT	Rare-earth materials (e.g. lithium)
LSO	Lasers, sensors and optics
MET	Metals (steel, aluminum, copper, titanium,…)
MIN	Mining (incl. all auxiliaries)
OMA	Other materials (e.g. rubber, leather, resins, wood, concrete, biomaterial,…)
OMP	Optimizing manufacturing processes, production and products (incl. cost reduction)
OTH	Others
PLA	Plastics and polymers
REC	Recycling and environmentally friendly product improvements and processes
ROB	Robotic systems, e.g. for production, inspection, …
RSY	Quality and safety systems (incl. repair systems, non-destructive detection, maintenance, etc.)
SAC	Sawing and cutting
SAT	Satellites and space topics
SIM	Simulation, numerical models, computer-aided systems, informatics
SUR	Surfaces
TXT	(technical) textiles
WEL	Welding, soldering, brazing

Table 2: Thematic categories

Although we tried to find categories which are widely application independent, so as to provide us with the information on what knowledge background is needed and used, the development of the categories depends upon what is funded and what topics underlie the projects. Additionally, not all categories are independent, which explains, e.g., the rise of RSY together with SAT, relating to earth observation with the help of satellites. Taking FP2 and FP3 as an example, besides the always prominent topics of RSY, OMP and LSO, especially metals and composite materials are especially in focus, corresponding to the time when composite materials started to grow in manufacturers' attempts to develop lighter aircraft. The effort to reduce weight is one of the critical sizes in aircraft engineering, as it directly influences the range and fuel consumption (Begemann 2008). Since the emergence of fiber-reinforced composite materials in the 1960s in space application, aircraft manufacturers used more and more such composite materials. Until the mid-1990s the amount was not higher than 10% of the total aircraft weight and only non-weight bearing parts (Chambers 2003). This changed with the launch of the Boeing 787 in the year 2011. This aircraft has an approximated amount of 50% of carbon fiber reinforced materials of total weight (Boeing 2006). The same will hold for the Airbus A350, which will be launched in 2014. So we can see a nearly 20 year gap between research and development time and the industrial application in the Framework Programmes and an overall gap of more than 60 years from the materials application in space and its full application in civil aircrafts. In FP4, OMP and RSY are the top-ranked categories, since the overall strategic goal for aerospace of the European Commission in FP4 was the management of more efficient, safer and more environmentally friendly transport systems. The latter can be seen in that REC was ranked for the first time in the top ten categories.

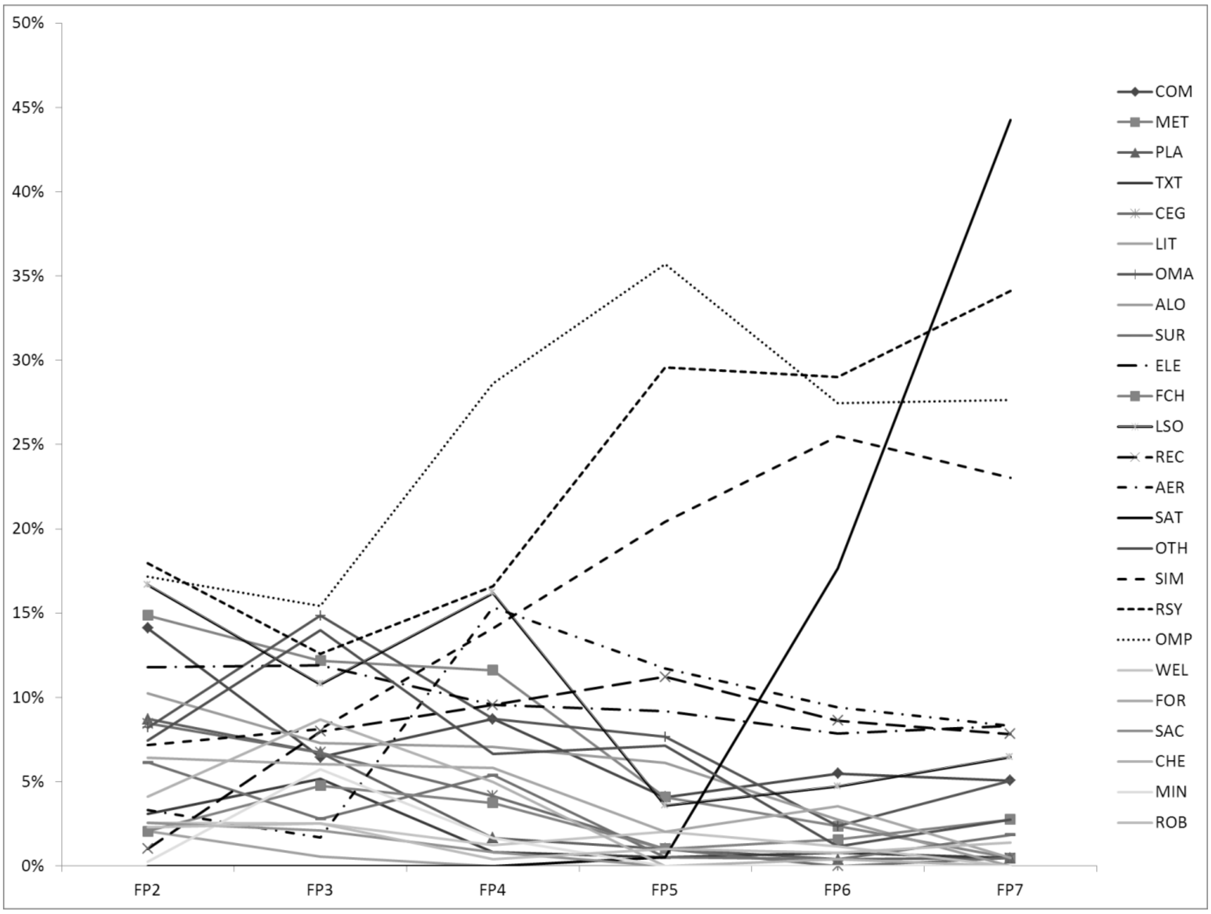

Figure 1: Thematic development of EU-funded aerospace R&D projects

In FP5 the general goals of FP4 persisted, again with a strong focus on efficiency and optimization (reducing aircraft procurement costs, improve their efficiency and performance) – again OMP and RSY are the top-ranked topics. Additionally more specific goals went into the focus: First, reducing aircraft impact on noise and climate change, which explains the increase of AER and REC.[17] Second, improving aircraft operational capability, which can be attributed to the increased number of projects dedicated to computer-aided systems (SIM). Notable is that in general material topics decreased over time. In FP6, admitted recognizable space category (SAT) emerged. This can be related to the goal to develop systems, equipment and tools for the Galileo project, and stimulate the evolution of satellite-based information services by sensors (LSO) and by data and information models (SIM). Another focus was on satellite telecommunications, which additionally lifted up the SAT category. On the aeronautic side again safety and security (RSY), reducing costs (OMP), and improving environmental impact with regard to emissions (REC) and noise (AER and OMP) are the most prominent goals. For FP7 the aerospace strategy of the European Commission focused on reduction of emissions and alternative fuels (REC), air traffic management (SIM), safety and security (RSY) and efficient aircraft production (OMP). Again, space topics as part of FP6 are most prominent. That optimization topics increased so drastically (from the middle 1990s) can be attributed to the industry influence, since at that time the focus shifted from pure innovation to affordability, i.e. better, cheaper and faster production to fulfill the increased orders. At that time, aircraft manufacturers were adapting lean principles from the automotive industry to satisfy the pressure to remain profitable.

In general, the European aerospace industry is a multi-technology industry. The knowledge underlying the research and development is extremely broad, ranging from materials and chemical processes to computer simulation tools, lasers and sensors. Thus, inter-industry knowledge spillovers are feasible within several relevant categories: Based on a search word analysis within our data we identified different possibilities of other industry application. We build search word families for twelve neighboring industries (compare table 3).

Industry search word famlilies			
Code	**Search words**	**Code**	**Search words**
AUT	automtotive, vehicle, car	MED	medicine, medical, implant
CON	construction, concrete, building, road	MIN	mining, ore
ELE	electric, electronic	RAI	railway, locomotive, train
ENE	energy, power generation, solar	SHI	ship, shipbuilding, naval
FOO	food, drink, meal, grocery	TXT	textile, shoe, leather, clothing, wool
LAS	laser, sensor	WOP	wood, paper, furniture

Table 3: Search word families of neighboring industries

The resulting search strings are applied on the information incorporated within each projects title and the objective text and checked individually for plausibility. The result can be seen in figure 2. Again the development is dependent on the projects; leading to FP2 and FP3 having more projects with possible inter-industry application. Due to the relevance for the aerospace sector, the electric/electronic-industry, the laser- and sensor industry and the energy industry seem to have the highest transfer potential. Further, the automotive and textile industries seem to have proximities in knowledge to the aerospace industry. Whereby the possible connections to the automotive and

[17] The REC efforts might not be purely driven by the environmental conscience of the aerospace industry, but driven more by underlying costs. The reduction of fuel consumption exhausted by the engines is the opposite trend to cover the increased fuel prices and demand driven on the side of the airlines.

textile industries are declining in the recent FPs, the electric/electronic industry relevance increased in the later FPs.

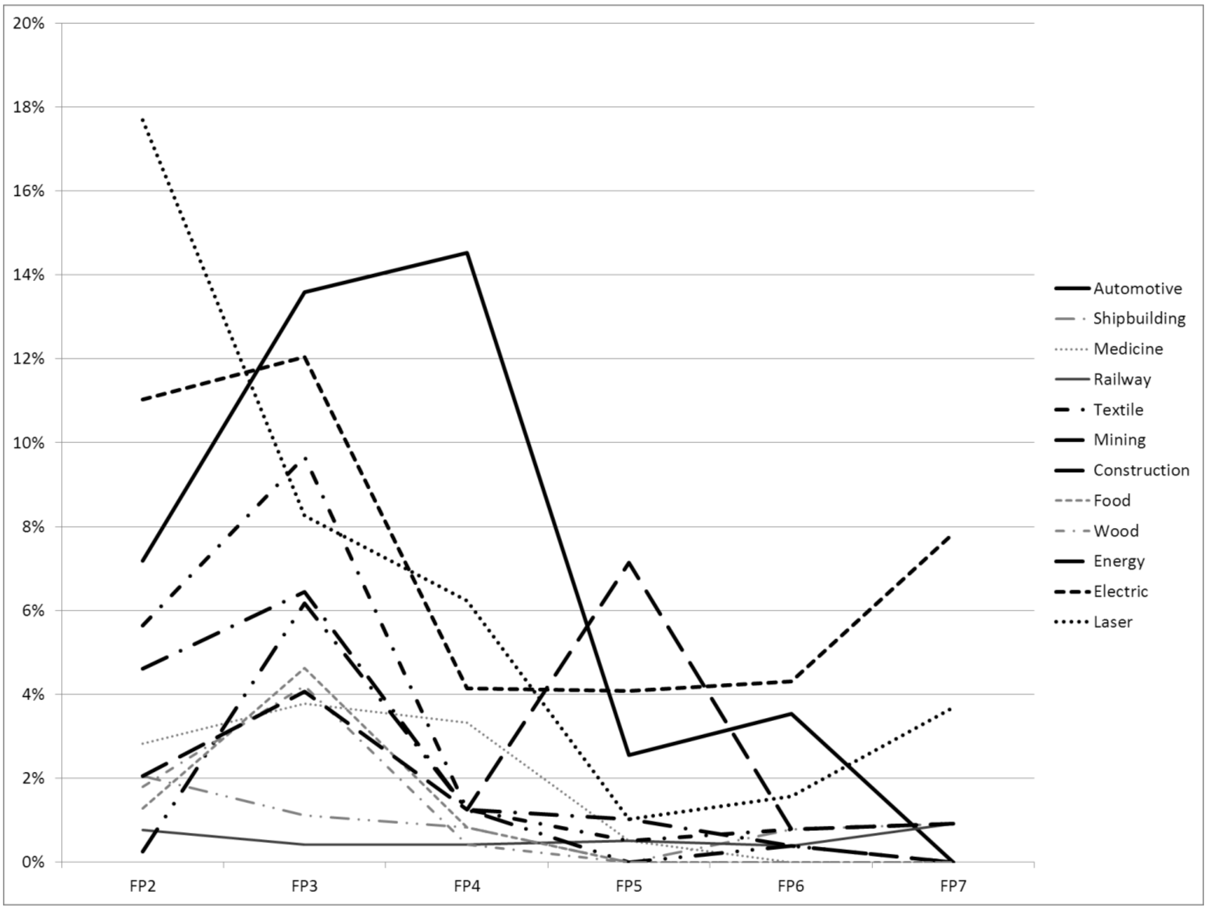

Figure 2: inter-industry application potential of EU-funded aerospace knowledge

Figures 3 and 4 visualize how the thematic categories are geographically located. Little difference can be observed between the knowledge specialization patterns between the European level and the level of countries, especially between the major aerospace countries (most of them parts of EADS). This may be expected, since these countries constitute the majority of the European aerospace industry as the aggregate of their historically independent national industries. Therefore we instead investigated specialization at the level of NUTS2 regions. For the sake of simplicity, we focus first on the top-ten regions with respect to their total FP project participation. We compare the regions based on their individual strength within the top-ten thematic categories over all FPs (figure 3). In figure 4, we show further regions that, while not continuously prominent in all FPS, were or more limited prominence in specific FPs, analyzing them as for the top regions in figure 3.[18] As a reference or base line, the sum of all regions — i.e. the European average of the different categories — is used in both figures. In figure 3 the specialization pattern of the top regions (with respect to the overall participation) over all FPs is shown. Differences ranging within the 2% amplitude are of minor importance. Therefore, when focusing on the greater amplitudes, we see that only some regions have an effective specialization in one or more topics. FR62 (the NUTS2-region where Toulouse is located) is strong in OMP, SIM and ELE, DE21 (Munich) in AER, UKK1 (Bristol) in RSY, SIM and AER,

[18] In this chapter we will only shortly mention the specialization of the regions. The results obtained here will find an application in chapter 3.2 when searching for explanations for the geographical development of the actors.

ITC1 (Turin) in OMP, UKI1 (London) in REC and ITF3 (Napoli) in OMP, RSY and AER. As these regions constitute the centers of the European aerospace industry, it is reasonable that (with the shown exceptions) the amplitudes are rather low — these regions play a key role in defining the European average.

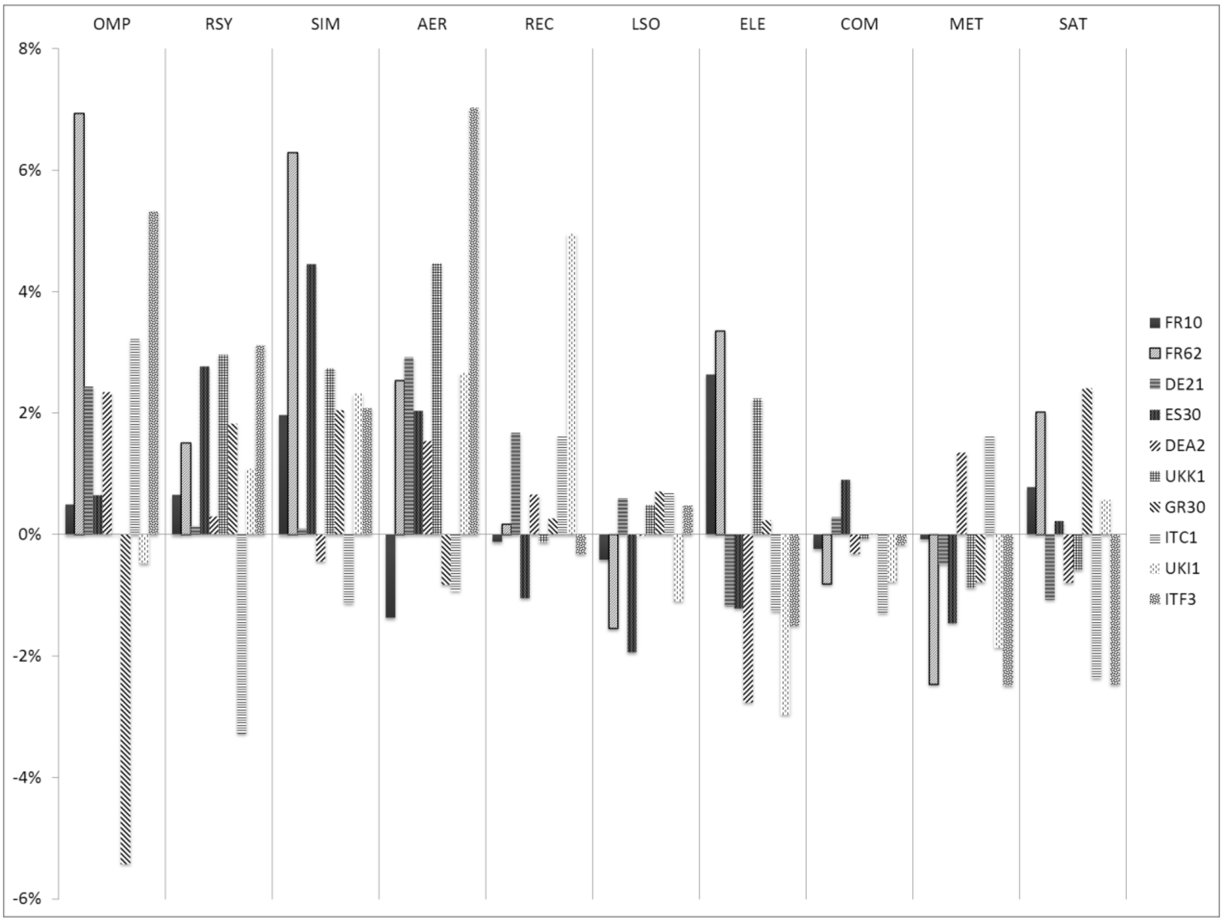

Figure 3: thematic specialization pattern of the top-ten European aerospace regions

In figure 4, we show five regions with peculiarities covering their semi-strong appearance in FP development. In general, these regions are more specialized than the top-ten regions, as amplitudes are higher than in the upper case. Noticeable amplitudes are to be discovered in SE23 (West Sweden), which is strong in OMP, AER and REC; NL32 (Nord Holland), strong in RSY, SIM and AER; and DE11 (Stuttgart), strong in MET. IE02 (Southern and Eastern Ireland) and PT17 (Lisbon) show a specialization pattern nearly similar to the European average.

An indication on the innovative output within regions is presented in figure 5, based on patent data. We used patent data[19] to show how the project participation rate is related to the invention output. We used NUTS2 regions as base – the scatterplot shows the number of FP-participations (over all

[19] For the general limitation of patent data usage and patents as strategic element see Granstrand (2010). Further Hollanders (2008, p.22ff.) discuss the role of patents in the aerospace industry, whereby the main argument states that patent are of minor importance since in the aerospace industry secrecy is the main method to protect knowledge. Nevertheless we suppose that this only (if at all) is correct for the two OEMs in the past. As now weights are changing and new competitors emerged patent usage and relevance will increase in the future. Begemann (2007) discusses the role of patents in the aerospace industry in a historical few, from the beginning with the Wright brother to the actual situation between Boeing and Airbus.

FPs) in relation to the number of patent applications in that region. For the sake of simplicity we only used IPC B64 which is dedicated to "aircraft, aviation and cosmonautics" patents. There is a positive relationship between FP-participation and patent activity. The area where no or only some patents within IPC 64 are applied might be the organizations, which are by their nature, not active in the aerospace industry, but participated due to related topics, which can be used in other industries and branches.

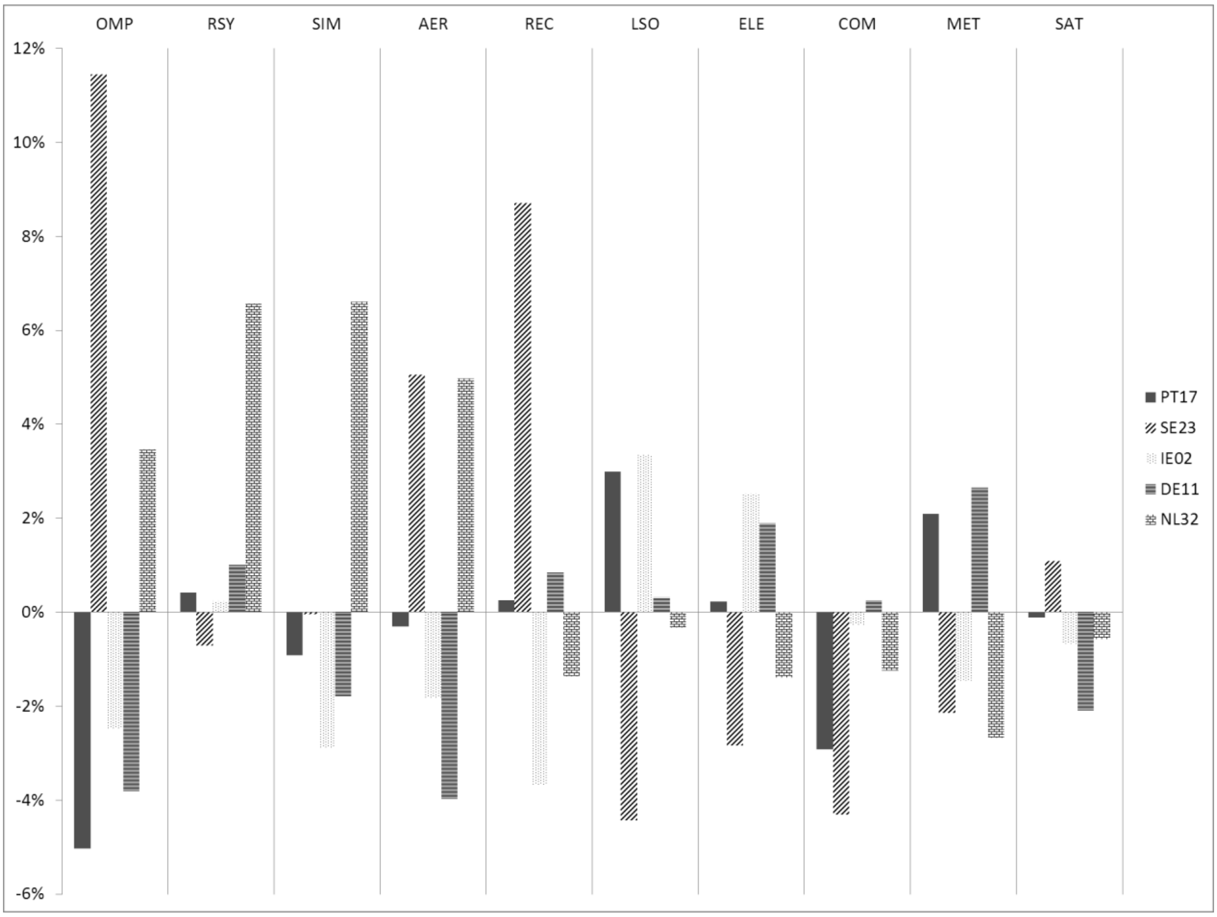

Figure 4: thematic specialization pattern of further important European aerospace regions

Taking the multi-technological features (presented in figure 1) into account, not only the different branches of knowledge concerning their usage (like electric or laser knowledge) have to be analyzed, but also the differentiation between their levels of knowledge, i.e. engineering knowledge versus scientific knowledge. Vincenti (1990) takes a look into Rosenberg's "black box" (Rosenberg 1982) and analyzes numerous kinds of complex knowledge levels that engineers in the aeronautical industry apply and use during the design process. He treats science and technology as separate spheres of knowledge that nevertheless mutually influence each other.[20] Concerning the level of knowledge, Vincenti (1990, p.226) states that engineers use knowledge primarily to design, produce, and operate artifacts (i.e. they create artifacts), while scientists use knowledge primarily to generate new knowledge (and as Pitt (2001, p.22) states: scientists aims are to explain artifacts). Emerging feedback processes in science are due to scientists' engagement in open-ended, cumulative quests to

[20] Beside the differentiation of scientific and engineering knowledge, another for the aerospace industry of increasing importance since the mid-1990s and for the future is operational or procedural knowledge. The underlying reasons are discussed in chapter 3.2.

understand observable phenomena. Vincenti (1990, p. 8) suggests that normal design is evolving in an incremental fashion and radical changes can be seen as revolutionary. In all his case studies Vincenti (1990, p.225) emphasized that the "growth of engineering design knowledge originated primarily out of prior engineering knowledge and was achieved primarily by engineering activities". For the case of radical changes he and several other studies observed always science to be invoked. Vincenti (1990, p.225) states that "while ideas for radical design may come from elsewhere, knowledge used in normal design originates and develops mainly within engineering". Nevertheless to argue that way does not mean that science's contribution to normal design can be ignored.

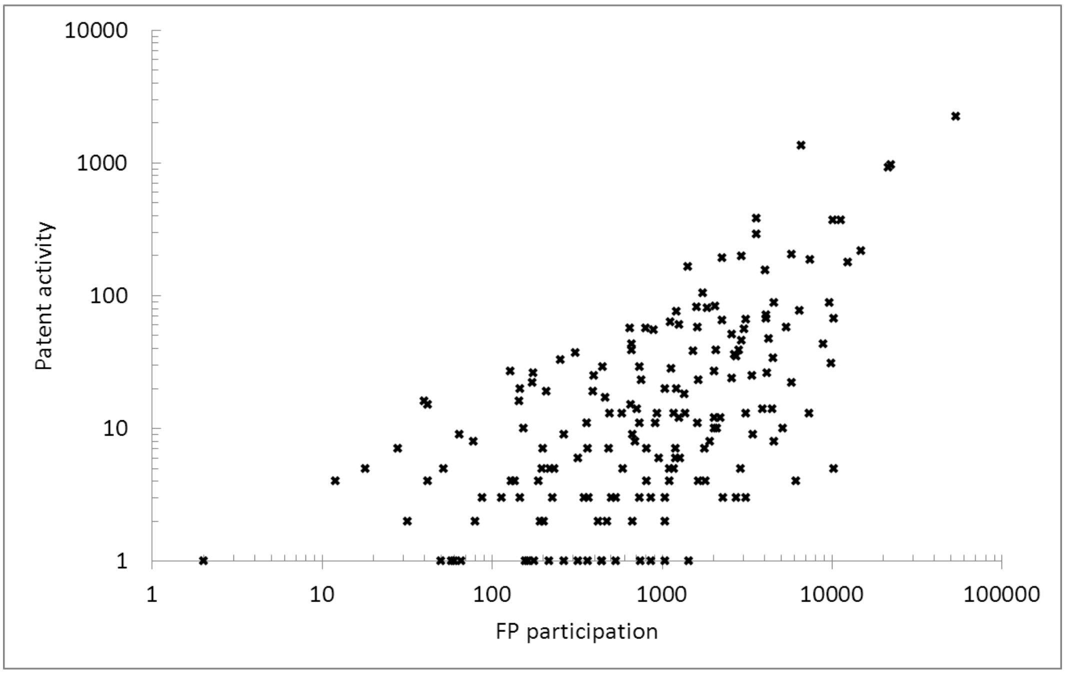

Figure 5: FP participation and patent activity in European regions.

The usage of either scientific or engineering knowledge might depend on the technological field and how this separation (if clearly possible at all) develops over time can be seen by the network participations of the actors to which the different kinds of knowledge may be allocated. We suppose the industry organizations (IND) to be stronger in engineering knowledge and education facilities and research organization (EDU and ROR) might be stronger in scientific knowledge.[21] Additionally based on the Schumpeterian thought that economists focused solely on the exploration of how industrial structure affects technical advance, Phillips (1971) proposed that the causal arrow goes in the opposite direction as well (Nelson 1995, p.171). So according to Nelson and Winter (1982) industrial structure and technical advance interact in complex ways, i.e. they co-evolve. Having shed light on the technological side, we now focus on the industry structure.

3.2 The composition of the European Aerospace R&D collaboration network

[21] Although Vincenti (1990, p.227) states that in industrial or governmental research laboratories, in applied science and some engineering departments in universities, knowledge generation for science and engineering goes in a combined way. He states that the knowledge they produce serves both understanding and design.

In the evolutionary perspective, actors are characterized by incomplete knowledge bases and capabilities, heterogeneity is the main source of novelty and learning takes place over time, i.e. is truly dynamic (Pyka 2002, p.156), and one expects that countries in a transnational collaboration recombine their individual national specialization pattern. Thus, in this section we focus on the heterogeneity of FP composition. Notable is that the overall number of projects falls with time. While there were about 400 projects in FP2 and more than 700 projects in FP3, the number of projects ranges between 200 and 250 in FP4 to FP7. On the other hand, the number of partners per project increases over time in a nearly equivalent fashion. Where there are on average less than six partners per project in FP2 and FP3, the amount constantly increased from about 10 in FP4, 12 in FP5, 15 in FP6 and 13 in FP7. It is noteworthy that the increase in average project size begins before the decline in the total number of projects seen in FP6.

Since the diffusion of knowledge does not happen automatically, but has to be absorbed through firms' differential abilities (Malerba 2002), we analyzed the community composition with the organizations distinguished into distinct types. These are: IND (industry), EDU (education and science facilities, like universities), ROR (research organizations, like the Fraunhofer Gesellschaft), GOV (government and other public authorities) and OTH (all other organizations). As shown in figure 6, the industrial share within the FP is nearly constant up to FP5, ranging between 50-60%. With begin of FP6 a fall down to 45% can be stated and in FP7 only 38% can be allocated to the industry part of the sector. On the opposite the lost share on the industry side was nearly fully absorbed by the scientific entities of EDU and ROR, where their combined share was nearly constant from FP2 to FP5 and rises afterwards to 45% in FP6 and 53% in FP7. This development is of course closely related to the thematic development. With the rising percentage of satellite and space topics relevance in FP6 and FP7 also the scientific knowledge demand raises, what asserts the rise in EDU and ROR.[22] In general the rapid technical change calls for a sound and robust scientific knowledge base, in domains such as air quality and climate change that are subject to large uncertainties and long development phases (ASD 2007).

Averaging across all FPs, an industrial actor participated in a mean number of 3.2 projects, with a standard deviation of 14.6, a research organization in 3.0 (11.1) projects, and a university in 2.6 (6.1) projects. Over all organization types, the fluctuation seems to be high, since they participate on average in about three projects over 26 years. The enormous variation indicates strong heterogeneity within the different types (for the industry type we will analyze the number of employee/number of participation relationship in chapter 3.4).

Over the last decades aerospace projects have grown much larger and tremendously more costly and technologically complex. Therefore, as Hickie (2006, p.713) states, "with technological complexity has come a much greater reliance upon formally educated scientific researchers and engineers, and the need for companies to understand and use scientific knowledge and technological developments." The rising complexity and costs have also led companies to specialize in particular types of aircraft or even particular parts of aircrafts: Airbus (FR) on large aircrafts, Airbus (GB) on wing production and Rolls Royce on turbofan technology. These focal regions of production are also in the center of our invention networks (together with the EDU and ROR institutions). From industrial reasoning the number of actors within the IND category should increase at least within the time from

[22] Additionally the fact that satellite and space topics can be seldom commercialized explains the fall in the industry share.

FP5 to FP7. The reason for this assumption is grounded in the rising use of risk and revenue sharing partnerships (RRSP), which start to flourish due to the extremely increased development costs and high risks of program failures, not only between the OEM and his first tier suppliers, but also between the Tier 1 suppliers and their partners (Paoli and Prencipe 1999).

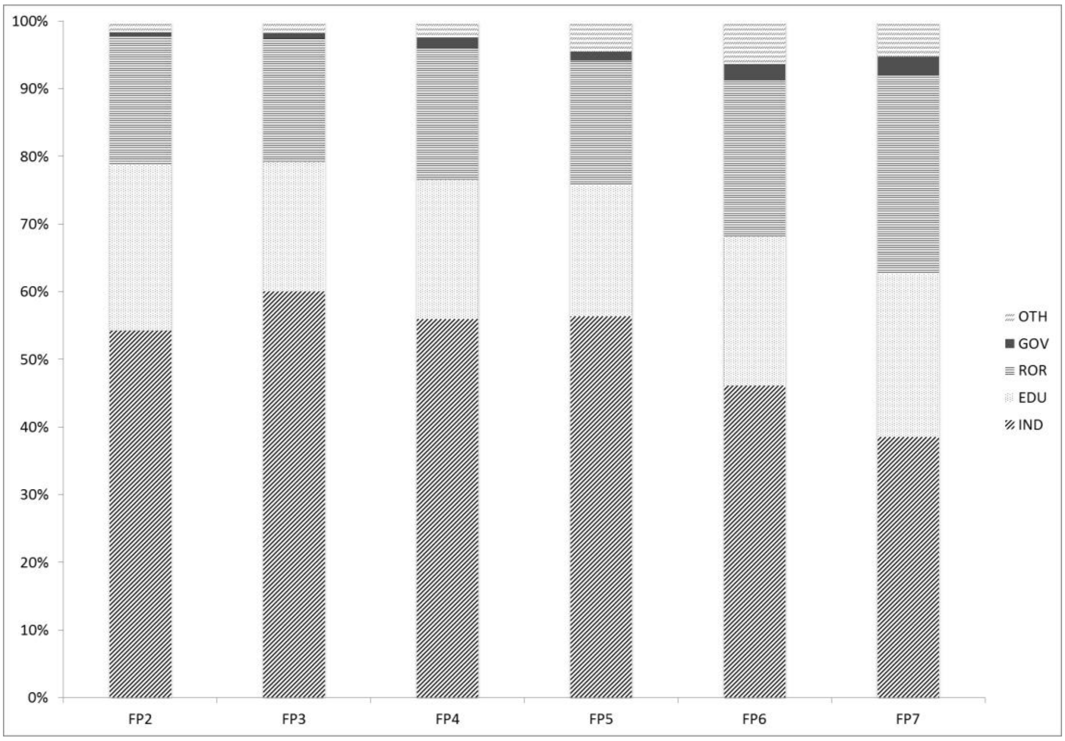

Figure 6: the organizational composition of the European aerospace industry

Participation in the FPs is fluid over time, with organizations entering, withdrawing, and returning during different FPs. Despite these changes, repeated collaborations are observed. In table 4, we show the repeated co-participations between FPs. Entries in the table show the number of distinct pairs of organizations present in an FP that recur in a specific later FP (e.g., 1260 pairs of organizations that collaborated in FP4 again took part in projects together in FP5) or any later FP. Diagonal elements show how many distinct pairs of collaborating organizations are present in each FP. To establish a baseline expectation of repeated co-participation, we include the expected numbers of repeated co-participations in randomized version of the aerospace collaboration networks, based on randomly switching organizations between projects; the values shown are averaged over 1000 instances of the randomized networks. By comparing to the expected values, we infer the presence of stable, repeated collaborations. Within each FP, the number of distinct co-participations is lower than would be expected if organizations were randomly assigned to projects, indicating that numerous collaborators take part in multiple projects together. In contrast, the number of co-participations repeating between FPs is higher than would be expected from the randomized networks, revealing the presence of collaborations that are stable over time.

Further, the repeated collaborations are seen to have some stability over time. In general, the sum of the FP-specific repeated collaborations is greater than the number of distinct collaborations repeated in any later FP. Thus, there must be numerous organizational pairs that re-occur across multiple FPs, indicating the presence of stable collaborative partnerships.

FP	2	3	4	5	6	7	Any later FP
2	**5722**	**422**	**256**	**185**	**57**	**104**	**728**
expected	6305.2	53.4	83.7	86.7	13.8	41.9	220.3
3		**13807**	**865**	**488**	**126**	**187**	**1169**
expected		14541.3	148.4	142.8	17.7	56.8	296.8
4			**12083**	**1260**	**180**	**269**	**1405**
expected			13122.5	691.7	77.0	164.7	796.3
5				**27679**	**518**	**689**	**1011**
expected				28526.5	272.1	467.1	670.4
6					**41811**	**1014**	**1014**
expected					43737.0	366.6	366.6
7						**23503**	
expected						24706.8	

Table 4: Development of repeated co-participation over the FPs

As Pyka (2002, p.160) states, through repetition, relations in innovation systems are institutionalized. Hakanson (1989) puts forth the argument that, with an increasing duration, formal R&D co-operative relationships mutate into informal relationships as mutual trust and confidence between partners is built up. This can be seen as an advantage of participating in funded projects, as formal relations get displaced by more flexible informal relationships over time and organizations cooperate in their R&D beside the funded projects by what knowledge is shared and the inventive potential increases.

3.3 The spatial distribution within the European Aerospace R&D collaboration network

Shedding light on the spatial distribution, intra-regional connections are of importance concerning the knowledge diffusion within the region and external or inter-regional relations are of extreme importance concerning the adoption of new knowledge and the frontier of existing knowledge, like Bathelt et al (2004) suggests. From a regional economic perspective one can say that those regions, whose innovation system is more open to new technologies, do have better chances to use development and growth opportunities. With respect to the adoption of new technology, according to Franz (2008), educational institutions (universities, colleges, etc.) and research organizations have the function within the innovation system to collect, prepare and transmit new knowledge. Regional agglomeration advantages lead to regional technological spillovers, which are the factors responsible for innovative and economic success of firms in these regions, due to the regional resources and capabilities (Pyka 2002, p.160). Interestingly, over the decades the industry has undergone changes caused by internationalization and economic concentration (Niosi and Zhegu 2010). Those changes impact clusters directly: most of the regions have been radically downsized and are now involved in international trade. Additionally, due to commercial and cost reasons, no entire aircraft is made in any region, even if the region is capable of producing it.[23] Together with the shrinking breadth of topics, this explains the centralization to distinct regions within Europe. What is clearly visible in figure 7 is that especially in FP2 and FP3 more regions are involved in the projects.[24]

[23] Recall that this applies only for large commercial aircrafts.
[24] In figure 7 the nodes give information about the overall number of participants per region. The links between the regions provide the number of connections between the regions: the darker the links the higher is the amount of connections of regions within the respective FP.

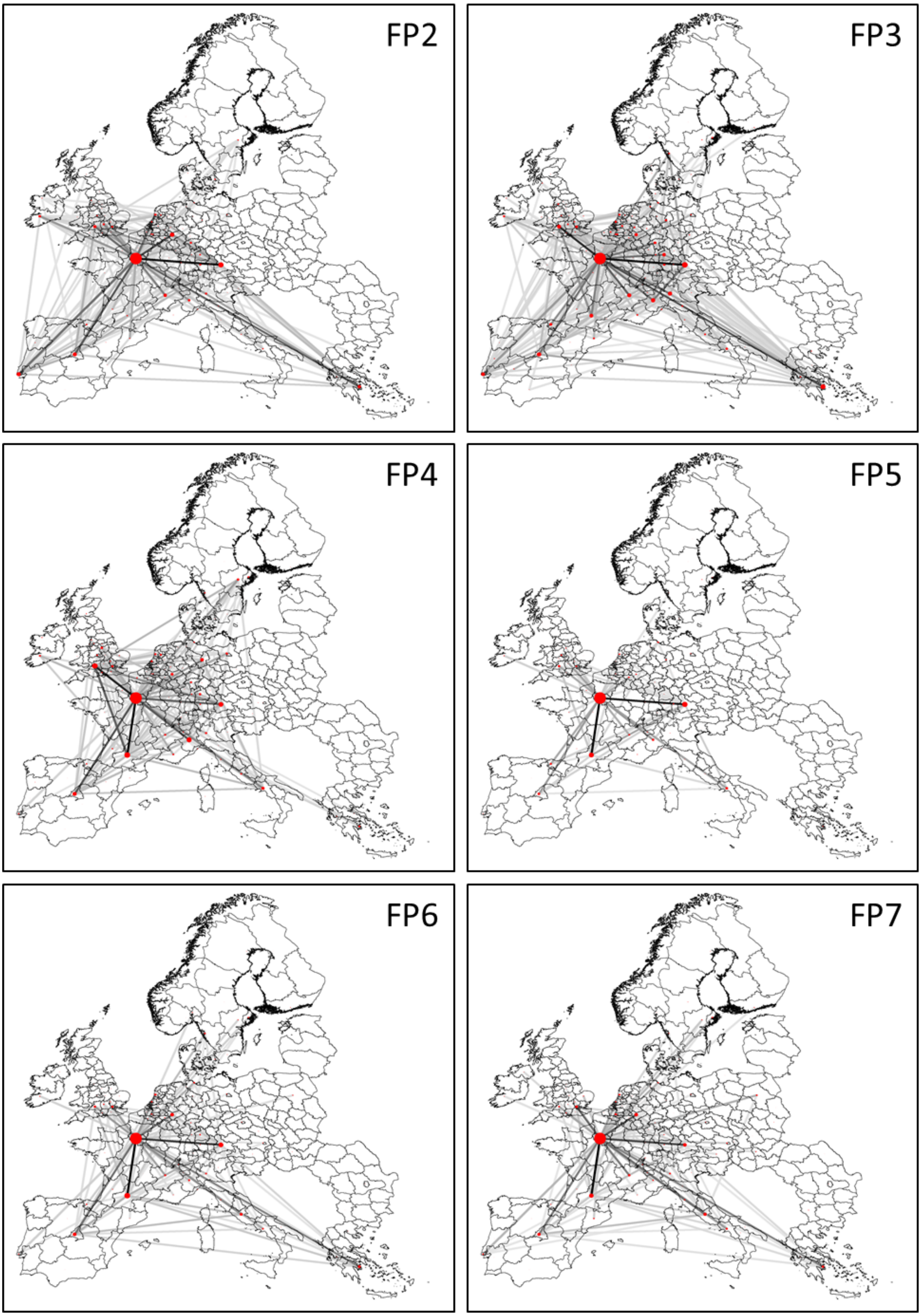

Figure 7: The European aerospace R&D collaboration network

This can be traced back to the thematic development in that FPs – as mentioned before; there is a much broader variance of topics. So this is another argument that technology influences industry structure, or in our case the invention structure of the European aerospace industry. In all FPs, aerospace invention centers can be observed. It is quite striking that the region FR10 (Paris) is the overall center.[25] On the one hand, this is plausible since EADS headquarter is located there; on the other hand, Scherngell and Barber (2009) gain the same results over all funded projects (not only aerospace) in FP5.

For FR62 (Toulouse), the prominence is straightforward to understand, as this is the main Airbus production location in Europe, therefore topics like optimization of the manufacturing process (OMP) are reasonable strong. Further through the agglomeration of a large supplier industry, the strong categories of simulation and numerical tools (SIM), aerodynamics (AER) and especially electric and electronic (ELE) are explainable. ELE is a key technology for avionics which is primarily done by Thales, located in that region. DE21 (Munich) has broadly capable in diverse topics, as indicated in figure 7. This appears due to the location of MTU Aero Engines (jet engines), Cassidian (defence technology), Eurocopter (helicopters) and the EADS innovation center. ES30 (Madrid) and UKK1 (Bristol) are further EADS and Airbus locations, focusing on tailplane fin and wing production, which explains the strength in SIM, RSY and AER. Additionally, UKK1 is especially strong in AER and ELE which might be traced back to the jet engine manufacturer Rolls-Royce. The reason for the high participation of Greece, specifically the NUTS2 region GR30 (Athens), can be traced back to the special knowledge located within this region (as we have shown in above). Besides the large number of education facilities and research organizations, especially the Hellenic Aerospace Industry S.A. is the major player. The company has considerable experience in unmanned vehicles (UAV) since the early 1980s. The knowledge incorporated in this product class — e.g. transmission and information technology knowledge, electronics and avionics knowledge — finds application in space and satellite topics, explaining the region's increased number of participations through FP6 and FP7.

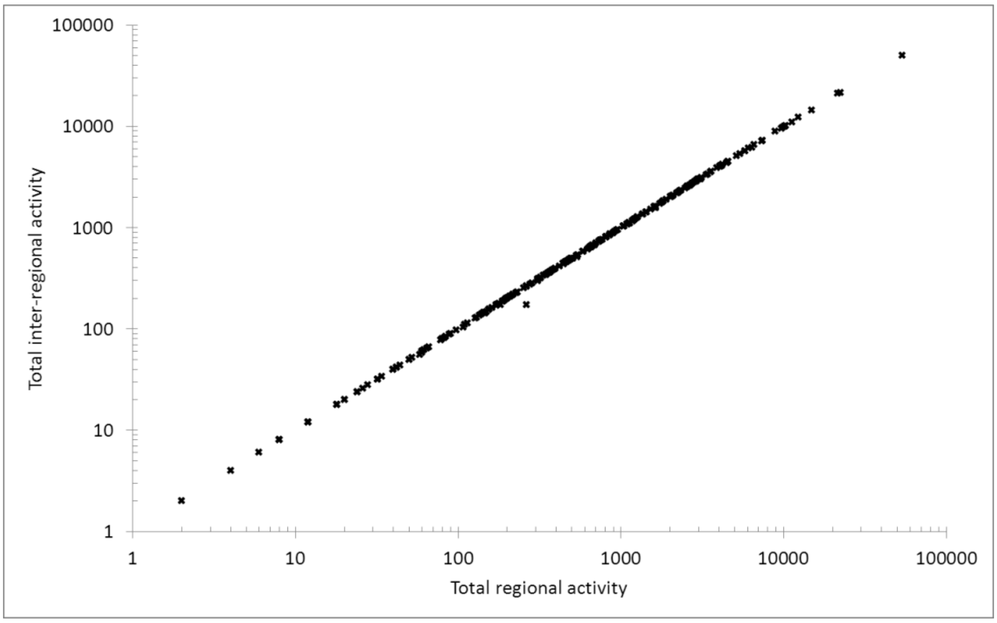

Figure 8: the relation between inter- and intraregional activity

[25] An interesting article focusing on the anchor tenant concept was written by Niosi and Zhegu (2010). They argue that the more anchors are located in one region, perform better than regions with only one or none anchor organization.

Concerning inter- and intraregional connections and therefore possible spillovers, we must keep in mind the participation premise for the European framework programs: at least two partners from two different nations have to take part in a project. What we can see in figure 8 is that intra-regional collaborations are relatively rare. With the exception of ES43, where about 17% of all project collaborations are implemented within the region, all other regions have a proportion of less than 3% of intra-regional collaborations. It seems to be more the case that these infrequently participating regions are in the first instance connected to the major regions, regardless of spatial proximity, suggesting a hub-structure in the European aerospace invention networks.

3.4 The special role of SME and one-time participants

In the following the special role of small and medium sized enterprises (SME) within the European aerospace invention community is analyzed. SME play an important role in the European aerospace industry. More than 90% of all aerospace companies have less than 500 employees, with about 80% having fewer than 50 employees (ECORYS 2009, pg. 149ff). This large share of SMEs indicates how many niches and complex tasks are ubiquitous in the aerospace industry. SMEs play a much more important role in Europe than, e.g., in the US. This can be traced back to the historical developments within the 1980s: due to strong growth, a hierarchy of supplier relationships formed structured as some (later, one) OEMs, few Tier 1 and numerous SMEs. During this time a moderate pressure to reduce prices caused suppliers to emerge and develop technological advances in specific domains. This resulted in the fragmented supplier structure with numerous SMEs seen in Europe. Based on the national interests in every (large) country, similar competences evolved and comparable supply chains emerged.

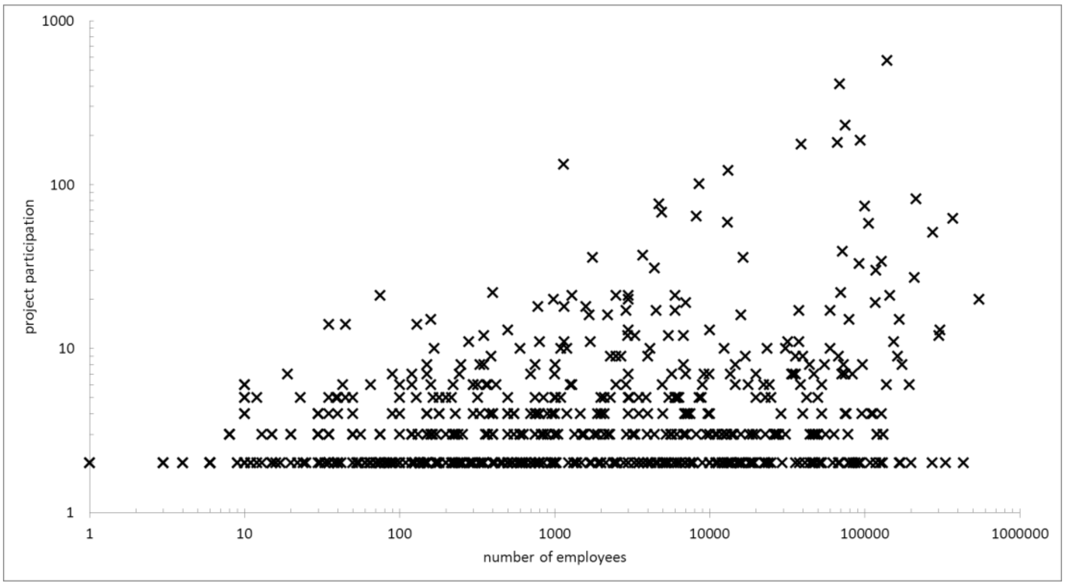

Figure 9: Company size versus project participation[26]

In terms of purchasing volumes, SMEs are not the players: only about 21% of purchases are delivered by SMEs (ECORYS 2009, pg. 150). Although the economic importance of SMEs is small when measured by their size and purchasing volumes, SMEs are important within the invention community, as they are considered to be vital due to their high flexibility and creativity. ASD (2005) measured R&D spending to be 13% of the SMEs' turnover and therefore close to the large companies

[26] Figure 9 depicts all industrial organizations that participate at least two times.

in the aerospace industry. Thus, according to Hollanders (2008), SMEs hold a significant part of the knowledge in the aerospace sector, even though the majority of SMEs are component makers, which limit their abilities to innovate. Countering this problem, network ties offer internally constrained SMEs access to a wider set of technological opportunities (Chesbrough 2003); by establishing networks, SMEs can overcome their internal resource constraints and obtain the advantage often associated with larger size (Nooteboom 1994).

This large share of small enterprises can also be identified within the EU FPs: about 45% of all participants out of the industry category (IND) with more than one project participation do have fewer than 500 employees.[27] This is on the one side industry-induced, due to the historical developments described above, and on the other side technology-induced, due to the specialization of SMEs and their deep knowledge in multi-faceted niche topics. Figure 9 represents the number of employees against the number of participations, where a positive correlation between company size and participation is apparent. That larger companies are privileged concerning their innovative ability, due to their possibility of R&D-capacity, based on a better division of labor and a more efficient usage of prior R&D is clear. Nevertheless, the size advantage shrinks as know-how increases in importance (Zimmermann et al. 2001). Those companies located in the bottom-right corner in figure 9, might be industry-external companies with specific knowledge needed in one or the other topic. Examples for such companies, often providing basic technologies, include ThyssenKrupp, BASF and Evonik.

	Projects >60	**Projects 40 -60**	**Projects 20-39**	**Projects <20**
SME average	9%	8%	6%	6%
MNC average	37%	29%	30%	23%
N/A average	54%	63%	64%	71%

Table 5: Average project participations of SME and MNCs

Due to the recent developments (starting in the mid-1990s) of cost-cutting pressure, a trend towards consolidation was established, which increased the pressure on SMEs. Due to this consolidation pressure from the OEM(s), suppliers (often SMEs) must provide complete sub-systems to stay in development and production programs. The problem behind this is that SME show a weaker risk-sharing capability and tend to have difficulties attracting money (investments). Therefore, developments toward clusters are necessary to stay in contact with Tier 1 firms. Mergers and acquisitions seem to be another possible solution. Ultimately, the risk of takeover by foreign players and knowledge transferring overseas does exist.[28] Additionally, there is an increasing conflict between the production and innovation sides: since the SMEs now have to focus on cost reductions, they are increasingly less able to invest in R&D and innovation (Hollanders 2008, pg. 47). The consolidation process among SME suppliers and the resulting adaption of the cost-cutting mind-set of the Tier1-suppliers poses a threat to the creative base and innovation capabilities of the aerospace sector (Hollanders 2008, pg. 55).

[27] We used a threshold of 500 employees, since compared to international standards and as compared to other companies within the aerospace industry; they can be labeled as SME. It is to mention that the one-time participants make a share of about 70% of all participants, wherefore we analyzed them in detail at the end of this chapter.

[28] E.g. the Austrian FACC, a specialist for composite airframes, taken over by Chinese Xi'an Aircraft Corporation.

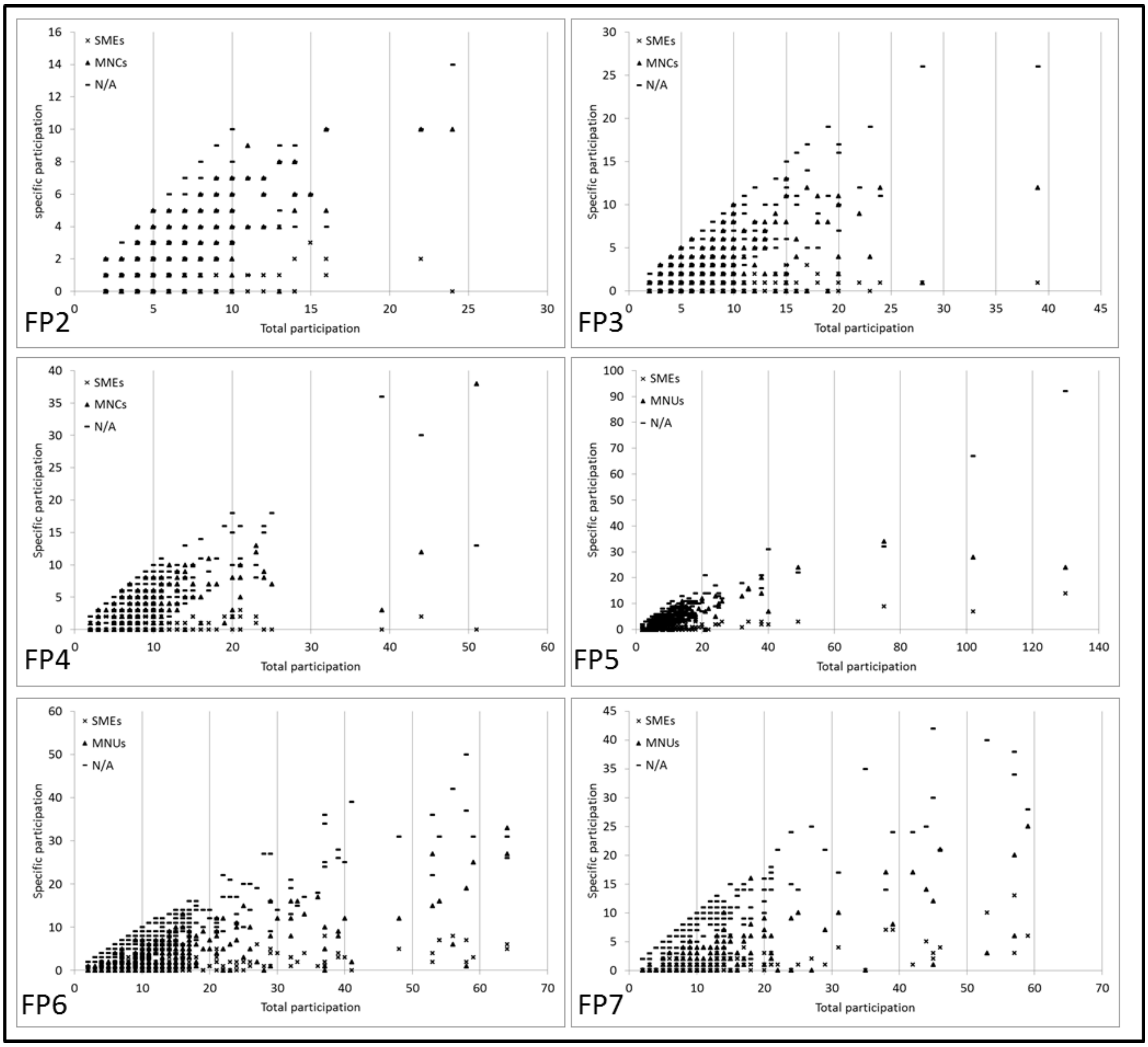

Figure 10: Project composition with respect to the organization size

In the following we discuss the question of how the different projects are composed with respect to company size. Based on our investigation of the company size (as can be seen in figure 10) we build two categories within the IND group: small and medium sized enterprises (SME) or multi-national companies (MNC). As can be seen in figure 10 the average size of the projects, as already discussed above, is increasing over time. In table 5 we differentiated between four project categories and counted the participation of the SMEs and MNCs. The category N/A comprises the following information: EDU, ROR, GOV, OTH and in general all one-time participants (whether SME or MNC or any other category). The amount of MNCs is ranging between 20% and 40% with the highest share in projects with more than 60 participants. SMEs participation share ranges between 6% and 9%, again with the highest share in projects with more than 60 participants. The smaller the projects are the higher the amount of N/As.

As about 70% of all participants do only participate in one project throughout time, the one-time participants play an outstanding role, since they form by far the largest group. How this group of one time participants is composed can be seen in table 6. With an amount of more than 73% the industrial group (IND) has the highest amount. All other groups are ranging below 10%. So what kind of industrial organizations are these companies only applying for one time? We suppose that this group is composed out of industry-extern companies (small or large) and aerospace-SMEs, specialized in niche topics. Nevertheless the examination of the one-time participants needs a more detailed consideration.

One-time participants		
Organization type	**Amount**	**Percent**
IND	2834	73,3%
ROR	355	9,2%
EDU	199	5,1%
GOV	87	2,3%
OTH	390	10,1%
Sum	3865	100%

Table 6: One-time participants by organization type

To summarize our findings on the European R&D collaboration network, the aerospace invention community is a highly concentrated, multi-technological network with a breadth of knowledge and a strong connection (and therefore a high spillover potential) to other industry branches. The core regions show no specialized knowledge base compared to the European average, while the peripheral regions are more specialized. Participation in EU FPs is positively correlated with invention output. Participation by EDU and ROR has been high from the earliest FPs and continues to increase. SMEs take a special role, as they are numerous throughout the industry due to many niche topics and technological specialization. Remarkably is the large amount of one-time participants, about 70%.

4. Differences on the national level – the German Aerospace invention community

In general, publically funded European R&D programs are orchestrated in a pyramidal fashion, composed out of EU, national and regional funding levels. Within the German Federal Ministry of Economics and Technology (Mathy 2011), the responsibilities are viewed as follows: For the EU, the enhancement of international competitiveness, technological demonstrators, projects with socio-economic benefits for Europe and projects with work-shares in different member states are funded. On the national level, projects that focus on national core competencies in industry and academia, as well as projects with socio-economic benefits for the country and joint projects with industry, SMEs and academia from different *Bundesländer* (German federal states) are funded.[29] On a regional level the enhancement of regional locations for industry and academia, projects focused on the regional supplier base and a concentration on SMEs and academia are most commonly funded.

Using the same approach as for the EU level, we analyze thematic, actor and geographical developments in the German aerospace R&D collaboration network (compare table 1 for general information statistics on the funding program). Therefore in section 4.1, we show the temporal development of the core topics and technologies for the German aerospace industry.

4.1 Thematic developments and knowledge bases

For the thematic development in Germany based on the *Förderkatalog* (FK), the same categories are applied as for the European Framework Programmes, ensuring comparability of the EU and German

[29] Note here that FP7 fosters creation of transnational networks which are not bound by the core competencies of certain national industries, which covers the whole European industrial value chain and which have the critical mass to integrate specific technologies into marketable innovations.

data. In figure 11 the thematic development over time is depicted as percentage within each FP, i.e. every point indicates what fraction of projects within the time period can be associated with the different categories.

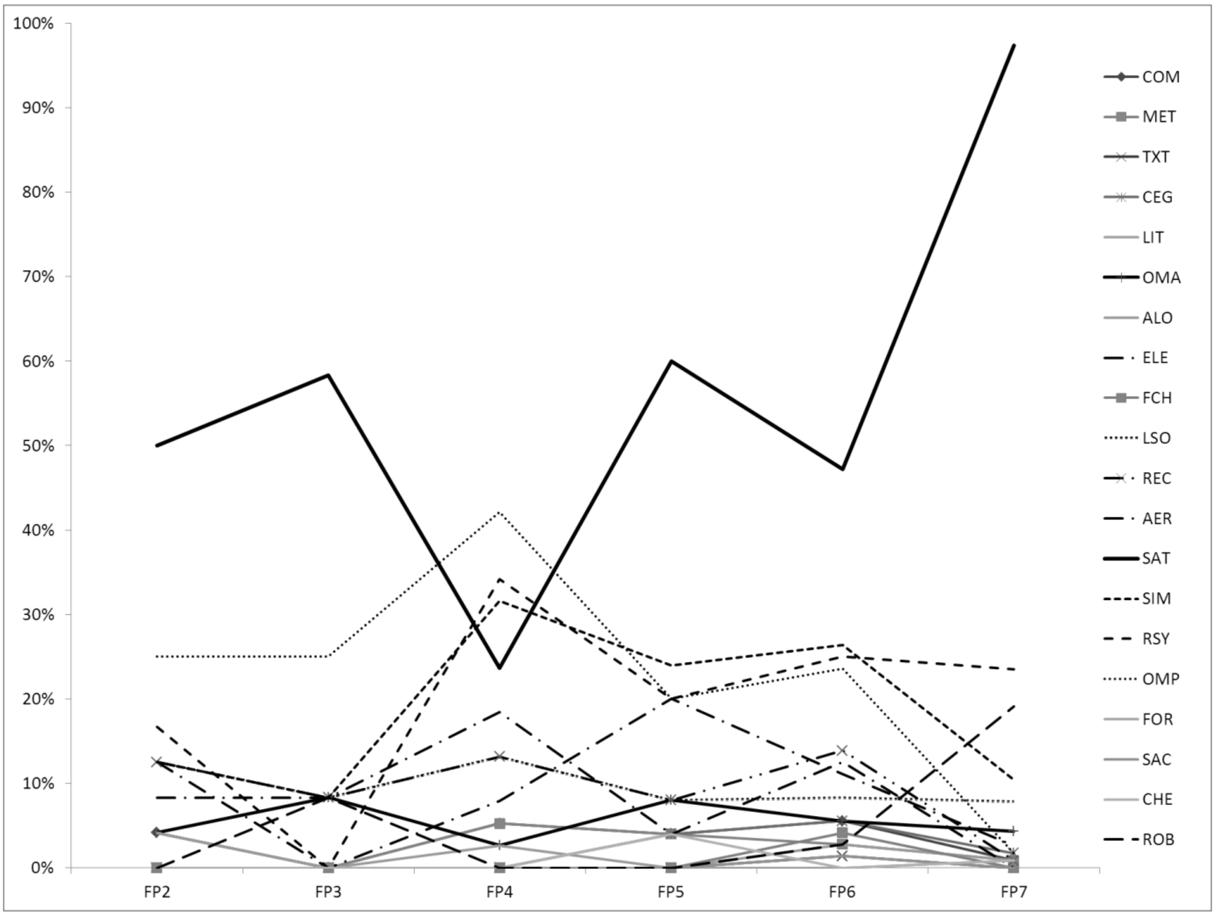

Figure 11: thematic development of the funded projects in the German FK

As in the EU FPs, different core areas can be seen, explaining the movement of categories and therefore the underlying knowledge. Compared to the EU FPs, the German FK covers fewer topics — primarily satellite and space topics (SAT), the optimization of the manufacturing process and supply chains (OMP), quality and safety systems, non-destructive detection and repair systems (RSY), simulation, numerical models and computer-aided systems (SIM) and lasers, sensors and optics (LSO). Striking is the relevance of space and satellite (SAT) projects within Germany. Within the logic of the pyramid funding, this may be seen as a core competence of the German aerospace industry. Ranging between 23% (in FP4, where parallel to the EU FP OMP was top-ranked) and 97% (in FP7), the overall share of the aerospace topics over time is 67%. As for the European case, the topics SIM and RSY can be directly related to the SAT development as they either are prerequisites for the improvement of satellite and space technology (in the case of SIM) or are the goal (in the case of RSY), where many projects are dedicated to earth observation with the help of satellites.

Remarkably, other technologies of core industry relevance are infrequently funded — e.g. materials, composites, lasers, sensors and electronics — despite the German aerospace industry proclaiming itself as strong (especially on the production side) in the domains of fuselage, fuselage-structures and complex cabin equipment. Nevertheless, according to the German Federal Ministry of Economics and Technology, there is an extremely high R&D rate, with 18% of turnover reinvested and a strong perspective towards industrial applications and products within the German aerospace industry (König 2006). As the thematic development reveals a strong focus on satellite and space topics, the question is how the R&D collaboration network is shaped. Since the focus rests on topics which require a strong scientific knowledge base, we might suppose that the share of EDU and ROR should be higher than in the EU FPs.

4.2 Actors landscape, community composition and the connection to the EU-level

Before proceeding with a detailed composition analysis, we note that the number of projects increases with time. As depicted in table 1, the number of projects over the FP2 to FP5 time frame was nearly stable, ranging between 13 (FP3) and 38 (FP4), it increased drastically, with 72 projects in FP6 and 115 projects in FP7. The number of participants varies nearly exactly with the number of projects, wherefore we achieve a nearly stable amount of partners per project that ranges between 2.6 and 4.1.

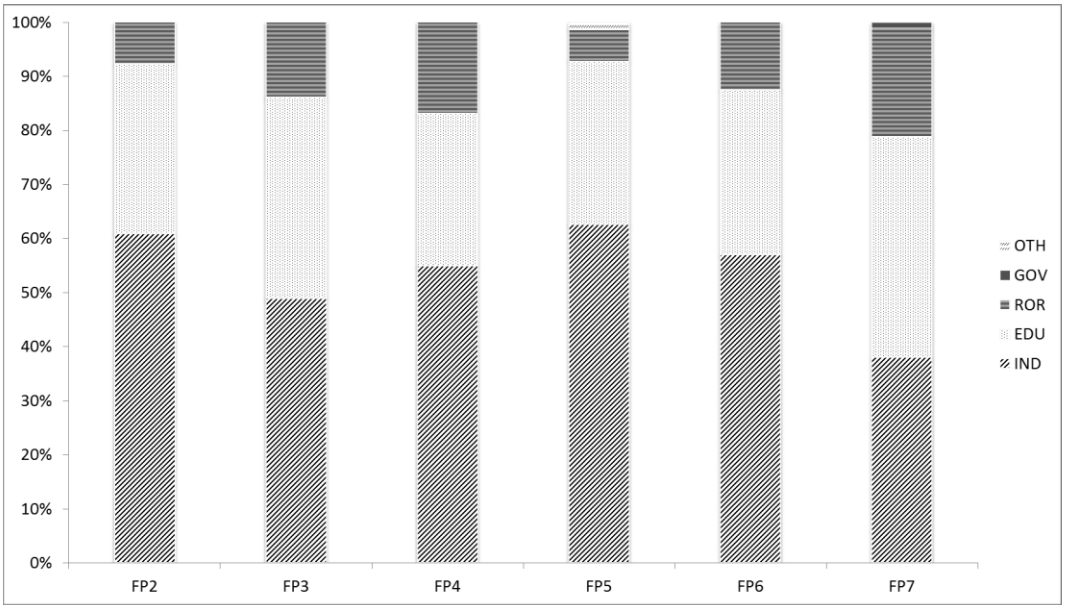

Figure 12: organizational composition of the German funded projects

Figure 12 depicts the invention community composition per FP. The three main organizational types are IND (industry), EDU (education and science facilities) and ROR (research organizations). The industrial share grew from between about 50% and 60% from FP2 to FP6. In FP7 a decrease down to 38% is seen. In combination with the development of the EDU and ROR shares — which in almost all FPs depict the complementary share to reach 100% — this confirms our hypothesis that, due to the increased satellite and space topics, the share of organizations intensely focused on scientific knowledge would rise.

The graphical representation in figure 13 of the actor network shows the centers of the German aerospace invention community. Again as on the European level the circles give information about the amount of participants in the respective region and the lines representing the connection between two regions. The thicker the lines are the higher is the amount of connections. With the exception of FP4, the Munich area can be seen as the center. Other active regions are Braunschweig (EDU and ROR), Cologne (ROR), Frankfurt (IND and EDU), and later (FP6 and FP7) Bremen (IND and EDU) and Berlin (IND, EDU and ROR) and slightly Stuttgart (EDU and ROR). Beneath these strong representation, numerous and varying (with respect to the spatial distribution) regions are participating, indicating the strongly fragmented German aerospace industry.[30]

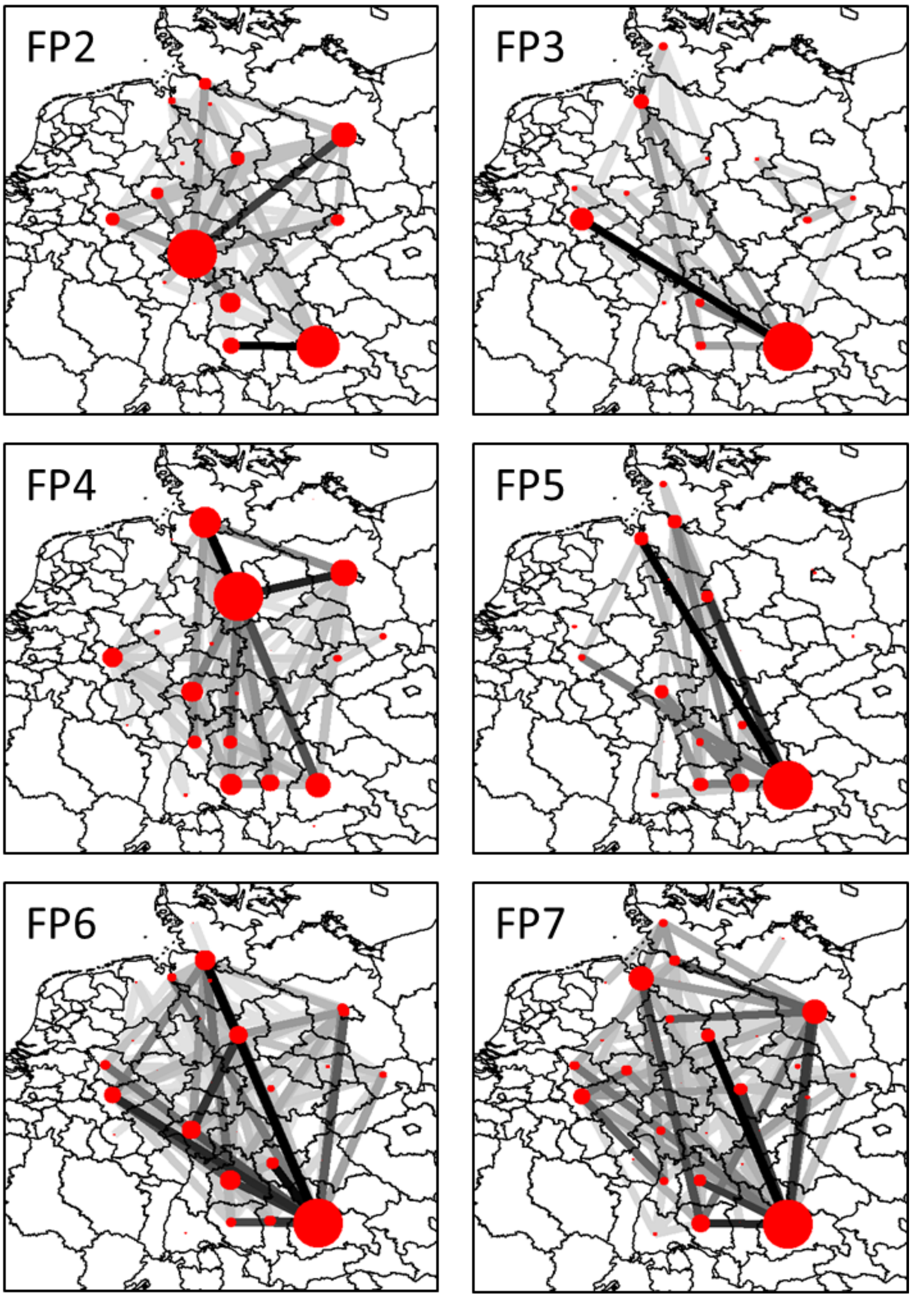

Figure 13: The German aerospace R&D collaboration network

An interesting fact is that only about 38% of all organizations in the German *Förderkatalog* are also participants in one or more of the EU FPs. On the one hand, this supports the importance of connecting European invention communities with national invention communities, to get a clear

[30] For the inter/intra-regional connections the result is not important since the amount of projects is too low and it approximately fits to the result on the European level.

picture of how development is to be evaluated.[31] On the other hand, it suggests that it might be easier to apply for nationally funded projects than those funded at the European level.

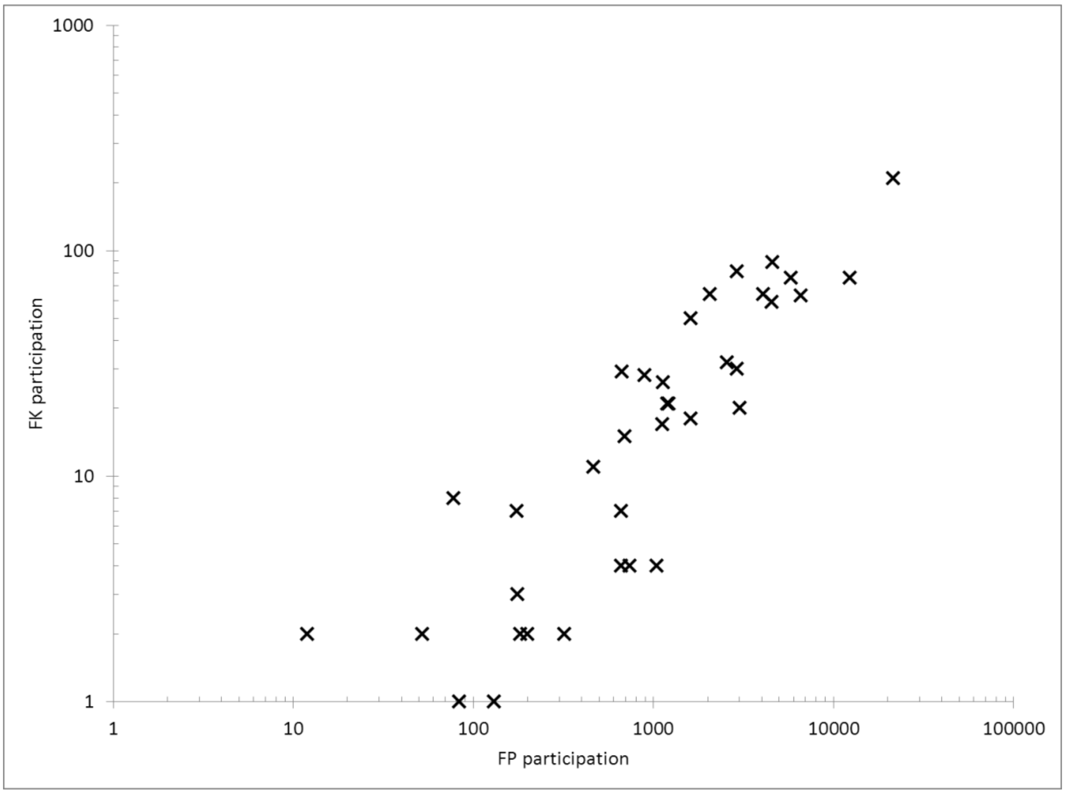

Figure 14: FP and FK participation in German regions. Not shown are the results for those regions which only take part in FP projects, without participating in FK-indexed projects; these are DE22 Niederbayern (208 projects), DE40 Brandenburg (82 projects), DE72 Gießen (146 projects), DEB1 Koblenz (366 projects), and DEE2 Halle (4 projects). No regions had FK participations without FP participation.

In general, based on figure 15, regions that participate more often in their national programs also more frequently participate in European funded projects. The number of participants engaged in funded projects on the national and international level is quite low. The reason can be provided with the help of figure 16. There, numerous organizations of all sizes only participating in one project indicates that there are many “industry-foreign” participants in aerospace projects in the German FK.

Especially in Germany the average share of SMEs is quite high, about 90% (2007), where this group delivered a purchasing volume of about 30%. Compared to France with an average amount of 65% SME with a purchasing volume of 25%, the German aerospace industry has the highest SME amount within Europe. The reasons can be seen in several factors: On the one side the national peculiarities outside the aerospace industry, like infrastructure, specific federalist funding systems, but also cultural and social factors. On the other side an “aerospace-intern” explanation might be that the consolidation in France is more sophisticated up to now.

[31] To gain an even more substantial picture, the regional funded projects by local governments could also be considered, as it might be the main source the internal R&D operations and non-funded projects with partners.

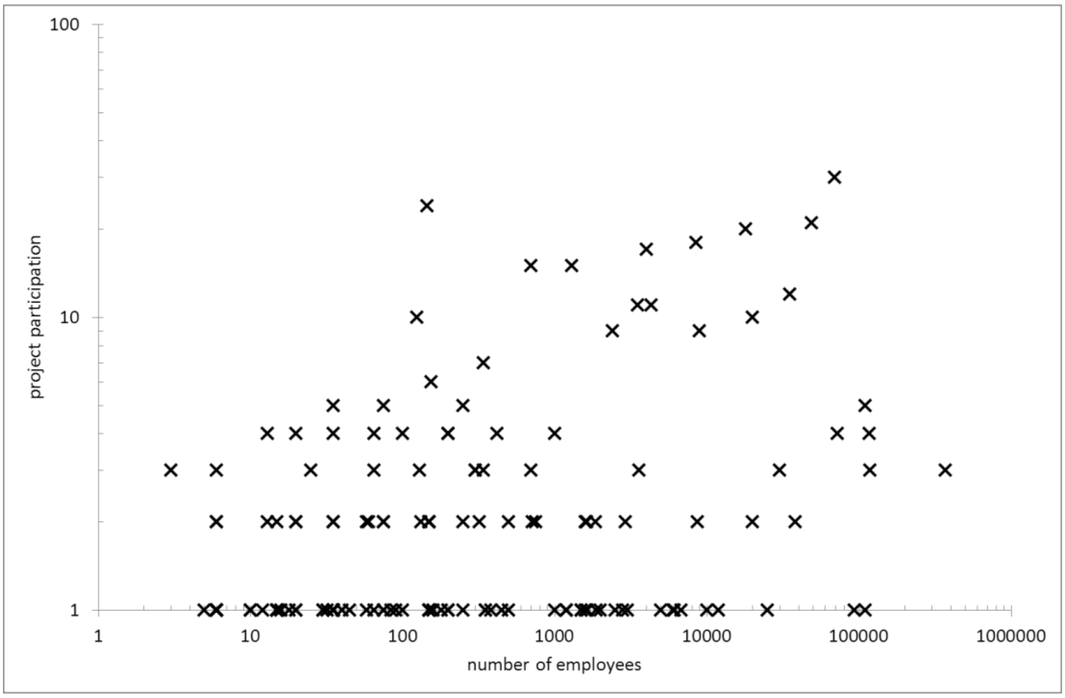

Figure 15: Company size versus project participation

Even if the aeronautic projects from a knowledge base point of view are underrepresented, due to the strong space and satellite (SAT) topics Germany might have an advantage concerning the spillover potential, since lots of spillovers have been directed from space to aeronautic and then to other industries, e.g. to automotive. Here the comparison to the EU level (thematic-geographic) might be useful. If there are other competences specialized within German regions, the argument loses its credibility. If especially space and satellite knowledge is prevalent the argument is to be favored.[32]

5. Conclusion

We used the sectoral innovation system approach to get an impression on how the European aerospace invention community interacts, what the key regions, actors and topics are and how these factors influence the development over time. We found that the European aerospace industry on a supra-national level is characterized by breadth of knowledge and multi-technological features which provides a wide application possible in lots of neighboring industry branches to generate inter-industry spillovers. Further a strong connection of the thematic development with its implications on the organizational composition can be seen.

The European aerospace R&D collaboration network is geographically highly concentrated within several core regions. These regions show no significant specialization on different topics. The reason has to be seen in the fact that in each country the aerospace industries developed on a national state since its beginning until the 1970/80s may be due to the close connection of the defense industry and national security considerations. Outside the core regions more thematic specialization is apparent, as these peripheral regions do not comprise such a plenty of organizations compared to

[32] This argument is not derogated by the minor aeronautic projects, since the argument that SMEs (which are mostly responsible for the technological development in the space industry) participate more often in nationally funded projects, due to easier access to the national projects and a lower capacity to participate on the national and the European level.

the core regions and therefore individual specialization of organizations carry weight much more than in diversified core regions.

Overall, the high participation of education facilities and research organizations supports the industry character of being a high-tech and knowledge intensive industry. Conspicuous is the large number of one-time participants (with more than 70% industry organization), indicating numerous niche themes and technological specialization possibilities. This is also the reason for a very high fragmented SME structure covering specialized innovation and production topics within the European invention and production community. The extreme high amount of education facilities and research organizations can be traced back to at least two factors. First, the participation is favored by the system itself. Second, the aerospace industry is a high-tech industry demanding a high amount of scientific knowledge. To conclude our findings and emphasizing the holistically approach, we can cite Malerba (2005, p.7f.): In an "evolution, an industry undergoes a process of transformation that involves knowledge, technologies, learning, the features and competences of actors, types of products and processes, and institutions."

The presented insights provide us with a profound understanding of the aerospace industry and its invention community for many possible further elaborations. For proximity considerations on each of the discussed levels – thematic, actor-based or geographic – our findings provide a comprehensive base. Further, since our thematic categories can be connected to patent classes, an analysis of the parallel development of codified knowledge might be an interesting approach to complement the chiefly tacit-knowledge developments in the European Framework programs and the German *Förderkatalog*. Further the presented one-time participants need to be analyzed in more detail, e.g. to include the consideration of the scientific organizations EDU and ROR. Additionally a breakdown of the inter-industry approach based on the actors (not only on the topics) might be interesting to follow.

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Universität Hohenheim
Forschungszentrum
Innovation und Dienstleistung
Fruwirthstr. 12
D-70593 Stuttgart
Phone +49 (0)711 / 459-22476
Fax +49 (0)711 / 459-23360
Internet www.fzid.uni-hohenheim.de