The Evolution of Aerospace R&D Collaboration Networks on the European, National and Regional Levels

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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.[1] 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. Innovation systems can be analyzed on national (Lundvall 1992) and on

[1]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.

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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 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, p. 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, p. 131). As Malerba (1999, p. 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, p. 5f) identifies six points that 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, and demand[2] levels
4. The role of non-firm organizations (universities, government, etc.)
5. The relationships among agents
6. The dynamics and transformation of sectoral systems

In this chapter 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; to get a holistic impression of the European aerospace industry, we investigate the supra-national European level, the national German level and Baden-Württemberg on a regional level. Our analysis is based on 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

[2]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”.

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: on the actor level (exceptions include Barber et al. 2006; 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 deeper analysis of the invention networks within the aerospace industry and their underlying technological and institutional evolution.

This chapter is organized as follows. Section 2 provides a background overview, with Sect. 2.1 giving a short historical abstract on the aerospace industry and its industrial and technological development in general, and Sect. 2.2 explaining the data sources. Section 3 focuses on the European aerospace invention community, describing the thematic development (Sect. 3.1) and the actor level (Sect. 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 draws attention to the regional level in detail to the Stuttgart region. Section 6 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[3] 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 twentieth century, the first flights of airplanes[4] 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

[3]Subsequent years are analyzed within the main chapters, since our data starts with the year 1987.

[4]Precursor works on bionics and other aviation specific researches led to the first flights: cf. Moon (2012).

entrepreneurs.[5] 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 from the USA. 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 Aeropostale 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 primarily from start to finish.[6] Also during this decade, technological and industrial complements for the first time split 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 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 consortium of the leading European aerospace nations. The underlying driver for consortium 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

[5]An interesting social network analysis about the entrepreneur years of the aerospace industry is provided by Moon (2012).

[6]This especially holds for Europe—except Germany, due to restrictions imposed by the allied forces, Germany was allowed (if at all) to produce systems and components in license. Nevertheless during the 1950s the US aircraft industry started to establish a pyramidal supply chain structure.

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.[7] On the industry level, the 1990s and the new century have been marked by crises, consolidation waves, industrial integration and a still ongoing global reorganization. These developments correspond directly to our data set.

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 aircraft. 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 were established, forming 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 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 and Giuri 2001). With the exception of the Concorde, aircraft saw now radical design changes and no new design trajectory 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 specifics of the industry are related to our findings in Sects. 3 and 4. According to Esposito and Raffa (2006) and Alfonso-Gil (2007) the aerospace industry can be characterized by a high technological level with a high R&D intensity,[8] 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

[7]Not only Airbus as the manufacturer of aircraft, but also the defense and space entities were centralized under the European holding company EADS (a consortium 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.

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

form of ownership,[9] 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 Sect. 3 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).[10] 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 organization names and other data consistent over time.

Our core data set to capture collaborative activities in Europe is the EUPRO database,[11] 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, 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*[12] or (standard only in FP7) *Space & satellite research*. We identify aerospace-related organizations as organizations taking part in at least one aerospace project.

[9]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.

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

[11]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).

[12]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.

Table 1 Time dimension and general statistics on FPs and FK

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* projects starting 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

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*[13] (FK). The funded projects are subsidized by five German federal ministries, with aerospace relevant projects funded by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economics and Technology (BMWi).[14] 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 2012, p. 351). To allow temporal comparisons between the national and European levels, we aggregated the German data comprised in the *Förderkatalog* into the European time ranges of the FPs (cf. Table 1). The two databases enable 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 develop over the mentioned time range.

3.1 Thematic Developments and Knowledge Bases Within EU FP-Projects

The technology embedded in the industry is the key factor and driving force for development. We inspected all projects (2013 in total) dedicated to the aerospace sector and classified each of them to one or more of 25 thematic categories. Those

[13]www.foerderkatalog.de.

[14]We identified all aerospace relevant projects with the help of the Leistungsplansystematik (“activity systematics”).

Table 2 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

categories are developed based on International Patent Classes (IPCs) and the German DIN-Norm (Table 2).[15] In Fig. 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 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

[15] 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.

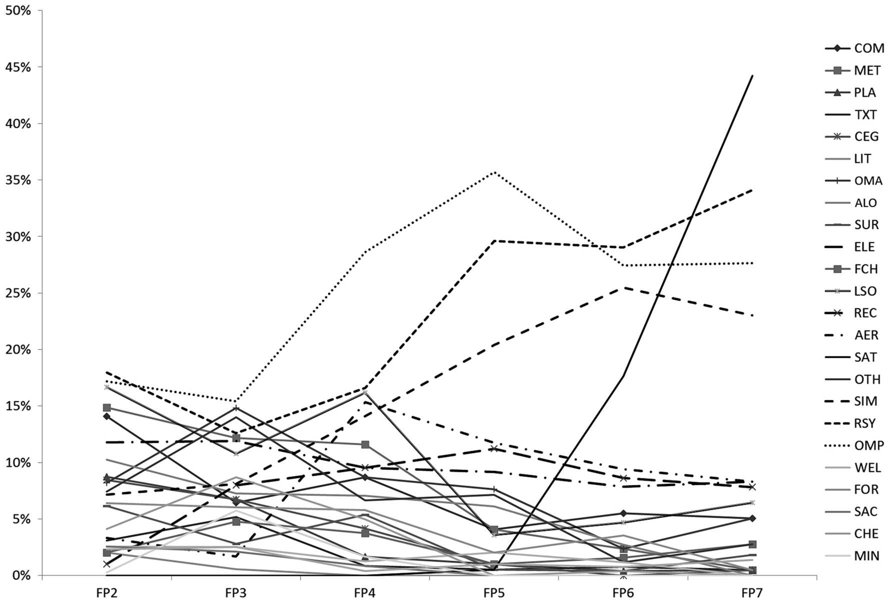

Fig. 1 Thematic development of EU-funded aerospace R&D projects

share within the FPs. Categories ranging between 5 and 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.).

Although we tried to find categories that 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 factors 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 increasingly used such composite materials. Until the mid-1990s the amount was not higher than 10 % of the total aircraft weight and only for non-weight bearing parts (ECORYS 2009, p. 181). 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 by total weight. The same holds for the Airbus A350, which was 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.

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, consistent with the increase of AER and REC.[16] 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, a 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 increased 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 adopting 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 defined search word families for 12 neighboring industries (compare Table 3).

[16]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.

Table 3 Search word families of neighboring industries

Industry search word families			
Code	Search words	Code	Search words
AUT	Automotive, 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

The resulting search strings are applied to the information incorporated within each project's title and objectives and checked individually for plausibility. The result can be seen in Fig. 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 textile industries are declining in the recent FPs, the electric/electronic industry relevance increased in the later FPs.

In Figs. 3 and 4, we visualize how the thematic categories are geographically located, restricting attention to the ten thematic categories most frequently occurring in projects over all FPs. We investigate thematic specialization at the level of NUTS2 regions.[17] For selected regions, we show their thematic specialization based on the frequency of occurrence of the categories in projects taken part in by organizations from the regions. To account for the varying overall occurrence of thematic categories, we show the difference of the regional values from the European average, i.e., the mean over all regions for the respective thematic category.

In Fig. 3, we show the thematic specialization of the ten regions producing the most project participations during the course of the FPs. Therefore, when focusing on the greater amplitudes, we see that several regions have effectively no specialization, with all thematic categories differing little from the European average. As regional specialization is represented through high occurrence rates in one or more thematic categories, we can see that those very active regions are generally close to the European average in nearly all thematic categories. Nevertheless in some regions certain focal knowledge specializations are visible. 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, ITC1 (Turin) in OMP, UKI1

[17]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.

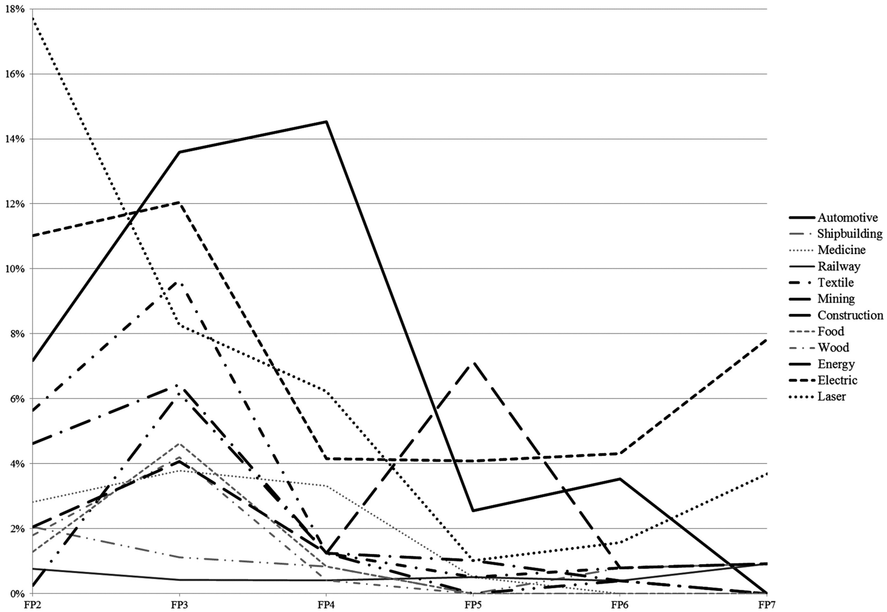

Fig. 2 Inter-industry application potential of EU-funded aerospace knowledge

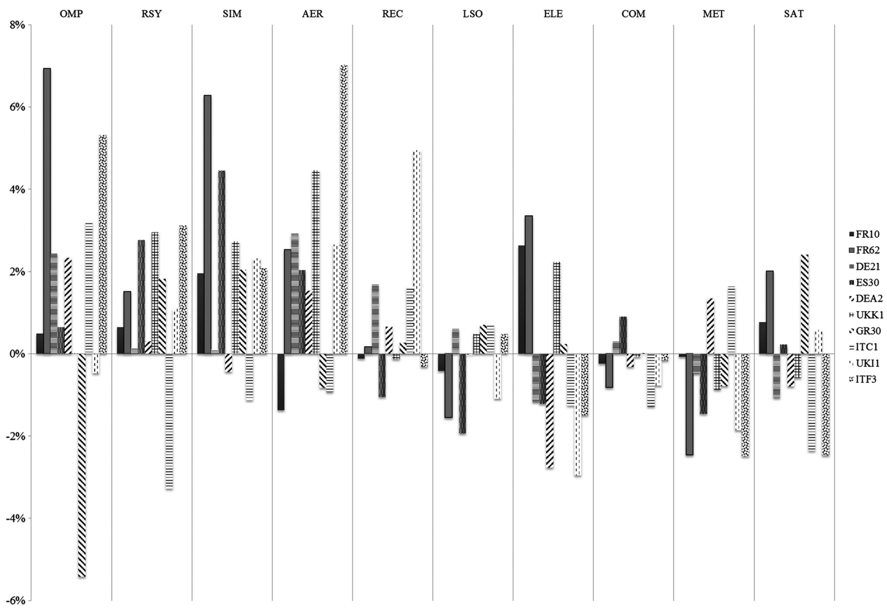

Fig. 3 Thematic specialization pattern of the top-ten European aerospace regions

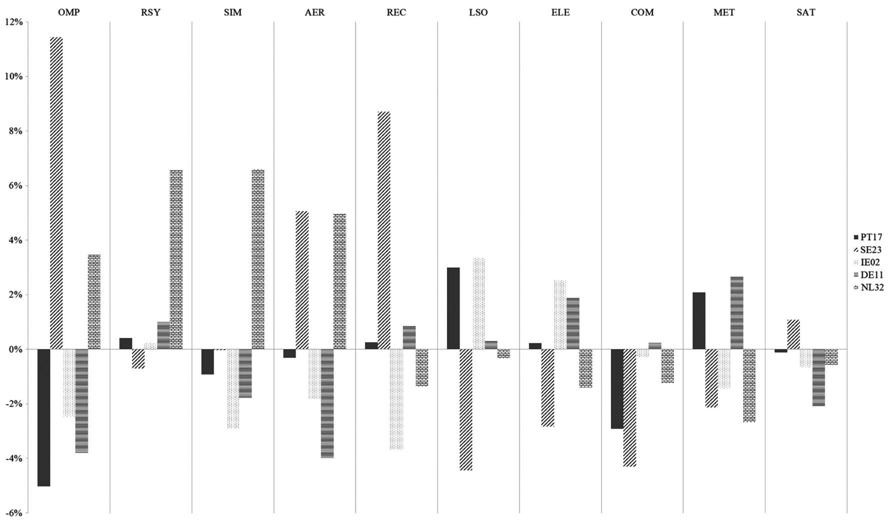

Fig. 4 Thematic specialization pattern of further important European aerospace regions

(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 values are rather low—these regions play a key role in defining the European average.

In Fig. 4, we show five regions that are prominent in some, but not all, of the FPs. In general, these regions are more specialized than the top-ten regions, with greater differences from the European average than those regions considered above. Noticeable values can be observed in SE23 (West Sweden), which is strong in OMP, AER and REC; NL32 (Noord-Holland), strong in RSY, SIM and AER; and DE11 (Stuttgart), strong in MET. The regions IE02 (Southern and Eastern Ireland) and PT17 (Lisbon) are nearly similar to the European average, i.e. compared to the European average they show no real specialization of their knowledge fields.

In addition to the detailed inspection of thematic categories, there is a need to identify the type of underlying knowledge, i.e. the differentiation between engineering and scientific knowledge.[18] The usage of either scientific or engineering

[18]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. 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 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.

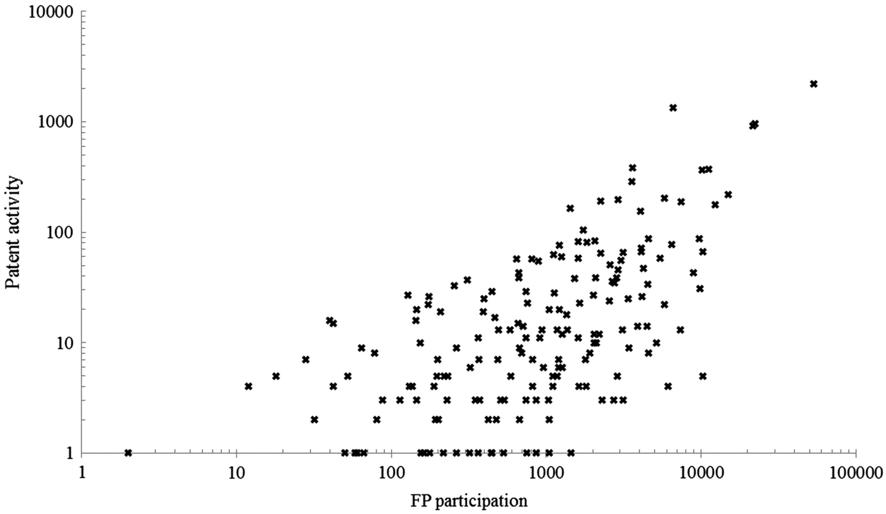

Fig. 5 FP participation and patent activity in European regions

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.[19]

An indication on the innovative output within regions is presented in Fig. 5, based on patent data. We used patent data[20] 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 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 that 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.

[19]This exceeds the purpose of this chapter, but might be a fruitful field for further research.

[20]For the general limitation of patent data usage and patents as strategic element see Granstrand (2010). Further Hollanders et al. (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 have emerged, patent usage and relevance will increase in the future. Begemann (2008) discusses the role of patents in the aerospace industry in a historical view, beginning with the Wright brothers and continuing to the current situation between Boeing and Airbus.

3.2 The Composition of the European Aerospace R&D Collaboration Network

In the evolutionary economics perspective, actors are characterized by incomplete knowledge bases and capabilities. Heterogeneity among actors is the main source of novelty, with learning takes place over time, i.e. learning is truly dynamic (Pyka 2002, p. 156). One thus expects that countries in a transnational collaboration combine individual capabilities derived from national specialization patterns. 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 fewer than six partners per project in FP2 and FP3, the number 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 knowledge does not automatically diffuse, but must 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 Fig. 6, the industrial share within the FP is nearly constant up to FP5, ranging between 50 and 60 %. Beginning with FP6 a decline to 45 % can be observed and in FP7 only 38 % can be allocated to the industry part of the sector. 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 increasing relevance of satellite and space topics in FP6 and FP7, the scientific knowledge demand also rises, leading to the rise in EDU and ROR.[21] 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).

Participation in the FPs is variable, with organizations entering, withdrawing, and returning during different FPs. 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; individual actors vary widely in how they participate in FP projects. Despite this, repeated collaborations are observed. In Table 4, we show the repeated

[21] Additionally the fact that satellite and space topics can be seldom commercialized contributes to the fall in the industry share.

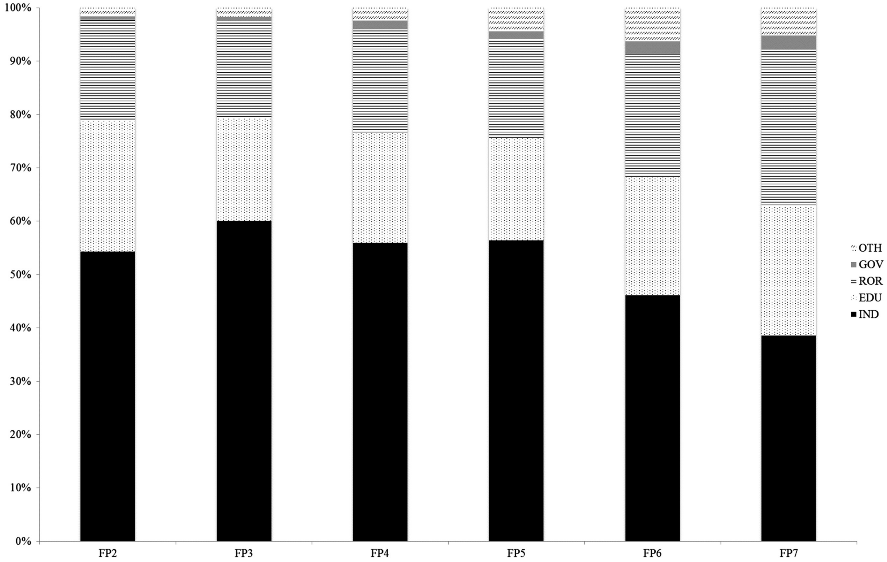

Fig. 6 The organizational composition of the European aerospace industry

Table 4 Development of repeated co-participation over the FPs

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		13,807	865	488	126	187	1169
Expected		14,541.3	148.4	142.8	17.7	56.8	296.8
4			12,083	1260	180	269	1405
Expected			13,122.5	691.7	77.0	164.7	796.3
5				27,679	518	689	1011
Expected				28,526.5	272.1	467.1	670.4
6					41,811	1014	1014
Expected					43,737.0	366.6	366.6
7						23,503	
Expected						24,706.8	

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.

As Pyka (2002, p. 160) states, through repetition, relations in innovation systems are institutionalized. Hakansson (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, as Bathelt et al. (2002) suggest. From a regional economic perspective, 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 aerospace 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, as well as the proportional allocation between the Airbus consortium member states, no entire

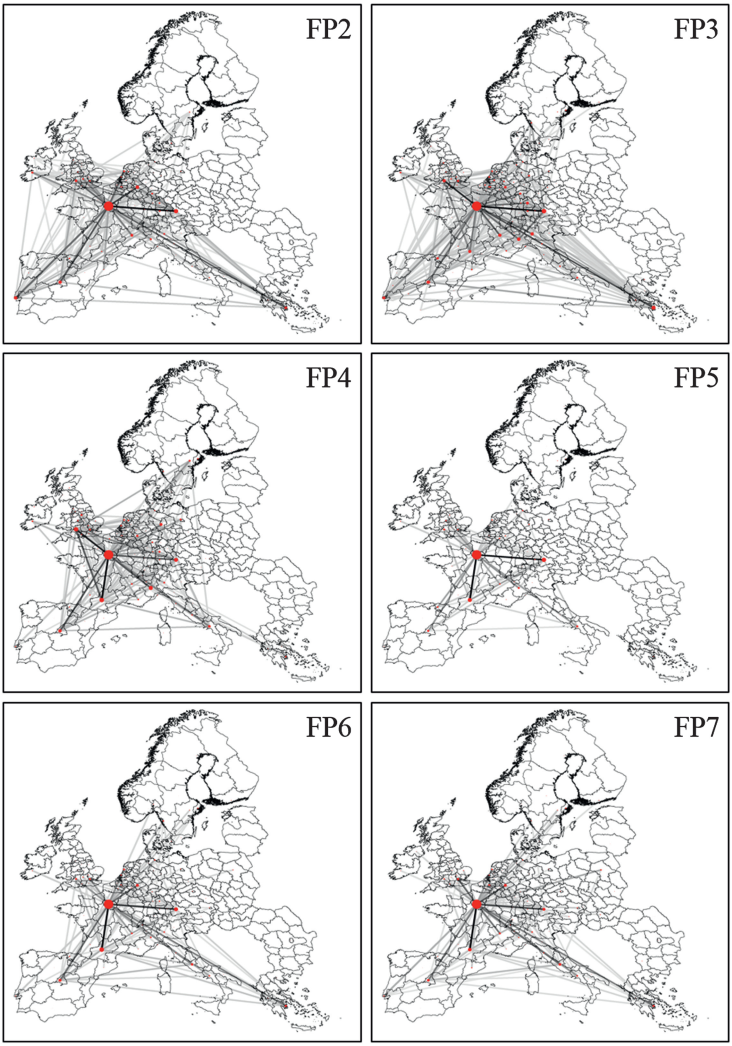

Fig. 7 The European aerospace R&D collaboration network. The nodes give information about the overall number of participants per region. The links between the regions provide the number of connections between the regions: the *darker* the links the higher is the amount of connections of regions within the respective FP

large commercial aircraft is made in any region, even if the region is capable of producing it. Together with the shrinking breadth of topics, this suggests the centralization to distinct regions within Europe. What is clearly visible in Fig. 7 is that especially in FP2 and FP3 more regions are involved in the projects.

This can be traced to the thematic development in the FPs, with the early FPs having greater diversity in topics. Again, this indicates 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.[22] On the one hand, this is plausible since EADS headquarter is located there; on the other hand, Scherngell and Barber (2009) obtain 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 projects focused on topics like optimization of the manufacturing process (OMP) are frequent. Further, through the agglomeration of a large supplier industry, the frequent 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 broad capabilities in diverse topics, as indicated in Fig. 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 above). Beside 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 participations through FP6 and FP7.

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 Fig. 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.

[22] An interesting article focusing on the anchor tenant concept was written by Niosi and Zhegu (2010). They argue that an anchor is able to spin off new firms and attracts other firms. That favors our findings in the aerospace centers as there is a high agglomeration of participating firms where at least one big player is located.

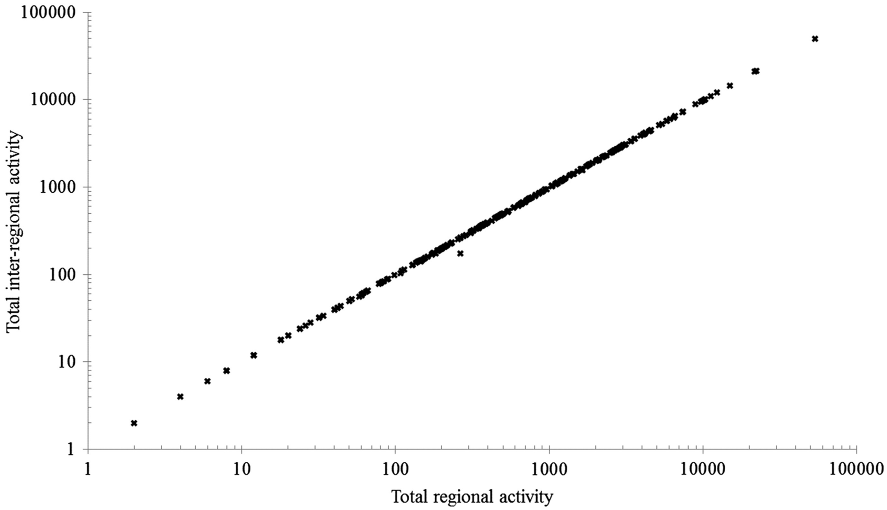

Fig. 8 The relation between inter- and intraregional activity

3.4 The Special Role of SME and One-Time Participants

In the following section, the special role of small and medium sized enterprises (SME) within the European aerospace invention community is analyzed. SMEs 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, p. 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 hierarchical supplier system was formed, with a few (later, one) OEMs, several Tier 1 firms, and numerous SMEs. During this time a moderate pressure to reduce prices led to the emergence of suppliers, who developed 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.

In terms of purchasing volumes, SMEs are not of paramount importance: only about 21 % of purchases are delivered by SMEs (ECORYS 2009, p. 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 in the aerospace industry. Thus, according to Hollanders et al. (2008), SMEs hold a significant part of the knowledge in the aerospace sector, even though the majority of SMEs are component makers, which

Table 5 Average project participations of SMEs and MNCs

	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

limits their abilities to innovate. Countering this problem, network ties offer capacity 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 advantages associated with larger firms, including technological, financial and human resources (Nooteboom 1994).

This large share of small enterprises can also be identified within the EU FPs (Table 5): of participants from the industry category (IND) with more than one project participation, about 45 % have fewer than 500 employees.[23] 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 presents 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 and Andres 2001). Those companies located in the bottom-right corner in Fig. 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.

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 SMEs show a weaker risk-sharing capability and tend to have difficulties attracting 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.[24] Additionally, there is an increasing conflict between the production and innovation

[23]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. The one-time participants are about 70 % of all participants; we analyze them in detail at the end of this section. The category N/A summarizes all participants out of the IND category where no information according to their sizes could be gained, plus all other categories.

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

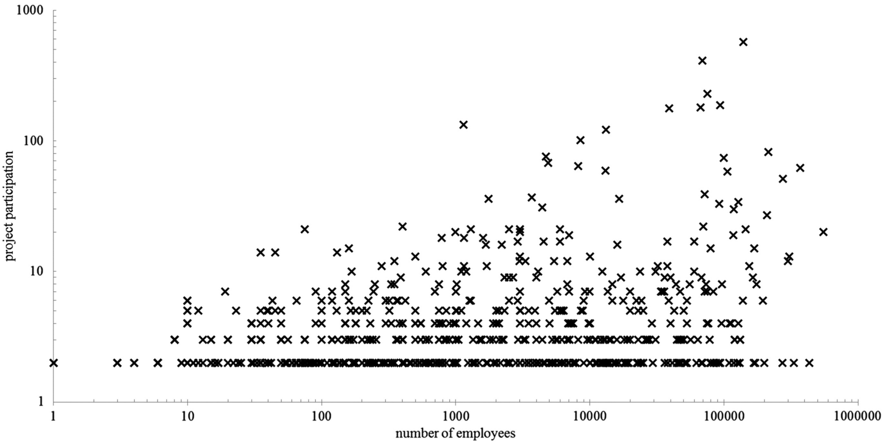

Fig. 9 Company size versus project participation. Included are all industrial organizations that participate at least twice

sides: since the SMEs now must focus on cost reductions, they are increasingly less able to invest in R&D and innovation (Hollanders et al. 2008, p. 47). The consolidation process among SME suppliers and the resulting adaption of the cost-cutting mind-set of the Tier 1 suppliers pose a threat to the creative base and innovation capabilities of the aerospace sector (Hollanders et al. 2008, p. 55).

We discuss now to 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 Fig. 10) we distinguish two categories within the IND group: small and medium sized enterprises (SME) or multi-national companies (MNC). As can be seen in Fig. 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-external companies (small or large) and

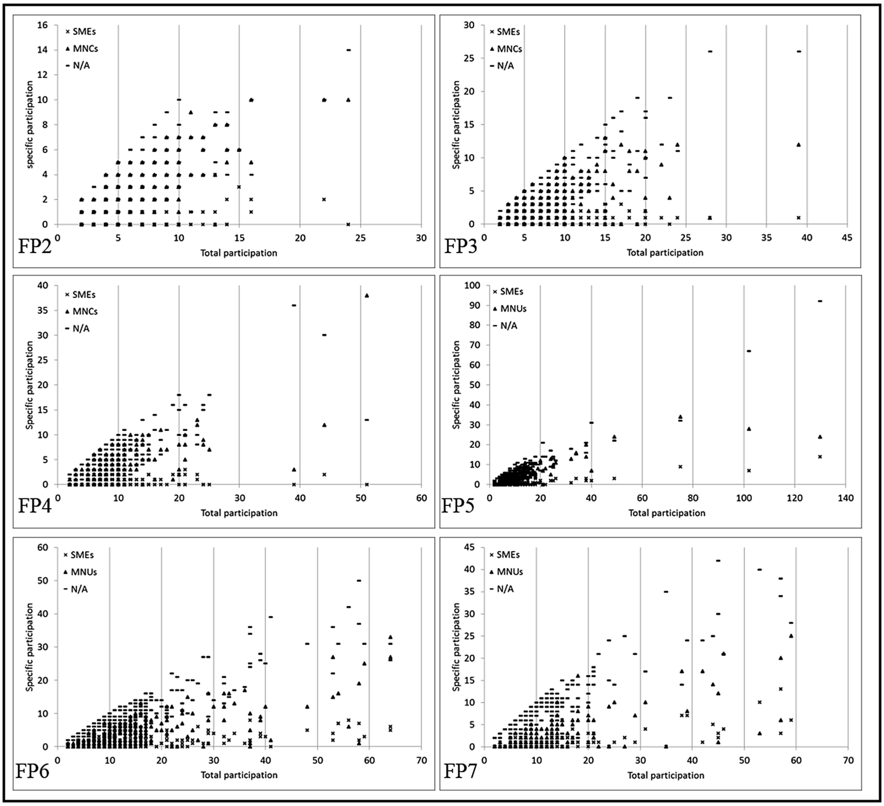

Fig. 10 Project composition with respect to the organization size

Table 6 One-time participants by organization type

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

aerospace SMEs specialized in niche topics. Nevertheless the examination of the one-time participants needs a more detailed consideration.

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. Remarkable is the large number of one-time participants, about 70 % of the whole.

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.

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

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 data. In Fig. 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.

As in the EU FPs, there are key knowledge fields. 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 pyramidal funding, this may be seen as a core

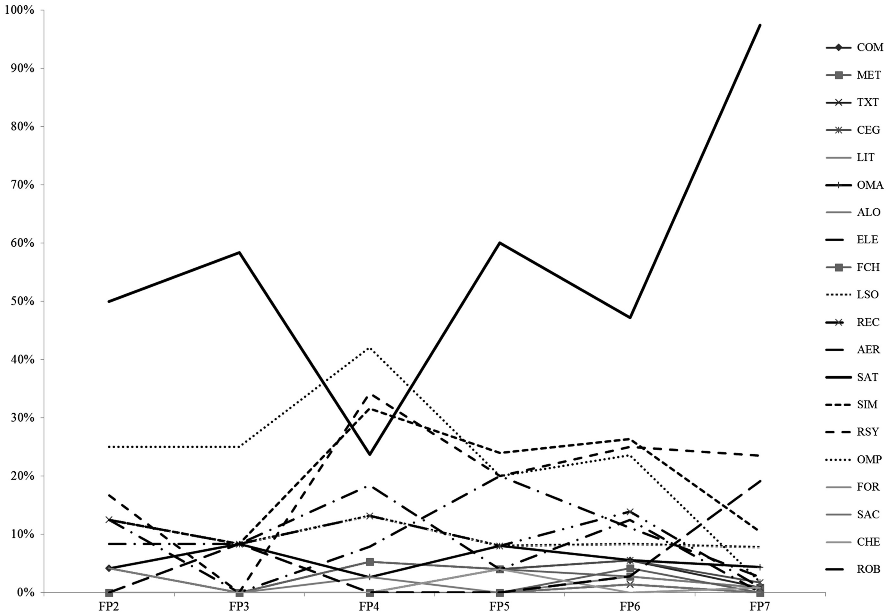

Fig. 11 Thematic development of the funded projects in the German FK

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, achieving a nearly stable number of partners per project that ranges between 2.6 and 4.1.

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 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 Fig. 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 number of participants in the respective region and the lines representing the connection between two regions. The thicker the line, 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). Beside these more or less dominant regions, several other and varying (with respect to the spatial distribution) regions participate, indicating the strongly fragmented German aerospace industry.

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 picture of how development is to be evaluated.[25] On the other hand, it suggests that it might be easier to apply for nationally funded projects than those funded at the European level.

[25] 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 of the internal R&D operations and non-funded projects with partners.

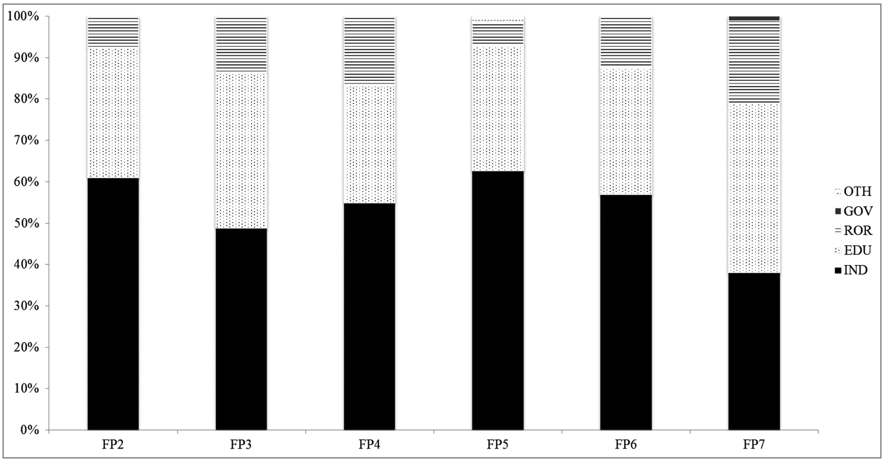

Fig. 12 Organizational composition of the German funded projects

In general, based on Fig. 14, 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 Fig. 15. There are numerous organizations of all sizes only participating in one project, indicating 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 % (ECORYS 2009, p.150). Compared to France with an average amount of 65 % SME with a purchasing volume of 25 % (ECORYS 2009, p. 150), the German aerospace industry has the highest SME fraction within Europe. The reasons can be seen in several factors: On the one hand, the national peculiarities outside the aerospace industry, like infrastructure, specific federalist funding systems, but also cultural and social factors. On the other hand, an aerospace-internal explanation might be that the consolidation in France is more sophisticated up to now.

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

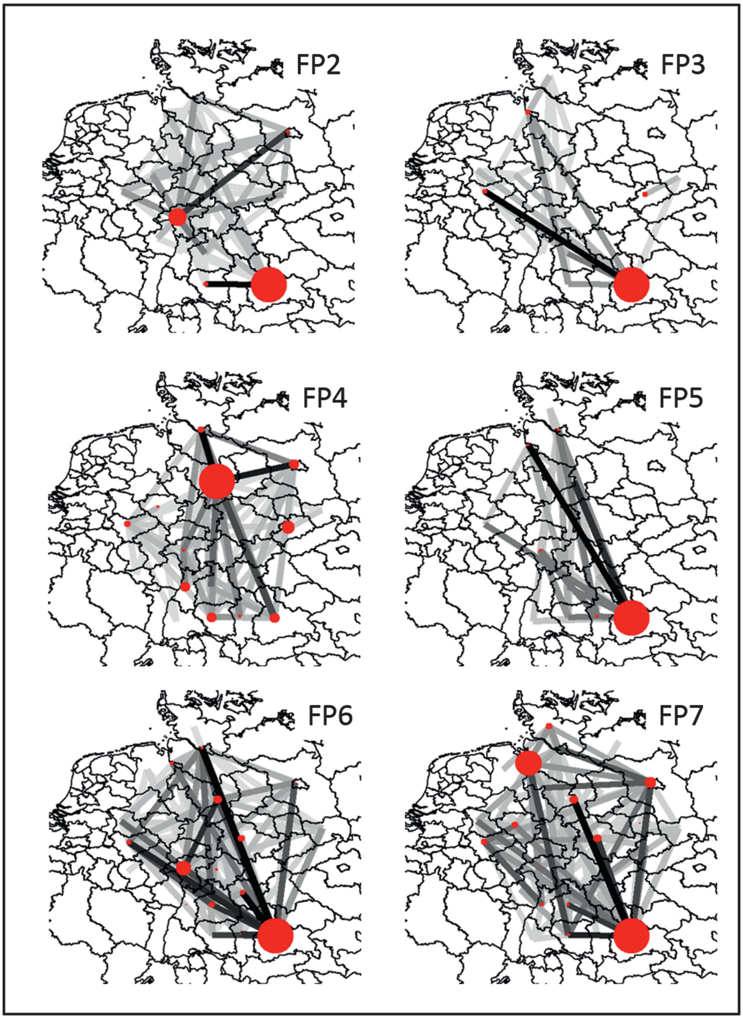

Fig. 13 The German aerospace R&D collaboration network

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.[26]

[26]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.

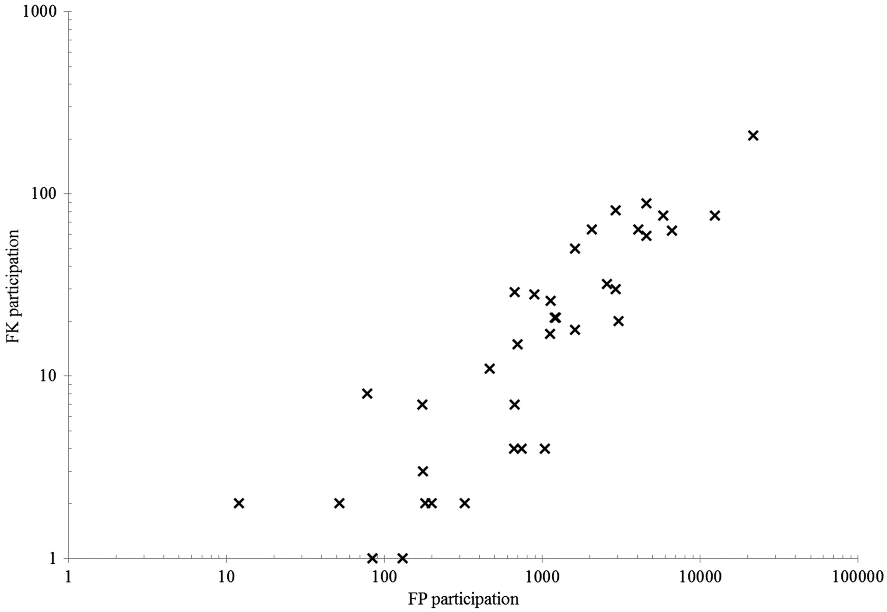

Fig. 14 Number of FP and FK participations in German regions. Not shown are the results for those regions which only take part in FP projects, without participating in FK-indexed projects; these are DE22 Niederbayern (208 projects), DE40 Brandenburg (82 projects), DE72 Gießen (146 projects), DEB1 Koblenz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

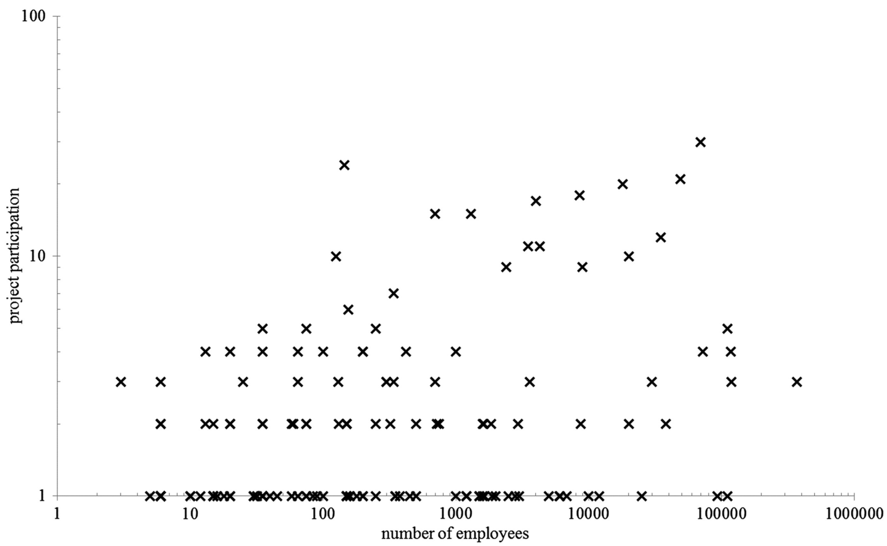

Fig. 15 Company size versus project participation

5 The Regional Level: Stuttgart Area

This chapter provides detailed insights into the aerospace activities of the region of Stuttgart (DE11) and the federal state of Baden-Württemberg (composed of DE11, DE12, DE13 and DE14). We analyze the region's structure and how the region is interconnected with other regions and industries.

In Baden-Württemberg about 14,000 people are employed in the aerospace industry and it has a trade volume of about 4.5 billion € (WRS 2011). The aerospace industry within this region is very fragmented concerning its knowledge base and the types of aerospace products supplied—many SMEs are active not solely in aerospace, but also in automotive, medical technology, electronics and software delivering functions. For the region of Stuttgart (DE11) it holds that research institutions—especially the University of Stuttgart and the semi-public research organizations of the German Aerospace Center (DLR) and the Fraunhofer-Gesellschaft—have an outstanding role and are responsible for most of the aerospace R&D activities within Baden-Württemberg. This is supported by the fact that 75 % of all German aerospace engineers graduate in Baden-Württemberg. This strong research orientation and a rather weak industrial and production orientation have been already noted on the European and national levels, when we saw that the Stuttgart region is of only minor importance with respect to the number of participations both in the European Framework Programmes and on the national side within the German *Förderkatalog*.

In this section we used another procedure to capture the aerospace industry compared to the preceding sections. We tried to grasp the Baden-Württemberg aerospace industry with the help of aerospace association membership. We used membership lists of the German aerospace associations of BDLI, LRBW, BavAiria and the Aerospace Source Book of Baden-Württemberg to get information about actors active in the Baden-Württemberg aerospace industry, including those organizations with at least one location in Baden-Württemberg and the respective project is executed in one of Baden-Württemberg's NUTS2 regions.

Based on the funding data of the German *Förderkatalog*, we elaborate a Baden-Württemberg specific R&D collaboration network. A prerequisite to be part of the network (shown in Fig. 16) is that at least one participant within a project has to be located in Baden-Württemberg. So the network only consists out of projects where a member of the Baden-Württemberg aerospace industry participates. The number of projects with participation of organizations located in Baden-Württemberg varies between 20 and 40 active projects per month, with a slight increase over time up to 30–40 projects; over the observed time span (1995–2010), there have been 132 funded projects. Project size typically varies between 2 and 10 participants; some bigger projects have up to 45 participants. The number of projects exclusively running within Baden-Württemberg is rather low—between zero and five at any time. Also the average percentage number of partners out of Baden-Württemberg is extremely low, varying between 2 and 20 %. The partners cooperating with Baden-Württemberg organizations (mostly science and research organizations) are regions and organizations seen in Sect. 4: Munich (TU, MTU

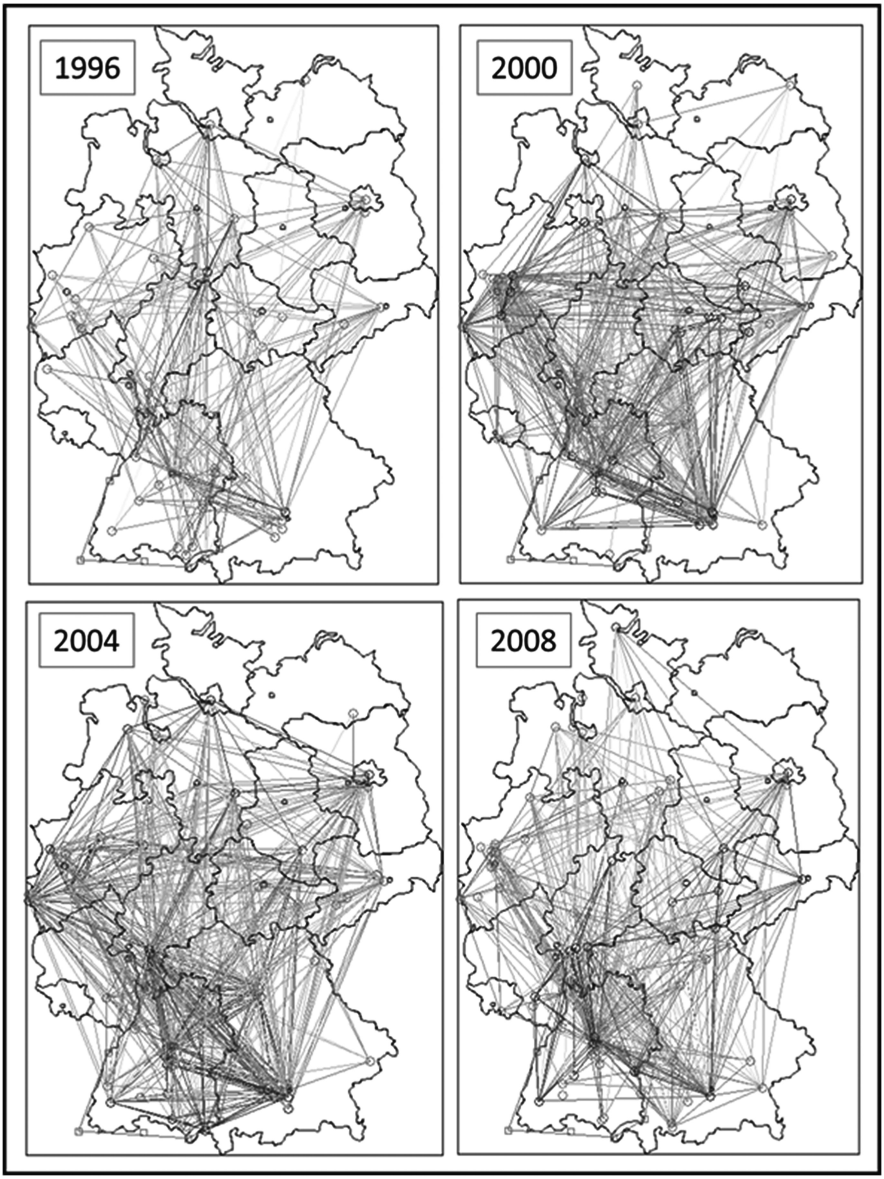

Fig. 16 The Baden-Württemberg partnering R&D collaboration network

Aero Engines, Eurocopter, Astrium, and Cassidian), Hamburg and Bremen (Airbus and OHB) and Aachen, Cologne and Berlin (RWTH, DLR and TU, and Rolls-Royce). Besides these core regions of the German aerospace industry, regional activity varies depending on the projects involved, e.g., there are some regions showing up in one time period and are not participating in another period. Again, as demonstrated in the preceding sections, the reason might be the high number of one-time participants. These one-time participants are mostly SMEs or industry-external organizations taking part in projects where aerospace organizations are active.

An astonishing finding, standing in contrast to the several theories of how a region develops (Ponds et al. 2010; Wolfe 2005; Gunasekara 2006), is that no aerospace industry is located in the region of Stuttgart, especially given the educational standing of the University of Stuttgart. We assume that other industries—especially the automotive industry—use the technology spillovers from the strong scientific landscape in Stuttgart. Of course some SMEs are located in the region, e.g. SMEs providing software or components for the space industry. Especially those SMEs will face problems in the near future, as the industry is undergoing a restructuring process, where suppliers must be able to quickly ramp up production and enlarge their production capacity while at the same time needing to be innovative to cope with the technological development process. Especially for the often family-owned niche-suppliers in Baden-Württemberg, this is a challenge. If the companies are not able to overcome this burden, they face the risk of being replaced by foreign manufacturers who are able to deliver components and parts with adequate speed, quality and costs. That Baden-Württemberg with its fragmented SME-supplier structure is facing a challenging time is supported by the fact that non-scientific organizations do only scarcely participate in the R&D network shown in Fig. 16. We expect this problematic structure to be observed in other regions of Germany and throughout Europe, in particular those regions where no anchor is located.

6 Conclusion

We used the sectoral innovation system approach to get an impression of 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. This also holds for the national level, in our case for the German *Förderkatalog*. Nevertheless there are differences with respect to the funded topics as well as the actors participating. Even if the same regions are of importance on the national level as on the European level, the funding structure with respect to the thematic content seems more complementary to the European content as the number of actors participating on the national and supra-national level is rather low.

The European aerospace R&D collaboration network is geographically highly concentrated in several core regions. These regions show no significant specialization on different topics. Outside the core regions more thematic specialization is apparent, as these peripheral regions do not comprise so many organizations compared to the core regions and therefore individual specialization of organizations carry more weight 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 fragmented SME structure covering specialized innovation and production topics within the European invention and production community. The great number of education facilities and research organizations can be traced to at least two factors. First, the participation is favored by the system itself, as educational and research organizations are favored to participate and it provides a way of gaining external funding. Second, the aerospace industry is a high-tech industry demanding a great amount of scientific knowledge. The detailed analysis of the region of Stuttgart depicts the problems that arose in the last years, especially for smaller companies and less important aerospace regions. Without the willingness to collaborate[27] on the innovation and production side, aerospace organizations in less-aerospace-intensive regions are expected to face hard times.

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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[27]Other possibilities are mergers or acquisitions, which have developed on the higher supply chain levels during the last years in an excessive manner (ECORYS 2009, p. 297; Vertesy and Szirmai 2010, p. 3; Nolan and Zhang 2003).

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