European medium-technology innovation networks: a multi-methodological multi-regional approach

Michael Steiner
Joanneum Research,
Institute of Technology and Regional Policy,
Elisabethstrasse 20, 8010 Graz, Austria
E-mail: michael.steiner@joanneum.at

Javier Alfonso Gil
Universita Autonoma de Madrid,
Dipartimento de Estructura Economica e Economia Desarollo,
Campus de Cantoblanco,
Ctra de Colmenar Viejo, 15, 28049 Madrid, Spain
E-mail: javier.alfonso@uam.es

Oliver Ehret
National Organisation Hydrogen and Fuel Cell Technology,
Kurfürstendamm 21, 10719 Berlin, Germany
E-mail: oliver.ehret@now-gmbh.de

Michael Ploder
Joanneum Research,
Institute of Technology and Regional Policy,
Elisabethstrasse 20, 8010 Graz, Austria
E-mail: michael.steiner@joanneum.at

Rüdiger Wink*
Hochschule für Technik,
Wirtschaft und Kultur – HTWK Leipzig,
PO Box 301166, 04251 Leipzig, Germany
E-mail: wink@wiwi.htwk-leipzig.de
*Corresponding author

Abstract: Most scientific studies on innovation deal with high-technology sectors, although medium-technology industries are still the most relevant contributors to employment and market shares in Europe. Based on three different methodological approaches (social network analysis, regression analysis and qualitative research), the importance of technology-specific, firm-specific and region-specific factors on the structure of innovation networks in medium-technology sectors is investigated. It can be shown within this explorative study that networks in the four investigated case regions
increasingly rely on knowledge instead of material linkages and firm characteristics determine the position of organisations within the networks. The actual structure of networks and the choice, which firm-specific factors are important for network positions, vary across the regions and cannot be explained by general regional characteristics. Thus, more concrete research on single regions is still necessary.

**Keywords:** social network theory; regional innovation systems; new economic geography; integrative technologies.


**Biographical notes:** Michael Steiner is a University Professor at the Department of Economics at the Karl Franzens University of Graz and the Head of the Institute of Technology and Regional Policy (INTEREG) at Joanneum Research, Graz. His main field of research cover theoretical, political and empirical contributions to regional economics, European integration, spatial development, interregional and international cooperation.

Javier Alfonso is a University Professor at the Department of Economics at the Universidad Autonoma de Madrid. His main research fields cover regional and industrial economics, economic development, technological change and evolutionary economics.

Oliver Ehret is an Expert on Hydrogen Infrastructure at the National Organisation Hydrogen and Fuel Cell Technology. Before that, he was a Research Fellow at the Centre for Advanced Studies at Cardiff University. His main fields of research cover social science research of technological evolution, technology and industry policies.

Michael Ploder is a Research Fellow at the Institute of Technology and Regional Policy (INTEREG) at Joanneum Research, Graz. He received his Diploma in Economics at Karl Franzens University of Graz. His main fields of research cover evaluation of regional and technological policy programs and investigations of structural changes of regions and technologies.

Rüdiger Wink is a Professor of Economics at Leipzig University for Applied Research (HTWK) and a Senior Research Fellow at Ruhr Research Institute for Regional and Innovation Policy (RUFIS), Ruhr University, Bochum. His main fields of research cover innovation, regional and environmental policies and institution economics.

1 **Introduction**

During the last few decades, notions of clusters and agglomerations have become central to scientific explanations of innovative capacities and regional growth (Acs, 2002; Cooke et al., 2006). In particular for small and medium-sized firms, interactions within network structures are regarded as a prerequisite for boosting innovation capabilities. The latter are enhanced by access to knowledge created by additional research and development
European medium-technology innovation networks

(R&D) and exchanged in international knowledge pipelines (Bathelt et al., 2004; Davenport, 2005). As a consequence, national and European policy programs supporting networking between firms, both within and between regions, have become more and more popular [for example the poles de compétitivité in France, competence centres in Austria or Finland and innovating regions on the EU level, see Wink (2009)]. Single regional and/or sectoral case studies were used to define models of success (Cooke et al., 2003). But the literature suggests that uncertainties regarding determinants of the structure, functioning and performance of networks remain (Iammarino and McCann, 2006; Bottazzi et al., 2002; Brenner, 2004; Steiner and Ploder, 2009). In spite of a growing consensus on the importance of network structures for knowledge interactions and innovation processes, models explaining differences between relevant structures in different sectors and regions are still missing. This paper contributes to the development of models by investigating the role those three different groups of innovation factors of recognised importance play in different regional settings. It assesses the relevance of technology-driven, firm-specific and regional factors and employs different methodologies to cover the specificities of the different factor groups for medium-technology sectors. A new and relatively comprehensive approach to conceptualising regional innovation will thus be developed and put to the test.

The focus on medium-technology sectors is motivated by the following observations:

1. medium-technology sectors are still the leading exporting sectors in all European countries (European Commission, 2005)
2. knowledge production processes in medium-technology sectors follow regularities and prerequisites that are different to high-technology sectors
3. the market environment for medium-technology sectors has changed drastically in recent years, due to the need to integrate knowledge from more science-driven sectors and to cope with increasing competitive pressures from outside of Europe (Benzler and Wink, 2005).

Thus, the medium-technology sectors experience processes of transition, which might decide the future of European industrial competitiveness and call for additional social science research.

The methodological approach to answer the questions raised in this paper is based on a combination of three elements. These are:

1. social network analysis focusing on the investigation of relations between individual firms, the determinants and structural characteristics of these relations, instead of analysing solely the activities of single organisations (Scott, 2000; Steiner and Ploder, 2009)
2. regression analysis to analyse possible connections between network relations and roles of single organisations and the characteristics of individual firms
3. qualitative interpretations of surveys and interviews with representatives of firms and other organisations in four regions with different characteristics.

The empirical analysis focuses on networks in the medium and low-tech sector (aerospace, automotive and mechanical engineering) in Hamburg, Styria, Wales and Madrid. The sectors have been chosen to cover the most important medium-technology
industries in different types of regions. Hamburg and Madrid represent typical metropolitan regions with a relatively high share of business-related services and infrastructures, Styria and Wales industrial regions experiencing structural adjustment processes. The study is concentrated on regional networks, while considering the increasing importance of trans- and interregional knowledge flows. In contrast to other papers on innovation networks, our work facilitates a multiregional comparison with a highly differentiated multi-methodological approach and helps identifying a wider set of factors determining structures of regional innovation networks.

The paper is structured as follows: After the present introduction, the regions of investigations are introduced. The structural specificities of regions are revealed and possible determinants of specific network structures are identified. Apart from regional factors, several technology-driven and firm-specific factors determining innovation network structures are theoretically discussed. Three working hypotheses are derived from the discussion, which will be examined in the empirical investigation. The different methodologies and the structure of the empirical analysis are outlined next. This includes clarifying the relationships between individual approaches and the relevance of each methodology for testing the hypotheses. In the fourth section, the results of the empirical analysis are presented and interpreted with recourse to the different methodological approaches. The conclusions stress the importance of multi-regional and multi-methodological approaches to covering the diversity of network structures and their driving forces and present an outlook on future research.

2 Factors explaining differences in innovation network structures

2.1 The regional dimension of innovation network structures

The regional dimension of networking has been stressed by different strands of literature. The models of the New Economic Geography, for example, focus on positive externalities within agglomerations in general (Krugman, 1991; Fujita and Thisse, 2002). Core propositions of the models have been confirmed and differentiated by many empirical studies of sectors and clusters on different technological levels (Dumais et al., 2002; Rosenthal and Strange, 2001; Acs, 2002). Apart from density within a region, the quality and diversity of the knowledge base, the availability of specific kinds of knowledge such as creativity or entrepreneurship, the institutional infrastructures, cultural or social norms and identity have been established as important factors for explaining differences in economic performance and knowledge externalities (Florida et al., 2007; Brenner and Mühlig, 2007; Antonelli, 2007). Not only networking, but also the mobility of human and real capital, the intensity of social contacts and the openness of the regional actors have been shown to influence the knowledge base. Regional networks play a particularly prominent role within approaches of regional innovation systems, where actors with different knowledge capabilities are systematically connected along the knowledge value chain, stretching from knowledge generation towards diffusion (Cooke et al., 2003; Harmaakorpi and Melkas, 2005). Again, regional specificities are used to explain differences in the emergence and design of regional innovation systems. Our multiregional comparison attempts to structure regions according to specific characteristics and should reveal key regional parameters of network structure to help explaining systematic similarities and differences between regional network structures.
We structured our regions of investigation according to four dimensions and examined their recent historical development. The dimensions are:

- level of agglomeration
- structure of economic sectors
- formal knowledge base
- institutional development.

The selection of the dimensions was motivated by the goal to cover the possible regional-specific influences on the structure of innovation networks. The level of agglomeration refers to the general explanation of the *New Economic Geography* that with increasing population density regions exploit scale economies due to spillover effects (Krugman, 1991). For innovation networks, there might be ambiguous effects, as on the one hand the pooling of firms and human capital can lead to accumulated and diversified knowledge, making cooperation within networks much more attractive. But on the other hand, the increased anonymity and the restricted availability of social linkages within metropolitan areas could cause more fears of default within networks and limit the intensity of knowledge interactions. The structure of economic sectors provides general information on the availability of possibly attractive network partners. We focus on the share of business services and high technology business services, to consider the role of knowledge-intensive partners using their experiences in different cooperation projects and diffusing knowledge (Müller and Zenker, 2001; Grabher, 2004). The third dimension refers to the availability of public and private R&D results in the region. Although much of the knowledge in medium-technology sectors is tacit, public and private R&D investments could support the emergence of cooperation along integrative technologies and could therefore intensify the relevance of technology-driven factors of network formation. This will be discussed in the next section. Finally, the institutional development and linkages provide information on general experiences with cooperation within the regions, the availability of common norms and the formal rules that the functioning of networks might require (Sørensen, 2003; Dupuy and Torre, 2006; Steiner and Hartmann, 2006).

**Table 1**  
Quantitative data on the regions of investigations

<table>
<thead>
<tr>
<th>Region</th>
<th>Population density, residents per sqkm, 2006</th>
<th>GDP in PPP per capita, EU-27 = 100, 2004</th>
<th>Share of business services on total employment, in %, 2004</th>
<th>EPO patents per million inhabitants, national average = 100, 2004</th>
<th>Private business R&amp;D expenditure in % of GDP, national average = 100, 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid</td>
<td>702.5</td>
<td>132.1</td>
<td>11.0</td>
<td>168.7</td>
<td>192.9</td>
</tr>
<tr>
<td>Hamburg</td>
<td>2,315.9</td>
<td>195.2</td>
<td>12.9</td>
<td>78.6</td>
<td>44.6</td>
</tr>
<tr>
<td>Styria</td>
<td>73.8</td>
<td>110.8</td>
<td>5.0</td>
<td>98.8</td>
<td>129.7</td>
</tr>
<tr>
<td>Wales</td>
<td>142.0</td>
<td>95.8</td>
<td>5.2</td>
<td>53.5</td>
<td>38.7</td>
</tr>
</tbody>
</table>

*Source:* Extracted from Eurostat database
These dimensions are analysed with quantitative and qualitative indicators. Table 1 provides some initial quantitative data on agglomeration density, economic structure and innovation performance, which will be explained in the brief portraits of the regions.

- Metropolitan region I: Madrid

Madrid was chosen for our investigation to integrate a metropolitan region in Southern Europe. The region of Madrid shows the highest population density in Spain and accounts for most of the Spanish R&D investments and patents registered with the European Patent Office. The share of business services and high-technology services is far higher than the national and the EU-27 average. Furthermore, the GDP per capita is higher than in the two industrial regions in transition in our analysis, Styria and Wales.

Within our empirical analysis, we focused on the aeronautical sector in Madrid. The aeronautical cluster of Madrid is characterised by the geographical concentration of a value chain dominated by two large original equipment manufacturers (OEMs) and EADS in particular. Historically, the cluster emerged from highly integrated production facilities run by a state-owned firm group engaging in civil as well as military aeronautics production. In the 1980s, the state-owned group was privatised and several parts of the firm were sold off, while increasing shares of orders were given to the spin-offs. Thus, next to the OEMs many diversified firms constitute the cluster today, specialising in different parts of the aeronautical production or acting as auxiliary members of the value chain with more conventional services [for further information see Alfonso-Gil and Vazquez-Baquero (2009)]. The interviews were undertaken with 15 industrial firms on different levels of the supply chain. These include the two global OEMs already mentioned and four larger firms that supply the OEMs, and also other industrial markets. Four medium-sized firms are specialising in manufacturing for the aeronautical industry, three firms primarily serve other markets, in particular the automotive industry and three firms focus on auxiliary activities. While the interviews with the industrial firms outlined above contribute to this paper, additional interviews with R&D and other service providers were not included into the quantitative comparison, due to compatibility concerns.

Due to the long history of civil and military aeronautics in Madrid, institutional linkages have been traditionally driven primarily by the original formal organisational linkages between firms belonging to the state-owned integrated OEMs and by personal and cognitive linkages established during common education at the faculties of engineering at the universities in Madrid. Only during the last two decades, additional international contacts and cooperation have evolved, in particular within the production structure of EADS/Airbus, but also with customers from other markets.

- Metropolitan region II: Hamburg

Hamburg is known as the region in the EU with the highest per capita GDP and shows within our sample by far the highest population density. Its economic strengths lie particularly with business-related service sectors, while the incumbent industrial sectors have declined in the last decade. Looking at the comparison of formal knowledge indicators, Hamburg performs relatively well in EPO patents, but compared to the national average, the private R&D expenditures and patents are remarkably lower than for Madrid and Styria. Consequently, despite the high share of business services, the share of high-technology business services in total employment is lower than in Madrid.
The aeronautical sector, strengthened by the strategic decision of Airbus in the 1990s to locate its second final assembly facility in Hamburg, is now the only industrial sector to grow with a high share of more conventional small and medium-sized enterprises (SMEs) from the mechanical sector and related segments, which went into the aeronautical sector due to the specialisation of Airbus in Hamburg on cabin interior. Due to the small size of the firms and the relatively weak formal knowledge base, interactions and cooperation have so far been relatively weak (Lubinski, 2003). In the last years, engineering service firms have gained importance for the cluster due to their consolidation towards larger units capable of assuming system functions. As the most important engineering schools and public R&D institutes for aeronautics are based at other locations in Germany, Hamburg has focused on new specialisations in building up the formal knowledge base, e.g., on cabin interior or composites. Institutional linkages, however, have been only recently intensified on a formal basis by a public-private partnership between the regional government, the OEM and big associations of firms to develop joint activities (Wink, 2007).

The interviews were conducted with 16 industrial firms, seven service firms and four R&D institutions. Most of the industrial firms are very small and conventional SMEs dependent on the regional supply chain. Only two regional OEMs – Airbus as the producer of big civil aircrafts and Lufthansa Technik as the international market leader in maintenance, repair and overhaul (MRO) – act as nodes having linkages with several of the other firms. The attempt to merge smaller firms towards a common system supplier holding – also one of the firms interviewed – failed due to the lack of compatible visions by the single firms and the management of the holding (Liyanage et al., 2007). Within the group of service firms, personal service and engineering firms were interviewed with the engineering firms showing a high share of academic employees. All interviews are integrated into the empirical study for this paper.

- **Industrial region in transition I: Styria**

Styria has experienced a far going structural change during the last decade, which has been accompanied and partially driven by the technological upgrading of traditional medium and low technology industries and new patterns of interaction between firms, but also between science and industry. Suffering from the problems of a typical *old industrial area* dominated by a large national industry and being exposed to a new economic situation due to the fall of the Iron Curtain on its border, Styria was confronted with considerable challenges. A massive structural change of the regional innovation system in Styria has been observable since the beginning of the 1990s, especially in street-related sectors such as the mechanical engineering sector, the machinery and the automobile sector. The successful catching-up process in Styria since the middle of the 1990s is reflected by the innovation-data in all sectors. High degrees of diversification and broad unspecified clienteles have been reduced to market niches and technological specialisation, and bigger lot sizes have opened up opportunities to exploit economies of scale by increasing capital intensity via automation, while still maintaining flexibility within a highly integrated production structure. Consequentially, Styria shows a high performance on patent as well as R&D expenditure indicators and has by far the highest share of industrial employment within our sample. The share of high-technology business services is also lower than in the other investigated regions. Institutional linkages have
been developed during the re-structuring process by initiating joint cluster activities and strengthening cooperation between regional firms and R&D intermediaries.

The interviewers observed a 32-actor-network comprising 18 industrial firms, five service firms and seven R&D institutions. The observed regional network can be assigned to the automotive sector, which has been one of the driving sectors throughout the re-structuring process and is a leading sector in the regional economy now. Eight observed firms are manufacturers of motor vehicles or vehicle parts, three firms are manufacturers of rubber and plastic products that mainly, although not exclusively, supply the automotive industry, five of the observed firms produce or treat fabricated metal products mainly, although not exclusively, for the automotive industry. The latter are medium and small sized low-technology firms. Half of the observed firms are not independent but part of different, mostly international, firm groups. The majority of the firms have been situated in the region for more than ten years. These firms may benefit from the capacity of international firm groups to internalise mechanisms of international integration. The range of observed firms is dominated by medium-sized and large firms. The R&D capacities of the observed firms varied widely. Nearly half of the firms have no permanent position for an R&D professional.

- Industrial region in transition II: Wales

Wales also went through structural changes from old industrial region towards modern industries like the aeronautics sector, in particular by attracting some very large foreign direct investments. Within our sample, however, Wales still shows the weakest performance in economic development and innovation indicators. In particular, less formal public and private R&D facilities are available in Wales than in the other investigated regions. The share of services and high technology business services in total employment is higher than in Styria, but far lower than the national average.

The Welsh aeronautics industry has emerged over the last few decades and assumes primary importance to the regional economy today. The industry comprises of over 150 companies that employ at least 20,000 staff (www.aerospacewalesforum.com). The aeronautics sector displays a north-south divide, with largely separate agglomerations at the corners of the country and little in between (Hayward, 2005). North Wales (NW) is dominated by a wing supply chain to Airbus at Broughton, one of the main Airbus UK sites. Though substantial manufacturing also takes place in South Wales (SW), the core strengths are in MRO and research, development and training (Flight International, 2006). Company size ranges from Airbus Broughton employing some 7,000 staff, via players such as GE Aircraft Engine Services (GEAES) with 950 people, to small enterprises such as Cottam and Brookes Engineering with 25 employees. Few firms are older than 30 years and many much younger. Ownership status varies, with most companies belonging to groups of firms, but some remaining in private possession. For the vast majority of companies, aeronautics is the only or core business. Remarkable is the generally low percentage of staff trained to university level and the low overall R&D intensity of the industry; characteristics mirrored by the relatively low-tech and traditional 'metal-bashing' expertise most companies still rely upon. There are also public sector R&D and training institutions, mostly based in SW, which raise the knowledge and skills base. Finally, there exist public bodies supporting the development of the industry and attempting to enhance cooperation. The set of organisations interviewed and analysed below consists of 15 industrial firms, five service firms and eight R&D institutions.

Table 2 summarises the main differences between the regional clusters investigated.
Table 2  Characteristics of investigated regions

<table>
<thead>
<tr>
<th>Socio-economic structure</th>
<th>Regional economic structure</th>
<th>Formal innovation indicators</th>
<th>Institutional development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid</td>
<td>High population density</td>
<td>High share of high technology business services</td>
<td>Higher than national average</td>
</tr>
<tr>
<td>Hamburg</td>
<td>Highest population density</td>
<td>High share of business services</td>
<td>Lower than national average</td>
</tr>
<tr>
<td>Styria</td>
<td>Lowest population density</td>
<td>High share of medium-technology manufacturing</td>
<td>For most of the indicators higher than national average</td>
</tr>
<tr>
<td>Wales</td>
<td>Low population density</td>
<td>Low shares in services</td>
<td>Lower than national average</td>
</tr>
</tbody>
</table>

The hypothesis we tested within our empirical study was based on the expectation of similarities between regions of the same type, namely between Madrid and Hamburg as the metropolitan regions and between Styria and Wales as industrial regions. Remaining differences were expected to be explicable with additional specificities within the other dimensions, e.g., the institutional development or the availability of formal knowledge.

H1 Regions with similar population densities and sectorial focus show similar network structures. Remaining differences can be explained by differences in institutional preconditions and the availability of formal knowledge.

The confirmation of this hypothesis would provide important insights for regional policy-making. If most of the potential for knowledge networks is determined by structural characteristics beyond political influence – such as the status as a metropolitan region, industrial history or geography – any initiative for regional network policies will necessarily remain of limited impact. On the other side, if differences between regions with similar structural characteristics can be explained by identifying specificities, which are receptive to adjustment by deliberate policies, custom-tailored recommendations for regional policy-making can be devised. These recommendations can be expected to be more effective and useful for policy-makers than the generic and broad recommendations many academic studies produce.

2.2 Technology-driven determinants of innovation networks in medium-technology sectors

Besides regional driving forces for network formation, many academic studies refer to the influence of technological development on the structure of innovation networks. The traditional model of networks within medium-technology industries was characterised by
a high share of material interactions within a supply chain dominated by a highly integrated OEM (Alfonso-Gil and Vazquez-Baquero, 2009). The role of the SMEs within these networks was limited to specific niches or standardised components and the relationships within the networks were based on long-term contracts with a high degree of personal and social proximities, often connected with geographical proximity [see Boschma (2005) and Torre and Rallet (2005), on concepts of proximities]. Famous examples for these types of networks include the Italian industrial districts or the German automotive clusters in Baden-Württemberg (Paniccia, 2002; Cooke et al., 2003; Carabelli et al., 2006). The framing conditions for these networks, however, have changed drastically since the 1980s.

First, the increasing level of international competition, extending to new competitive areas in Middle and Eastern Europe, Asia and South America, have caused pressures on existing organisational models within incumbent industries (Liyanage et al., 2007). As a consequence, supply chains have been restructured and even within so far protected markets, where policies tried to soften pressures to obtain cost efficiency, as in the case of the aeronautics and defence industry, dominant OEMs have reduced their level of integration (Alfonso-Gil et al., 2007). Secondly, the increasing pressure by competition has forced the firms to accelerate their speed of innovation, making knowledge the key competitive factor within future markets (Poon et al., 2006). This knowledge, however, is no longer restricted to specific disciplines or industries, but requires a high level of integration between more theoretical and science-driven knowledge on one side and direct technological application within industrial production on the other side. The development of new ‘smart’ materials such as composites, including sensors for adjustment to external disturbances in aeronautics as well as automotive industry, is a typical example for this trend. This is typical for integrative technologies because this development requires science-driven knowledge on the materials and the development of sensors and analytical as well as problem-oriented knowledge from engineering on the concrete integration into the aeroplanes or cars. Additionally, the general trend towards customisation with increasing relevance of customer-specific services and product elements requires the integration of another knowledge dimension, with the symbolic knowledge stressing more the individual expression by the customer than the actual content of the product.

As a consequence of these overall trends, the function and dimensions of networks tend to change. The attractiveness of networks is no longer defined by the need for material linkages, but by the need to receive access to complementary knowledge. New types of linkages have been developed, mainly based on knowledge that had to be shared, as only the interaction enabled firms to create, diffuse and absorb the necessary integrative knowledge (Novotny et al., 2001, on the new mode 2 of knowledge). This has also changed the relationships between the firms and the type of organisations involved. Within incumbent networks based on traditional supply chains, the OEM used to dominate the whole process of knowledge processing. New ideas were developed by internal R&D and necessary adjustments by the suppliers were initiated by hierarchical orders. Within the new type of knowledge networks, the main objective of networking is improving the knowledge base. Consequently, all members are dealing with the creation of new knowledge and the processing of experiential knowledge. Accordingly, the relationship between OEM and other knowledgeable members is characterised by cooperation within a club of members with the same interest to secure exclusiveness of knowledge. Instead of completely dependent conventional SMEs without any formal
R&D and knowledge base, specialised knowledge-intensive firms and system suppliers with complex combinative capabilities are integrated within the networks. Within aeronautics supply chains, recent delays of important new projects by Boeing (Dreamliner 787) and Airbus (A380) caused by missing or non-compatible parts produced by suppliers reveal the increasing dependence on suppliers of the OEM (Jalabert et al., 2008). These broad trends, however, should not neglect the still important roles of traditional and hierarchical material supply chains, as in the case of Airbus production in Wales (Ehret and Cooke, 2009). As a result, transaction costs are increased for OEMs and suppliers to achieve the expected cost savings and benefits of innovations. Specialised knowledge-intensive firms are often created as spin-offs from public research institutes or big multinational firms and are still closely connected to scientific research [Andersson (2003) and Piscitello and Rabbiosi (2006) on the resulting challenges for multinational firms]. The relationships within such a network are characterised by mutual dependence, since the OEM crucially depends on specific knowledge from the other network members, while the other members need the OEM as a channel towards international markets.

Within our empirical study, we investigated whether the change from material towards knowledge networks is a general trend materialising across different medium-technology sectors or only restricted to single events. Within the sample, we had three regions with a focus on aeronautics but with different specialisations. In Wales, many of the firms involved are engaged in more conventional – mechanical – metal wing production and MRO. Similarly, the firms in Hamburg focus on more conventional mechanical production based on the machinery sector for the cabin interior segment. In Madrid, many firms are also serving the defence next to the civil aeronautics sector with a larger share of electronic technologies. In Styria, the main technology focus concerns the automotive industry based on materials and machinery, requiring conventional technologies as well as advanced formal R&D. Against the background of these technological and sectorial differences, we formulated our second hypothesis as follows:

H2 In medium technology sectors, networks are more and more based on (pre-competitive) knowledge than on material linkages regardless of specific industries or technologies.

If this hypothesis can be confirmed, the consequences for SMEs are obvious. The more conventional SMEs will face severe problems in achieving access to networks and come under increasing competitive pressure by cheaper producers in low-cost countries. The medium technology industries will increasingly rely on two-tier approaches of production, which in many cases have already been adopted today. More standardised production would be shifted from Western Europe and other advanced industrial countries to low-cost regions, leaving only more advanced production based on cutting-edge tacit knowledge to be carried out in a few knowledge centres around the world. From this point of view, the recent discussion on the relocation of parts of the European aircraft production towards Asia, as well as Middle and Eastern Europe, only represents the most recent step in an ongoing process of losing conventional medium-technology production in Europe to low-cost regions.
2.3 Firm-specific determinants of innovation network formation

Technological changes and regional specificities, the first two groups of determinants considered by our analysis, represent dynamics that may affect knowledge flows between individual organisations both in the presence or absence of networking intentions of the parties involved. Knowledge spillovers may be caused by the mobility of factors or exploitation of formalised knowledge elements – thus, they may be ‘just in the air’ (Breschi and Lissoni, 2001). The propositions of the third group of determinants, however, firm-specific factors, assume that networking is taken up as a consequence of deliberate decisions made by individual organisations [Giuliani (2005) and Steiner and Plocher (2009) on these approaches]. The willingness of actors to initiate or join networks depends on the expected benefits – namely access to new and valuable knowledge – and the expected costs, especially the ones arising from the exploitation of secret and protected exclusive knowledge and the direct costs of networking activities (Miotti and Sachwald, 2003; Antonelli, 2007). Accordingly, the existing knowledge capabilities, including access to knowledge networks in other regions, determine the attractiveness of individual members and their standing in the networks. This entails the following two challenges for medium-technology SMEs:

1. achieving a level of attractiveness in terms of knowledge sufficiently advanced to be invited into networks and to be able to exploit future opportunities to apply this knowledge in additional markets

2. devising measures to prevent exploitation by bigger network partners with more international relationships and market access.

Starting with the first challenge, the impact of the aforementioned technological changes on the SMEs within the medium-technology sectors and their networking opportunities should vary according to their knowledge capabilities and experiences. The more conventional firms are still dependent on personal and social proximities, closely connected with geographical proximities. They need precise information by the OEM transmitted down a hierarchical supply chain and are only rarely capable of meeting formalised standards on knowledge management and R&D requirements. Consequently, SMEs will be the most vulnerable part in the new industrial environment and may easily be substituted by low-cost suppliers in other countries. For them, overcoming the barriers towards joining knowledge networks would be a crucial success factor for market survival. In many regions, intermediaries were created to help SMEs. In practice, however, such initiatives are often limited in their effects due to a lack of cognitive proximity between the conventional SMEs, the intermediaries and the members of the knowledge networks. In most cases, intermediaries had to decide, whether to focus on cognitive linkages – running the risk of losing the conventional SMEs without necessary cognitive premises – or to focus on social linkages with the risk of losing access to more advanced and multinational firms. On the other hand, experience shows that the more advanced system suppliers and service firms became crucial within the networks. This is because they gained an exclusive understanding of the complexity of the synthetic knowledge needed to connect specific knowledge from different suppliers towards complete sub-systems within the value chain. Thus, within the knowledge creation and diffusion process, advanced SMEs became equal (or even superior) partners of the OEM, integrated in joint R&D projects and able to sell their capabilities to OEMs from different
sectors. Instead of geographical, social and personal proximities, these firms obtained cognitive and organisational proximities with the OEM. This was facilitated by high shares of academic employees with close connections to science and R&D departments of big firms and enabled the SME to cope with formalised standards for technological cooperation fixed by the OEM. For example, Airbus invited its most important suppliers to join the knowledge creation process within a ‘concurrent engineering’ system, which requires compliance with specific technological standards. Similar approaches can be observed in the automotive industry. In the context of the financial and organisational dimension, this means that the firms have to develop capabilities to take over greater financial risks from the OEM and to manage complex processes of internationalising production to restrict their costs. Reflecting such disparities between SMEs, the third hypothesis refers to the relevance of firm-specific capabilities to the positioning of firms in knowledge networks.

H3 Firms with a higher export and R&D intensity, as well as integration within a firm group, are more central within regional networks.

Even for the more advanced and attractive SMEs in medium-technology sectors, however, risks are given. The protection of the firm-specific knowledge base in networks is a steady challenge. Many multinational firms concentrate their activities on issues where they see no alternative to networking as a means to gain access to attractive commercial knowledge controlled by SMEs. Networks are seen as an attractive way to secure exclusive access for members and bloc access for direct competitors. The superior market power of the multinationals causes fears by the SMEs that they might lose their exclusive knowledge without adequate compensation and mutuality (Steiner and Ploder, 2009).

In the next section, the methodological approach will be explained, before the empirical results arising from exploring the three hypotheses will be presented.

3 The multi-methodological approach

Within our hypotheses, we referred to different groups of determinants for network formation. Consequentially, we used the following methodological approaches to identify the relevance and influences of the groups:

- social network analysis to identify the relevance of knowledge, instead of material linkages, for revealing the importance of technology-driven determinants
- regression analysis to identify the connection between firm-specific characteristics and their integration and positioning within the innovation networks
- in-depth qualitative interpretation of single case studies of firms and organisations within the investigated regions, to identify the specificities of the regions and their influence on network formation, which have previously mostly been treated as residuals within other analyses of innovation network structures.

Social network analysis is a method well-established in the social sciences. Recently, the method has been applied to the analysis of production clusters (Krätke, 2002), innovative activity and knowledge exchange (Giuliani, 2005; Steiner and Ploder, 2009), alliance
networks (Gay and Dousset, 2005) and R&D networks (Cantner and Graf, 2006). It proves to be a helpful tool for discussing the structure of networks and facilitates the mapping and measuring of the relationships (communication and transaction) between different actors. By using the method, the underlying relations between different actors can be exposed and phenomena that cannot be reduced to the properties of individual actors or firms can be revealed. Such relations have to be interpreted as properties of systems rather than of individual actors.

To define the empirical basis for the network analysis, in all four regions the snowballing method of sampling in cluster and network investigation has been used. This corresponds with the relational approach and involves following up the references to other actors previously interviewed stakeholders made (Frank, 1979; Scott, 2000). An assumption of the approach is that the segment of the network that forms the sample is representative for the whole network. Therefore it has been necessary to acquire deeper knowledge about the parent population and basic relations. Interviews with representative actors in the regions were thus conducted to gain the necessary knowledge on the parent population. Additionally, qualitative interviews are used for deeper understandings of the precise conditions for the single cases and the activities of individual network members to avoid possible misinterpretations of data at the aggregate level. The starting points of the investigations of the regional networks in Styria, Wales, Hamburg and Madrid have been large system suppliers in the aerospace and automotive sectors, respectively. The snowball method led to the identification of firms belonging to different sub-sectors and cultivating related supply-chain and innovation-strategies. The interview teams followed the citation path and identified step by step the network-structures in terms of the immediate regional suppliers (production or commercialisation of goods and services) and of regional partners in the field of R&D (cooperative R&D and related activities and exchange). The network analysis has been based on the interactions revealed between the interviewed firms and their regional partners. Interactions have been analysed in terms of the delivery of goods and services (DELIV) and in terms of knowledge-based exchange (R&D), such as cooperative R&D or contract research. The results of the relationships explored can be graphically illustrated. The illustrations will help the discussion of the regional networks in Hamburg, Styria, Wales and Madrid and facilitate a comparative view on the dimensions of interaction in the regional networks. While the analysis has focused on regional relations, it is important to be aware that interregional and international relations also exist. Though the latter might have proved influential if investigated, they could not be systematically covered by this study.

Apart from the graphical presentation of results derived from social network analysis mentioned above, two additional sets of analysis were used to identify the specific role of individual network members and the characteristics of these actors determining their relevance within the network. First, the density of the observed regional networks, which is the ratio between the relations actually realised and the total number of maximum possible relations and the centrality of actors in their regional networks, have been measured. Second, regression analysis has been used to identify correlations between the structural features of the actors on the one hand and their position in the dimensions of
networking (DELIV, R&D) on the other. For this reason, the firms have also been asked to provide the following additional structural indicators, which help to characterise firms:

- sector: medium or high technology sector (SECT MID HIGH), technical business service (SECT SERV), R&D institution (SECT R&D)
- part of a firm-group (firm group)
- size of the firm as function of the logarithmic number of employees (LOG employees)
- low export orientation (under 0.25 exportintens)
- high export orientation (EXP 4 over 0.75 export)
- non-regional sales over 25% (over 0.25 nonreg sales)
- high qualification level (over 0.25 tertiary degrees)
- no R&D capacities (no R&D resources)
- high R&D intensity (over 25 R&D intensity).

These characteristics represent a helpful base for interpreting different patterns of interaction, but also the role of single actors in their respective networks, when considering the existing studies on the role of firm-specific factors and their influence on networking.

The analytical tools presented above are to reveal the relevance of firm-specific and technology-driven determinants of network formation. The third step is a regional comparison of the results. Our first hypothesis has been based on the expectation that similar regional structures (metropolitan areas with high shares of business services and industrial areas with low shares of business services, respectively) should lead to similar network structures and that remaining differences need to be explained with regional specificities. The regional specificities have been identified by in-depth case studies of the firms and organisations involved into the empirical analysis. Thus, the interviews have not only been used to identify relations with other actors in the region and firm-specific characteristics, but also to gain a deeper understanding of the interplay between the regional environment and single organisations. The qualitative interpretations serve to cover the multitude of regional influences on network formation. In the next section, the empirical results are presented and interpreted.

4 Results of the empirical study

4.1 Network density

By graphically illustrating the network structure and calculating the density of the networks, the relative importance of material and knowledge interactions shall be
revealed for the different regions investigated. This will help identifying the influence of technology-driven factors on network formation.

Following the socio-centric approach, network density is indicated by the ratio of relations actually realised to the total number of maximum possible relations. Therefore, we have dichotomised the relations in all regional networks. That is, we have only differentiated between existence and non-existence of a relation between two actors [0; 1] and therefore temporarily disregarded the intensity of the relations (in our case the frequency of interaction) to avoid problems relating to measurement of the density of weighted graphs [Scott, (2000), pp.73ff] In the case of the network with \( n \) actors (i.e., \( n \) is 32 in the case of network observed in Styria, \( n \) is 30 in the case network observed in Hamburg), the maximum possible number of relations, where each actor is related directly with all other players, is \( n(n-1) \). If also the direction of relations is accounted – to consider, whether both sides of a potential relation use the same weight to describe the actual relation – and asymmetric relations exist, the number of maximum possible relations is \( r_{\text{max}} = \frac{n(n \times (n - 1))}{2} \), where \( n \) is the total number of actors (possible nodes in the network). If there are asymmetric relations, i.e., for some relations \( r_{ij} \) no reciprocal relation \( r_{ji} \) exists, the formula for network density is

\[
\frac{\sum r_{ij}}{n(n-1)}
\]

where \( \sum r_{ij} \) is the number of relations present and \( n \) is the total number of observed actors. It seems appropriate to assume that each actor has limited relational capacity. The density of a network of relations usually decreases with the number of actors; therefore it is not possible to compare density measures across networks of different sizes (Scott, 2000; Friedkin, 1981). The density figure yields information on the general structure of the network as a whole.

Table 3 shows the results for the network density for the different regions. In three of the four regions of investigations, the network intensity for pre-competitive R&D cooperation has been higher than for material linkages. Only in Hamburg, material linkages have been slightly more relevant, which might be explained by the relatively low level of R&D intensity of the firms in this cluster. This result confirms to a large part our second hypothesis: regardless of region and sector, medium-technology sectors depend increasingly on knowledge networks.

### Table 3  Network density for material and knowledge networks in the investigated regions

<table>
<thead>
<tr>
<th></th>
<th>Material linkages</th>
<th>Knowledge linkages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid</td>
<td>0.13</td>
<td>0.228</td>
</tr>
<tr>
<td>Hamburg</td>
<td>0.077</td>
<td>0.051</td>
</tr>
<tr>
<td>Styria</td>
<td>0.04</td>
<td>0.107</td>
</tr>
<tr>
<td>Wales</td>
<td>0.042</td>
<td>0.161</td>
</tr>
</tbody>
</table>

These results are also illustrated by the graphical description of the regional innovation networks.
Figure 1  (a) Knowledge interactions and (b) material linkages in Wales network
Figure 2 (a) Knowledge interactions and (b) material linkages in Styria network
Figure 3  (a) Knowledge interactions and (b) material linkages in Hamburg network
Figure 4  (a) Knowledge interactions and (b) material linkages in Madrid network.
As mentioned above, there is no possibility to directly compare the network density between the regions, as the total numbers of interviewed organisations differ between the regions and the density should decrease with the number of observed actors. Remarkably, however, the network density in Styria (total number: 32, total density: 0.137) was even higher than in Hamburg (total number: 27, total density: 0.115), with R&D linkages strongly contributing to this result. This underlines the dominant role of R&D in medium-technology networking. Therefore, the findings in the scientific literature on the importance of technology-driven factors for the network structure – formulated in Hypothesis 2 – can be confirmed in general. The case of Hamburg, however, shows the exception to this rule and the resulting need to extend analysis to regional specificities.

4.2 Network centrality and regression analysis

One of the core-features of an actor, which can be identified in network analysis, is his respective centrality. Using the concept of centrality we gain insights into the specific features of the interaction of the actors, as well as their specific position and/or embeddedness, in the network. This helps us to identify the firm-specific determinants of network formation, i.e., to find out which firm characteristics explain the role of firms within a network. While the density focuses on the properties and general structure of the network as a whole, centrality tries to capture the position of individual actors or groups of actors within the network. This is again based on the relations that have been revealed by the actors, but here the relations are weighted ordinally in terms of the frequency of interaction. The potential centrality of an actor is determined by a broad range of industry and sector specific factors, as well as by capacity and by individual motivation (Bayona et al., 2001). A high centrality is positively associated with the number of possibilities of receiving information and generating knowledge. Diverse measures of centrality can be differentiated and used complementary. It is possible to distinguish between the synonymous terms of ‘point centrality’, ‘local centrality’ or ‘degree centrality’ on the one hand and ‘graph centrality’, ‘global centrality’ or ‘closeness centrality’ on the other hand (Nieminen, 1974; Freeman, 1979; Scott, 2000). The terms ‘degree centrality’ on the one hand and ‘closeness centrality’ on the other, have been accepted widely in the literature and incorporated into software-tools for network analysis.

The concept of degree centrality is based on the idea that actors with high centrality in a network maintain a lot of direct relations with other actors. The degree centrality $C_i(n_i)$ measures the number of direct relations going out from actor $i$ (out-degree) between two actors $i$ and $j$. In directed networks, a relation can be stated more precisely by the dimensions of ‘reception’ and ‘emission’. In-degree centrality therefore captures the centrality of an actor from the perspective of ‘reception’, while out-degree centrality measures the centrality of an actor from the perspective of ‘emission’. The out-degree centrality of actor $i$ in directed asymmetric networks is measured in the following way:

$$C_i^o(n_i) = \frac{\text{od}_i}{n - 1}$$

Degree-based centrality can be extended beyond direct connections to include those at various path distances. The ‘global centrality’ or ‘closeness centrality’, defined as the sum of all geodesic distances (in graph theory the shortest distance between two points is
called the geodesic), thus takes into account direct as well as indirect relations to all other actors. Closeness centrality is measured by the inverse of the sum of distances from an actor to all the other actors. The closeness centrality $C_c(n_i)$ can only be calculated in complete networks where each actor is in relation with at least one other actor (otherwise the distance would be infinite). Isolated actors are thus excluded from the calculation. The formula for the standardised closeness centrality $C'_c(n_i)$ is

$$C'_c(n_i) = \frac{N - 1}{\sum_{j=1}^{N} d(n_i, n_j)}$$

for $i \neq j$.

Analogous to the degree centrality for a directed network (as in our case), in-closeness centrality and out-closeness centrality is measured separately, depending on whether the distances ‘from’ or ‘to’ other nodes are considered.

Beyond the measurement of the centrality of actors by means of direct or indirect relations to other actors, another interpretation of centrality is of interest: the ‘betweenness centrality’ that measures the significance of the intermediary role of actors resulting from their position in the network. Betweenness centrality is based on the probability that an actor obtains the role of a critical gatekeeper (possibly a bottleneck) in the course of indirect exchange between two arbitrary actors in the network. Gatekeepers play a critical role because they are in a position to control exchange (of goods, information, etc.) between different agents. The number of shortest mediate paths (geodesics) is thus set against the number of geodesics crossing the observed actor.

The betweenness centrality $C_B(n_i)$, is defined as

$$C_B(n_i) = \sum_{j<k}^{n} \frac{n - 1}{6} b_{jk}(n_i)$$

for $i \neq j \neq k$.

where

$$b_{jk}(n_i) = g_{jk}(n_i) - \frac{1}{g_{jk}}$$

The maximum centrality is dependent on the size of the network. The standardised betweenness centrality is defined by the formula

$$C'_B(n_i) = \frac{2C_B(n_i)}{n^2 - 3n + 2}$$

These measures of centrality indicators were used as a basis for the regression analysis to find clues for explaining the relevance of single actors within the networks. Among the diverse measures of centrality used, multivariate linear regression analysis has been employed to identify correlations between structural features of the actors and their position in the dimensions of networking. Multivariate linear regression analysis has tested the ability of the observed characteristics to explain the network-position of the actors, supplementary to the results of the qualitative interviews for all dimensions of interaction discussed.
The assumption of the independence of statistical observations, which is a prerequisite for standard OLS-estimations, cannot be held in the case of social network analysis (Scott, 2000). The alternatively employed regression algorithm performs in a first step a standard multiple regression across corresponding cells of the dependent vector (the degree centralities) and independent vectors (selected characteristics of the actors in the network). In a second step the regression is recomputed by random permutations (50,000) storing resultant values of r-square and all coefficients. Based on this procedure, estimates of standard error and ‘significance’ are computed. The regression analysis has been conducted for each degree-centrality (dependent variable) on the basis of the following explanatory variables: in-degree deliv. (relevance as recipient/demander in the dimension of material delivery), out-degree deliv. (relevance as supplier in the dimension of delivery), in-degree R&D (relevance as recipient/demander in the dimension of R&D) and out-degree R&D (relevance as supplier in the dimension of R&D). The analysis has been conducted in two sequential steps: first, with a single step variable selection approach and second, with a stepwise variable selection approach. (Criteria: probability-of-F-to-enter <= 0.050, probability-of-F-to-remove >= 0.100).

It would be beyond the scope of this paper to present all results of the regression analysis. The hypothesis on firm-specific determinants on network formation has been based on the expectation that the export intensity, R&D intensity and integration within a firm group could explain centrality within the networks. This general expectation, however, could not be confirmed. The qualitative analysis has already shown that in all regions OEMs and/or system suppliers play a major role within the networks. This result has not only been caused by our snowball approach, starting with these kinds of firms and their most important contacts within the regions, but also been confirmed by the interviews with representatives of the network member organisations in the regions. The importance of individual firm-specific characteristics explaining the positioning within the networks, however, differs between the regions. Tables 4–7 provide results for the different investigated regions.

**Table 4 Regression results for Madrid**

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>P (&gt; observed)</th>
<th>P (&lt; observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.011</td>
<td>0.13</td>
<td>0.03</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Under 0.25</td>
<td>0.164</td>
<td>0.062</td>
<td>0.004</td>
<td>0.996</td>
<td></td>
</tr>
<tr>
<td>export</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm group</td>
<td>0.157</td>
<td>0.07</td>
<td>0.016</td>
<td>0.984</td>
<td></td>
</tr>
<tr>
<td>Over 0.25</td>
<td>0.282</td>
<td>0.11</td>
<td>0.009</td>
<td>0.991</td>
<td></td>
</tr>
<tr>
<td>R&amp;D intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Analysis of variance – R-square = 0.744; F-value = 20.334
Table 4b  Out-degree material delivery

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P(&gt;\text{observed})$</th>
<th>$P(&lt;\text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.008</td>
<td>0.13</td>
<td>0.031</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Under 0.25 export</td>
<td>0.178</td>
<td>0</td>
<td>0.064</td>
<td>0.003</td>
<td>0.997</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm group</td>
<td>0.148</td>
<td>0</td>
<td>0.073</td>
<td>0.027</td>
<td>0.973</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D</td>
<td>0.278</td>
<td>0.001</td>
<td>0.115</td>
<td>0.015</td>
<td>0.985</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: R-square: 0.712; F-value: 17.339

Table 4c  In-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P(&gt;\text{observed})$</th>
<th>$P(&lt;\text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>–0.009</td>
<td>0.139</td>
<td>0.041</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.041</td>
<td>0</td>
<td>0.013</td>
<td>0.001</td>
<td>0.999</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D</td>
<td>0.17</td>
<td>–0.001</td>
<td>0.151</td>
<td>0.137</td>
<td>0.863</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: R-square: 0.602; F-value: 16.64

Table 4d  Out-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P(&gt;\text{observed})$</th>
<th>$P(&lt;\text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>–0.028</td>
<td>0.157</td>
<td>0.051</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Under 0.25 export</td>
<td>0.125</td>
<td>0</td>
<td>0.093</td>
<td>0.093</td>
<td>0.907</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log employees</td>
<td>0.037</td>
<td>0</td>
<td>0.015</td>
<td>0.009</td>
<td>0.991</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D</td>
<td>0.236</td>
<td>0</td>
<td>0.169</td>
<td>0.091</td>
<td>0.909</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: R-square: 0.666; F-value: 13.942
Table 5  Results for Hamburg

Table 5a  In-degree material delivery

<table>
<thead>
<tr>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.047</td>
<td>0.077</td>
<td>0.006</td>
<td>0.992</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.799</td>
<td>0</td>
<td>0.175</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Note: R-square: 0.789; F-value: 93.727

Table 5b  Out-degree material delivery

<table>
<thead>
<tr>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.05</td>
<td>0.077</td>
<td>0.006</td>
<td>1</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.065</td>
<td>0</td>
<td>0.078</td>
<td>0.112</td>
</tr>
<tr>
<td>No R&amp;D resources</td>
<td>0.219</td>
<td>0</td>
<td>0.047</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: R-square: 0.854; F-value: 70.157

Table 5c  In-degree R&D

<table>
<thead>
<tr>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.026</td>
<td>0.051</td>
<td>0.01</td>
<td>0.999</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.243</td>
<td>0</td>
<td>0.066</td>
<td>0.038</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D intensity</td>
<td>0.039</td>
<td>0</td>
<td>0.025</td>
<td>0.069</td>
</tr>
</tbody>
</table>

Note: R-square: 0.773; F-value: 40.752

Table 5d  Out-degree R&D

<table>
<thead>
<tr>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.021</td>
<td>0.051</td>
<td>0.008</td>
<td>1</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.171</td>
<td>0</td>
<td>0.091</td>
<td>0.037</td>
</tr>
<tr>
<td>Sect. R&amp;D</td>
<td>0.162</td>
<td>0</td>
<td>0.048</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Note: R-square: 0.535; F-value: 13.785
Table 6 Results for Styria

### Table 6a  In-degree material delivery

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.166</td>
<td>0.04</td>
<td>0.061</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.036</td>
<td>0</td>
<td>0.012</td>
<td>0.001</td>
<td>0.999</td>
</tr>
<tr>
<td>Firm group</td>
<td>0.073</td>
<td>0</td>
<td>0.042</td>
<td>0.054</td>
<td>0.946</td>
</tr>
</tbody>
</table>

Note: R-square: 0.504; F-value: 13.691

### Table 6b  Out-degree material delivery

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.026</td>
<td>0.04</td>
<td>0.05</td>
<td>0.999</td>
<td>0.001</td>
</tr>
<tr>
<td>No R&amp;D resources</td>
<td>0.046</td>
<td>0</td>
<td>0.015</td>
<td>0.001</td>
<td>0.999</td>
</tr>
</tbody>
</table>

Note: R-square: 0.316; F-value: 12.956

### Table 6c  In-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.118</td>
<td>0.106</td>
<td>0.059</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.037</td>
<td>0</td>
<td>0.011</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D intensity</td>
<td>0.125</td>
<td>0</td>
<td>0.038</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: R-square: 0.616; F-value: 21.663

### Table 6d  Out-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>$P (&gt; \text{observed})$</th>
<th>$P (&lt; \text{observed})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.195</td>
<td>0.107</td>
<td>0.088</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Sect R&amp;D</td>
<td>0.172</td>
<td>0</td>
<td>0.079</td>
<td>0.018</td>
<td>0.982</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.045</td>
<td>0</td>
<td>0.016</td>
<td>0.003</td>
<td>0.997</td>
</tr>
<tr>
<td>Over 0.25 R&amp;D intensity</td>
<td>0.108</td>
<td>0</td>
<td>0.075</td>
<td>0.086</td>
<td>0.914</td>
</tr>
</tbody>
</table>

Note: R-square: 0.805; F-value: 35.846
Table 7 Regression results for Wales

### Table 7a In-degree material delivery

<table>
<thead>
<tr>
<th></th>
<th>Observed (mean)</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>P (&gt; observed)</th>
<th>P (&lt; observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.043</td>
<td>0.042</td>
<td>0.038</td>
<td>0.992</td>
<td>0.008</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.147</td>
<td>0</td>
<td>0.066</td>
<td>0.039</td>
<td>0.961</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.018</td>
<td>0</td>
<td>0.01</td>
<td>0.027</td>
<td>0.973</td>
</tr>
</tbody>
</table>

Note: R-square: 0.674; F-value: 25.847

### Table 7b Out-degree material delivery

<table>
<thead>
<tr>
<th></th>
<th>Observed (mean)</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>P (&gt; observed)</th>
<th>P (&lt; observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.051</td>
<td>0.042</td>
<td>0.035</td>
<td>0.999</td>
<td>0.001</td>
</tr>
<tr>
<td>Under 0.25 export intensity</td>
<td>0.042</td>
<td>0</td>
<td>0.023</td>
<td>0.028</td>
<td>0.972</td>
</tr>
<tr>
<td>Log employees</td>
<td>0.017</td>
<td>0</td>
<td>0.007</td>
<td>0.004</td>
<td>0.996</td>
</tr>
</tbody>
</table>

Note: R-square: 0.264; F-value: 4.494

### Table 7c In-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed (mean)</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>P (&gt; observed)</th>
<th>P (&lt; observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.082</td>
<td>0.161</td>
<td>0.019</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.251</td>
<td>0</td>
<td>0.099</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>Sector R&amp;D</td>
<td>0.214</td>
<td>0</td>
<td>0.056</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: R-square: 0.668; F-value: 25.119

### Table 7d Out-degree R&D

<table>
<thead>
<tr>
<th></th>
<th>Observed (mean)</th>
<th>Expected (mean)</th>
<th>Standard deviation</th>
<th>P (&gt; observed)</th>
<th>P (&lt; observed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.064</td>
<td>0.161</td>
<td>0.022</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Over 0.75 export intensity</td>
<td>0.344</td>
<td>-0.001</td>
<td>0.118</td>
<td>0.006</td>
<td>0.994</td>
</tr>
<tr>
<td>Sector R&amp;D</td>
<td>0.255</td>
<td>0</td>
<td>0.067</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: R-square: 0.723; F-value: 32.603
For Madrid as a metropolitan region with a high relevance of R&D linkages, the centrality in all dimensions is affected by the R&D intensity of the firms. For the reception and emission within knowledge networks, size plays a major role, while for material linkages export intensity and the integration into firm groups are more important. R&D service providers could not be included into the investigation in Madrid.

In Hamburg, centrality in all dimensions is affected by export intensity, underlining the problems for conventional SMEs without international experiences to gain access to network linkages. In material networks, lack of R&D resources has an influence on the importance of firms as providers. In contrast to the other metropolitan region within the sample, Madrid, size does not play a major role. For the R&D networks, R&D service providers are important for emissions, while firms with high R&D intensity are typical receivers of R&D. In Styria, in-degree centrality within material networks is affected by the firm size and integration within firm groups, similar to Madrid. Out-degree centrality within material networks depends more on R&D activities. R&D linkages as recipients or providers are also influenced by the firm size, but R&D intensity and R&D service providers are seen as important providers as well. In Wales, the material linkages are again affected by firm size, but similar to Hamburg also by export intensity. For the R&D networks in Wales, R&D service providers are important as recipients and providers, while export intensity plays an important role once more.

These findings confirm the observation within the literature that firm-specific characteristics can explain the structure of material and R&D networks and the role of individual firms and organisations within the networks. Thus, Hypothesis 3 can also be confirmed in general. The regions, however, differ according to the importance of single characteristics in explaining the centrality of individual actors. Therefore it is necessary to look at the regional specificities more closely, to understand, why these single characteristics are important within the single regions. In the following section, we use the qualitative analysis of case studies on the individual actors and regions of investigation to provide first explanations for the differences.

4.3 Qualitative interpretations of regional case studies

Besides the quantitative analysis on network structures, densities and centrality of single organisations, the specific regional conditions were investigated by qualitative studies. Our first hypothesis was based on the expectation that regions with similar socio-economic densities and sectorial focus reveal similar network structures. The quantiative results, however, could not confirm this expectation. Rather, Hamburg has emerged as the only region with a higher network density for material linkages, while Madrid displays strong R&D linkages. But this appears to be explicable with the formal knowledge endowment and the historical development of the regions. While Hamburg has a long tradition as a location for civil aeronautics production in Germany, this does not extend to aeronautics education and public research. The major engineering schools and public research institutes are based in other German cities and regions. The technological specialisation on cabin interior has only recently materialised and not as yet been matched by the development of a strong R&D base in the region. In contrast, Madrid has long been the Spanish powerhouse for civil and military aeronautics engineering, exercising a dominant influence on the national aerospace industry. Personal
linkages are crucial for developing and maintaining cooperation structures between firms. Moreover, several aeronautics companies started as spin-offs from the initial state-owned firm group in Spain. Thus, close informal and cognitive linkages are stronger and have been present for a longer time in Madrid than in Hamburg. This suggests that R&D intensity and R&D linkages play the most important role for networking in the Madrid cluster. In Hamburg, on the other hand, the material supply chain is still the dominant mode of cooperation, with multinational OEMs primarily relying on contacts to organisations outside the region. Recent initiatives in Hamburg towards attracting foreign system suppliers, investing in public aeronautics R&D and fostering public-private networking activities, tackle the problem of insufficient knowledge interactions. But according to the interviews the problem remains that many SMEs do not benefit from the initiatives, as they are essentially dependent from the OEMs and a few R&D-intensive suppliers.

With the industrial regions, similar differences could be observed. Styria with its history of a successful structural change from traditional heavy industries to knowledge-intensive medium-technology industries shows typical structures of knowledge networks, organised as clubs with exclusive access for relatively big firms and R&D-intensive SMEs. Moreover, R&D-service providers, in particular the ‘competence centres’ focussing on different technological topics, are important nodes for connecting SMEs with big multinational partners and absorbing knowledge from outside the region. Therefore, size and R&D intensity are important factors for defining the centrality of actors. In contrast, the Welsh network is more based on firms with high export intensity, typically multinational OEMs, suppliers and subsidiaries of multinational firms. The Airbus Broughton plant in North Wales, in charge of manufacture and assembly of wings within the international Airbus consortium, plays a major role in boosting the well-developed skills and tacit knowledge within the region. Most of the R&D, however, is undertaken at another Airbus UK site. Similarly, the MRO and service firms of South Wales rely on a well-developed pool of skills and mainly tacit knowledge. Thus, formal R&D intensity cannot assume the importance it has in Styria with the typical knowledge clubs. Consequentially, the big multinational firms concentrate their knowledge interactions on few R&D service providers, but do not collaborate with R&D-intensive SME partners in Wales.

Table 8 summarises the observations for the regions. Common to Madrid and Styria is that knowledge interactions play a vital role for networking and that the firms central to the networks are characterised by a high share of R&D intensity, a large size and the integration into firm groups. This leaves the interpretation that knowledge clubs have been established where SMEs are integrated, dependent on their R&D intensity and knowledge excellence. In both regions, linkages have been in place for a longer time due to integration into joint firm groups, joint professional backgrounds and specific public initiatives, respectively. Hamburg and Wales show weaker knowledge network structures. Rather, multinational firms represent major driving forces within the regions. In the absence of R&D-intensive SMEs, R&D service providers are the only suitable partners for knowledge exchange. In both regions, initiatives for the enhancement of institutional linkages have only recently started. Diversity and intensity of cooperation within the knowledge clubs has not been achieved so far.
Table 8 Summary of the observations on the regional level

<table>
<thead>
<tr>
<th>Network structure</th>
<th>Characteristics of central firms in the networks</th>
<th>Institutional linkages</th>
<th>R&amp;D and economic structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid Knowledge club based on R&amp;D intensive firms</td>
<td>R&amp;D intensity, size, firm groups</td>
<td>Former integration, cognitive linkages</td>
<td>National concentration of formal R&amp;D and services</td>
</tr>
<tr>
<td>Hamburg Hierarchical material cluster</td>
<td>Export intensity, R&amp;D sector</td>
<td>Weak, only at the beginning and based on cluster initiatives</td>
<td>R&amp;D concentrated at other places in the country, business-related services</td>
</tr>
<tr>
<td>Styria Knowledge club based on R&amp;D intensive firms</td>
<td>R&amp;D intensity, R&amp;D sector, size, firm group</td>
<td>Cognitive linkages via R&amp;D service providers and formal cluster initiatives</td>
<td>Geographical concentration of medium-technology R&amp;D, high share of medium-tech industry</td>
</tr>
<tr>
<td>Wales Export-oriented specialised value chains</td>
<td>Export intensity, size, R&amp;D sector</td>
<td>Weak, only at the beginning and based on first formal initiatives</td>
<td>R&amp;D concentrated at other places, public services and foreign direct industry investments</td>
</tr>
</tbody>
</table>

Thus, Hypothesis 1 can only partly be confirmed. There are neither pronounced similarities between the metropolitan regions nor between the industrial regions in the sample. Differences between the regions can be explained by their specific histories and institutional experiences as well as the different firm pools. Therefore, regional factors prove to be important in influencing network structures directly and indirectly via the interplay with firm and technology specific characteristics.

5 Conclusions and further discussion

The objective of the empirical investigation has been to establish the relevance of different groups of factors influencing the structure and functioning of networks and to examine the suitability of our previously developed multi-methodological approach to account for the significance of different factors to defining network properties. Many papers exclusively focus on technology-driven or firm-specific structures to explain the nature of regional innovation networks. Here our concern is that the complexity and differentiation of network formation in different European regions might easily be missed.

We have suggested three hypotheses to be tested by an empirical investigation of medium-technology clusters in four different European regions. We could confirm those two hypotheses using arguments on technology-driven and firm-specific characteristics.
It could be shown that in three of the four regions the investigated knowledge networks are more relevant than the traditional material linkages. This clearly underlines the general trend towards new types of networks structured as knowledge clubs, where control of specific knowledge capabilities represents a prerequisite for membership and a high level of exclusiveness is guaranteed by network-specific codes of communication. The only region with a higher relevance of material linkages has been Hamburg, which showed the lowest level of network density overall due to structural disadvantages (fewer R&D institutions within the region, higher share of conventional SMEs with low formal R&D intensity). Therefore, the first basic result of this investigation is that knowledge clubs are increasingly important in medium-technology industries in Europe. This adds to the findings of the literature that have so far identified the relevance of knowledge clubs in high-technology sectors only. Also, our results imply that social network analysis is a useful tool for specifying the nature of innovation networks.

Second, we could contribute to the more recent discussion on microeconomic determinants of network structures. Here, the hypothesis that there are deliberate decisions by firms to join or not to join networks, based on characteristics of the single firms, could be confirmed. This has been based on regression analysis regarding the centrality of actors in regional innovation networks with different dimensions. Again, these deliberations differ across regions and types of networks. This finding stresses the need to discuss and devise political and institutional support mechanisms helping SMEs in medium-technology industries to overcome barriers preventing access to emerging knowledge clubs. The competence centres of Styria – public-private intermediaries between basic research, multinational companies and SMEs – provide an example how support mechanisms may help overcome potential market failures caused by bounded rationality, knowledge asymmetries and lack of strategic resources. These centres might serve as a hint for possible further policy approaches based on regionally specific conditions.

The third and maybe most important insight from this investigation, refers to the relevance of regional factors for network formation. These influences, exemplified by industrial and institutional history, norms, population density, sector structure, qualification and R&D structures, are more difficult to identify, as they are qualitative and interconnected. The qualitative approach used within our investigation has proven its usefulness for analysing different sources of specific network formation in the individual regions. For example, medium technology industry networks in Styria – with its relatively high rates for all innovation indicators and its well advanced intermediary infrastructure (competence centres) – are mainly geared towards knowledge interactions influenced by the R&D intensity of individual actors and the role of competence centres as gatekeepers to knowledge from other networks. On the other hand, the networks in Wales (another industry region in transition) are mainly driven by the knowledge interactions between export-oriented firms. The two metropolitan cases, Madrid and Hamburg, are characterised by completely different networks. Hamburg is more concentrated on material linkages driven by few multinational OEMs, while the network in Madrid is increasingly based on knowledge interactions between firms with relatively high R&D intensity. Therefore, regional characteristics still play a major role in explaining the emergence, nature and structure of networks in medium-technology industries. This suggests that they have to be analysed in greater detail by further in-depth
case studies to arrive at regionally specific conclusions and recommendations. This could also be done with recourse to other indicators for regional factors used by this paper.

The investigations presented in this paper could only serve as a first exploratory step to show the potential the combination of methodologies used offers for the analysis of European regional policies supporting medium-technology industries. Future studies should extend the scope of empirical investigation to other types of regions and medium-technology industries and explore the use of further indicators for identifying the impact of regional factors on social network formation, to examine the general applicability of the model. Transregional aspects of knowledge flows should also be integrated into the social network analysis. It is of special importance to understand the increasing relevance of transboundary knowledge flows within Europe and beyond in the present era of globalisation and the even more complex challenges the management of these flows poses for SMEs in the medium-technology industries.

References


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Notes

1 We would like to thank the EU for research support (Contract No. CIT2-CT-2004-506242).

2 The novelty of this trend might be discussed controversially, as Freeman and Soete (1997) show clearly that several radical innovations typically and simultaneously pervaded and defined most industry sectors within each historical wave of technical change. The novelty, however, has to be seen in the new role of science-driven knowledge making it necessary to combine different types of knowledge (science-driven plus engineering knowledge).

3 Within the Madrid sample R&D intermediaries and engineering service have not been included. This explains the non-existence of linkages to the different ‘r’ and ‘s’ positions.