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Aviation, Space or Aerospace? Exploring the knowledge networks of two industries in the Netherlands

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Abstract:

Little effort has been made to identify industries' knowledge networks, and to what extent knowledge relations occur between actors in different industries. This paper presents a network study on the Dutch aviation and space industry. Both industries are often treated as similar and categorized as aerospace accordingly, although they tend to rely on different knowledge bases. Our study shows that the structure of the knowledge networks differs between the two industries, and few knowledge linkages have been established between the two. Our findings also suggest that the gap between the two industries' knowledge networks is more pronounced for market knowledge than for technological knowledge. Non-profit organizations do seem to bridge the knowledge networks of the two industries.

Keywords: aerospace industry, knowledge base, knowledge network, bridging organization

JEL Classifications: R11, R12, O18, O33

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1. Introduction

There is an expanding literature that studies knowledge networks in regions and clusters (see, e.g., Boschma and ter Wal, 2007; Cantner and Graf, 2004; Morrison and Rabellotti, 2009). Given the limited resources firms can invest in research and development, they increasingly rely on their ability to collaborate and make use of external knowledge (Boschma and ter Wal, 2007; Hagedoorn, 2003; Mowery et al., 1998/9; Singh, 2005; Sorenson and Stuart, 2001). The core message of these studies is that being highly connected may yield benefits to actors. Boschma and Frenken (2009) have argued that being well connected to a great number of other actors may, however, not be a sufficient condition to benefit from knowledge exchanges. They state this requires networks that consist of agents with complementary knowledge bases.

The same kind of reasoning has been applied to cross-industry knowledge spillovers. While regions and cities with a highly diversified economy might enhance inter-industry knowledge spillovers, recent studies suggest this is especially true when local industries are technologically related (Boschma and Iammarino, 2009; Frenken et al., 2007). However, little effort so far has been made to identify industries' knowledge networks, and how these industry's networks overlap, i.e. to what extent knowledge relations occur between actors that are active in different industries. This may depend, among other factors, on the type of knowledge bases that might be associated with particular industries. Asheim and others (e.g. Asheim and Coenen, 2005) have drawn attention to three different knowledge bases (synthetic, analytical and symbolic), but have not made explicit how the structure of the knowledge networks might look like for each of these knowledge bases.

The first objective of this paper is to analyze and compare the structure of two industries' knowledge networks, namely the aviation industry and the space industry. Although these two industries are often aggregated as 'aerospace', they differ in their underlying knowledge bases, that is, space industry relies more on science-based analytical knowledge, while the aviation industry is more geared towards an engineering-type of synthetic knowledge. Using these two industries as an example, we employ social network tools to study how the different knowledge bases translate into varying structures of knowledge networks. We will demonstrate that the reliance on different knowledge bases, among other factors, may have caused a higher density of the network in the Dutch space industry, as compared to the aviation network.

The second objective of this paper is to investigate the extent to which these two knowledge networks overlap, and which organizations bridge the two. The aggregation of the space and aviation industry to an aerospace industry, which is frequently found in the literature, suggests that there exists some technological and organizational overlap between the aviation and space industries. Our Dutch network study shows that the two industries are clearly technologically related. The two knowledge networks are basically connected by organizations that are simultaneously active in the two knowledge bases. This bridging function is mainly performed by non-profit organizations. Our analysis also shows that one needs to differentiate between technological and market knowledge (Giuliani, 2010). Few and seemingly ineffective links exist between the market knowledge networks of the two industries. Taken together, this suggests that the gap between the two industries' knowledge networks is more pronounced for market than for technological knowledge.

The paper is structured as follows. In the next section, we discuss the notions of knowledge networks and knowledge bases, and relate those to the aviation and the space industries in the Netherlands. Based on that, we formulate some hypotheses concerning the structure of their knowledge networks. In Section 3, we present the data that have been collected in the Netherlands in both industries. Section 4 provides the main empirical results. Section 5 discusses the findings and concludes.

2. Knowledge bases and knowledge networks in aerospace industry

2.1. Knowledge bases in space and aviation industries

When studying knowledge networks, two types of studies can be distinguished (ter Wal and Boschma, 2009). Some studies employ large databases covering entire economies to identify driving forces behind network formation. For example, Breschi and Lissoni (2009) use Italian patent data to analyze the importance of social relations and mobility for the creation of links between firms. Studies of this kind normally do not explicitly consider industries but rather focus on technologies. Other studies investigate knowledge networks and their effects on economic actors for a specific industry in a particular region. Such studies primarily consider network relations among actors within one industry (Boschma and ter Wal, 2007; Giuliani and Bell, 2005; Morrison, 2009).

However, few studies take an inter-industrial perspective and investigate how industries are linked through knowledge networks. Exceptions are Park and Kim (1999) and Han and Park (2006), who investigate primarily the intensity of interaction between industries. So far little is known, however, about the extent to which industries are related to each other and how knowledge networks span industrial borders, how inter-industrial knowledge networks are structured, and what characterizes actors that connect different industries.

In this paper we study the example of the aviation and space industries. The aviation and the space industry have been extensively studied (see, e.g., Hickie, 2006; Niosi and Zhegu, 2005; Sammarra and Biggiero, 2008). However, little attention has been paid to their knowledge networks. If accounted for, studies have focused on one of the two industries (e.g. Broekel and Boschma, 2009), or on the combined aerospace industry, without differentiating between space and aviation activities (Sammarra and Biggiero, 2008). We fill this research gap by providing an in-depth case-study on these two industries' knowledge networks.

What makes the two industries interesting from our inter-industry perspective is that they rely on different knowledge bases (Wolfe et al., 2005). According to Asheim and Coenen (2005), industries can be classified according to their embeddedness into one of three knowledge bases: synthetic (engineering-based), analytical (science-based) and symbolic (artistic-based). Space represents a clear example of an industry relying on an analytical knowledge base. This knowledge base "… refers to trial settings, where scientific knowledge is highly important, and where knowledge creation is often based on cognitive and rational processes, or on formal models" (Asheim and Coenen, 2005). The aviation industry's knowledge base is more synthetic-based. There is greater reliance on production technology and cost reduction, and innovations occur mainly through the application and recombination of existing knowledge (e.g. Wolfe et al., 2005). There is also a clear focus on problem-solving activities that happen in close interaction with clients and suppliers (Asheim and Gertler, 2005; Asheim and Coenen, 2005).

Despite these differences, the space and aviation industries are often categorized as aerospace. With few exceptions (Beaudry, 2006; Broekel and Boschma, 2009), studies do not consider this separation and focus on the aerospace industry as a whole (Gray et al., 1996; Hickie, 2006; Lublinski, 2003; Niosi and Zhegu, 2005; Sammarra and Biggiero, 2008). The reason for this is the existence of significant similarities between the two industries. Frequently, the same firms are active in aviation and space. The two largest aircraft produces Boeing and EADS (Airbus) are also major players in the space industry. However, there are also companies that focus on either industry, like Bombardier, which is the world's third largest aircraft producer but has no significant space activities. Both industries are also high-risk activities that are subject to heavy competition: commercial competition in the aviation industry and governmental/military competition in the space industry (Maryniak, 2000). The industrial structures of the two industries look quite similar as well. The aerospace industry is known for being highly agglomerated in a few locations worldwide, like Seattle and Toulouse (Hickie, 2006). In particular during the last two decades, a strong concentration processes has led to the emergence of large system integrators dominating the aviation industry. A similar development starts to take place in the space industry. These firms' headquarters and main facilities function as attractors for other businesses, e.g., specialized suppliers, subcontractors and service companies. The industrial structure of these clusters typically look like hub-and-spokes with large system integrators as hubs (Gray et al., 1996).

Moreover, the two industries' core technologies concern aerodynamics, propulsion, electronics, navigation and materials. Technological differences with respect to their products are of smaller importance. Notable exceptions are production technologies though, which are far more important in aviation than in space. This is related to a key difference between the two industries: the size of product series and the number of product variations. The amount of types of airplanes exceeded the 250 only ten years after the first flight of the Wright brothers in 1903 (Pinelli, 1997). The series produced of a single product are much larger in case of aviation than in space. The more scientific environment of the space industry as well as the distinctiveness of each asset results into a very knowledge- and labor-intense design- and manufacturing process (Fortescue and Stark, 2001). The most successful airplane models are produced by the thousands. This makes mass production technologies and efficient production systems much more important in aviation than in space.

Another and related difference is the rate of commercialization. The aviation industry commercialized much faster than the space industry (Handberg, 1995). As (Maryniak, 2000) put it, "the most important difference between the two has to do with the *public expectations* formed during the early years of both activities" (p. 13). The first space activities were directed and organized by governmental and military agencies. In particular, military programs as well as the space race between the Soviet Union and the USA made clear that space was a governmental domain. This shaped the customer structure of the space industry, which, until today, consists primarily of public actors. In contrast, aviation started as a private domain with a clear focus on consumer needs, commercial success and cost control. Maryniak (2000) claims that this difference in attitude is still visible in today's space engineering, which focuses on performance rather than cost. In the more competitive aviation industry such an attitude is not likely to be successful.

2.2. The Dutch aviation and space industries

The history of the Dutch aerospace industry is to a large extent the history of the Fokker Company. Since its establishment in 1919, Fokker dominated the aerospace industry in the Netherlands for almost eighty years (van Burg et al., 2008). At its peak in mid 1991, about 13,000 people worked for Fokker (Ligterink, 2001). In 1996, Fokker had to declare bankruptcy, which meant the Dutch aviation industry lost its sole aircraft producer and one of its technological flagships. However, a number of significant public actors remained. Foremost this applies to the Technical University of Delft (TU Delft), with its Faculty of Aerospace Engineering. The national research organization TNO has also a strong position in aerospace related fields. The same is true for the Netherlands Agency for Aerospace Programs (NIVR) and the National Aerospace Laboratory, which provides testing facilities and laboratories.

The Dutch space industry emerged during the 1960s through governmental programs. The space research organization GROC (Foundation Space Research Committee) was founded in 1959. In 1971, a separate space division was added to the NIVR. It was then responsible for the management of the first Dutch satellite ANS launched in 1974. Another asset of the Dutch space industry is the ESA research center ESTEC (European Space Research and Technology Center) which was established in 1968, and which forms the technical heart of the ESA with about 2.000 specialists. Fokker started with space activities in the 1960s. It evolved into Dutch Space, which remains the corner stone of private space activities in the Netherlands.

The Dutch aerospace industry primarily consists of SMEs (NAG, 2008), which account for a total employment of about 5,000 employees. When maintenance and overhaul of aircrafts is included, the number of employees increases to 15,000, and the turnover to Euro 2.2 billion (NAG, 2008). Having said that, the Dutch aviation sector is marginal in comparison to Germany and France.

2.3 Hypotheses

The previous discussion leads us to formulate a number of expectations concerning the structure of the knowledge networks in both industries in the Netherlands.

First, we test whether the knowledge networks in both the aviation and space industries are indeed highly centralized and characterized by star type structures. In addition, we expect that the successor firms of Fokker in both industries hold central positions in their knowledge networks. As noted above, when the Fokker company went bankrupt in 1996, its space related activities were consolidated in a new firm that is still a major player today. Also, the viable aviation business of Fokker was consolidated in a new firm after 1996. Given the fact that many of the industries' current entrepreneurs and top-managers are former employees of Fokker, their knowledge searching and sharing activities are still likely to be shaped by these experiences and biased towards their former co-workers (see, e.g.,Broekel and Binder, 2007). In others words, this old-boys network might still impact on the current structure of the knowledge network, and therefore, we expect that the two successor companies of Fokker are likely to be located in the center of these networks.

We also investigate the relationship between the particular knowledge bases in the two industries (analytical versus synthetic) and the structure of their knowledge networks. Our aim is to test if the difference in the knowledge bases translates into varying knowledge network structures. Scientific knowledge is of higher relevance in industries with an analytical knowledge base, and also has a higher degree of codification than synthetic knowledge. Moreover, the close interaction with science implies that a lot of new knowledge is published in public journals and magazines. This makes analytical knowledge easier accessible. Adding to this is the demand coming primarily from public actors. As this might reduce obstacles for collaboration (see, e.g., Kesteloot and Veugelers, 1995), we expect to find more collaboration in space than in aviation. In other words, we expect that the use of analytical knowledge in space results in a higher density of its knowledge network, as compared to aviation, which is more based on synthetic knowledge base. We also expect that public organizations take more central positions in space than in aviation.

We also think it is essential to make a distinction between technological and market knowledge networks (Sammarra and Biggiero, (2008)[1]. Technological knowledge refers to all kinds of technical information, specifications and know-how necessary to create and produce a product. Market knowledge refers to information on future market developments, potential customers and demand, which is crucial for firms to create and sell their products. We expect that the structures of market knowledge network differ considerably between the space and aviation industries because of their different demand structure. In space, public agencies represent primary demand and may therefore be key suppliers of market knowledge. This is why we expect them to hold more central positions in market knowledge networks in space. Being comparatively small in size, aviation firms in the Netherlands need to cooperate to get access to the global market. We expect that associations take up this coordinating role and act as important collectors and distributors of market information. This is why we expect them to hold central positions in the market knowledge network of the aviation industry. Here the difference in both industries' knowledge bases also becomes visible. While non-profit organizations are much more central in space with its analytical knowledge base, profit organizations integrate the networks in the synthetic knowledge base of aviation. Therefore, associations are expected to be more crucial in the aviation's market knowledge network, while public research organizations are more central in the market knowledge network in space.

As the customer structure of the two industries differs substantially, we expect there is little to gain from exchanging market knowledge between the two industries. Therefore, few links are likely to exist between the two industries concerning market knowledge, which is rather shared among actors belonging to the same industry. In contrast, a significant technological overlap exists between the two industries, despite their different knowledge bases. We therefore expect stronger linkages between the two industries concerning the exchange of technological knowledge. It is however also well-known that in order to access knowledge, actors need sufficient absorptive capacity (Cohen and Levinthal, 1990). As this involves a certain degree of diversification, we expect in particular large actors that are simultaneously active in

[1] Sammarra and Biggiero (2008) differentiate between three types of knowledge (i.e. managerial, technological and market knowledge) . Our data, however, cover only the latter two.

space and aviation to function as bridges between the two industries' networks. In our empirical study, we will test all these expectations.

3. Data collection

Our empirical study on the Dutch aviation and space industry is based on own data collection. In late 2008-early 2009, we interviewed 55 organizations that belong to the aviation industry in the Netherlands. Most of these organizations are members of the Netherlands Aerospace Group (NAG), which is the most important trade organization. Their members account for about 95 percent of the total turnover generated by Dutch firms in the aviation industry (NAG, 2008). In 2008, the organization had 83 members. We interviewed only those members that were active in manufacturing and/or engineering, since for these activities, innovation and the exchange of technological knowledge is of utmost importance.[2] This applies to 39 firms, of which we interviewed 36. The three firms that were not interviewed do not show any eye-catching features. In the course of the interviews, five additional firms were named as being relevant, which were not member of the NAG, but clearly active in the aviation industry. All of these have been interviewed as well. This increased our total population to 44, of which 41 have been interviewed by extensive semi-structured interviews on the spot. Accordingly, our response rate is 93 percent.

The list of the NAG also includes non-profit organizations, which we interviewed in a different way. These organizations, as well as additional non-profit organizations named during the firm interviews as relevant knowledge sources, were asked to indicate the intensity of interaction with the other relevant non-profit organizations. This applied to 14 organizations, which increased our sample to 55 organizations. The intensity level ranged from 1 to 3, with 1 indicating no interaction and 3 indicating very high intensity.

In a similar manner as for the aviation industry, we collected data for the space industry by relying on the Space Directory (www.spaceoffice.nl) published by the Netherlands Space Office (NSO). The NSO is the official Dutch agency for space affairs. This directory presently contains 72 organizations. Of these 72, only 38

[2] We interviewed also 2 firms that were not active in manufacturing or engineering. These firms confirmed the low importance of technological exchange for their firms' competiveness. Moreover, none of the interviewed firms mentioned any maintenance-oriented firm as a relevant knowledge source.

provide engineering or manufacturing services and had a significant presence in the Netherlands before 2009. The others are either established after 2009, or they offer consultancy, advisory and human resource services. Some other process satellite data, or offer services based on data collected by satellites. 26 of the 38 organizations are profit-oriented. Seven out of the 26 are also active in aviation, and fourteen have been interviewed in 2009 with the same questionnaire as the aviation firms. With respect to profit organizations, our response rate is 81 percent. Of the twelve non-profit organizations, nine are also part of the aviation industry and the remaining three have been interviewed in a similar manner as their counterparts in aviation. Accordingly, our response rate for the entire space industry is 33 out of 38 corresponding to 87 percent. For the two industries, our total sample consists of 72 organizations.

Concerning data on knowledge links, we asked firms to name their most important knowledge sources for market information as well as for technological knowledge. For each of the named contacts, we gathered further information during the interviews as well as from the Internet. For the aviation industry, the network consists of 55 nodes with 200 market knowledge links and 121 links concerning technological knowledge. The space industry's networks are characterized by 33 nodes with 115 market and 87 technological links. The combined aerospace network has 72 nodes with 315 links concerning market knowledge and 272 technological links. Figures 1 and 2 show the technological knowledge networks of the aviation and space industry, respectively. The corresponding market knowledge networks are depicted in Figures 3 and 4. The aviation industry's technological network is characterized by 22 isolates (not shown in figures). In contrast, for the space industry, one organization is not connected to any other Dutch space or aviation firm. One more isolate is an organization that has significant activities in both industries. In case of the market knowledge networks, these figures are smaller with only aviation having 13 isolates. Following (Broekel and Boschma, 2009) we treat all links as undirected because we assume that all knowledge exchanges are bidirectional.

4. Knowledge networks in Dutch aviation and space

4.1. Some basic characteristics

We divided the organizations into three types: those solely active in space (17), those that have only aviation activities (39), and organizations that have significant business in both industries (16). These numbers show that the aviation industry is larger in terms of number of firms as well as employment. The summed employment is 1,170 of the interviewed firms in the space industry (excluding organizations active in both industries and non-profit organizations). The same number for the aviation industry is 3,086, almost three times higher. Tables 1 and 2 highlight the most important none-network related differences between the profit-oriented organizations of each group. The tables show that the Dutch aviation and space industry are more or less similar when it comes to firms' age and employment. We therefore expect these characteristics not to bias the results.

- Table 1 here -

- Table 2 here -

4.2. Knowledge bases

In Section 2, we pointed out space and aviation rely on different knowledge bases. This is confirmed by our data to some extent, as shown in Tables 3 and 4. Space firms employ a significantly larger share of persons with a scientific background than aviation firms. This refers primarily to persons having university degrees in physics, chemistry and biology. As expected, apparently, the space industry requires analytical skills of scientists rather than problem-solving skills of engineers. In general, a much higher share of space employees have graded from university. The magnitude of the difference displays the larger importance of manufacturing activities in aviation.

- Table 3 here -

- Table 4 here -

Firms in the space industry rank academic journals to be more important as knowledge sources than their aviation counterparts. This indicates a larger relevance of codified knowledge in space, which is another characteristic of an analytical knowledge base (Asheim and Gertler, 2005). Adding to that, space firms assign a higher importance to recruit from universities than aviation firms. They also value external knowledge more than aviation firms. This translates also in more links to universities to exchange technological knowledge as well as more connections to research organizations. In sum, we find space firms to be closer related to the scientific sector than the aviation industry. This refers to their workforce, knowledge exchange patterns, recruitment and perception of external and codified knowledge. Accordingly, the space industry draws merely upon an analytical knowledge base. In comparison to space, aviation relies more on a synthetic knowledge base, which confirms the results of Wolfe et al. (2005). Nevertheless, aviation is also an innovation-oriented and research-intensive industry with complex products (Hickie, 2006). In our sample, the share of R&D employees on total employment is quite high (0.15). For space, it is only somewhat larger (0.19). In both industries, the majority of highly qualified employees are engineers (77 and 60 percent).

4.3. Network centralization

We argued before that the typical hub-and-spoke type industrial structure found in both industries should be found in their knowledge networks as well. Table 5 presents three common centralization measures for the four different knowledge networks (see, e.g., Freeman, 1979; Wasserman and Faust, 1994). Centralization describes in general how a network is centralized around a few nodes. Loosely speaking, the degree centralization captures the discrepancy of the observed network from a perfect star-type network with the same number of nodes. It can be estimated via:

$$C_D = \frac{\sum_{i=1}^{g}\left[C_D(n^*) - C_D(n_i)\right]}{\left[(g-1)(g-2)\right]}$$

whereby $C_D(n_i)$ indicates an actor's degree (number of links), $C_D(n^*)$ the maximum degree, and g the total number of possible links in a graph. Similarly, betweenness centralization refers to the extent to which actors' shortest paths connections run through the same nodes. The maximum value of this measure corresponds again to a perfect star-type network. It can be estimated by:

$$C_B = \frac{\sum_{i=1}^{g}\left[C'_B(n^*) - C_B(n_i)\right]}{(g-1)}$$

with $C_B(n^i)$ as actor level betweenness centralization and $C'_B(n^*)$ as the maximum value found in the network. An actor's betweenness is computed by:

$$C_B(n_i) = \sum_{j<k} g_{jk}(n_i)/g_{jk}$$

with g_{ik} as the geodesic distance (shortest path) between actor j and k. Lastly, the importance of high scoring connections (those between nodes with many connections) in a network is approximated by eigenvector centralization. It can be written as:

$$C_v = \frac{\sum_{u\varepsilon N}(v_{u^*} - v_u)}{\sqrt{\frac{n-1}{2}(\sqrt{n-1}-1)}}$$

whereby v_{u^*} indicates the highest actor level eigenvector centrality, and v_u the eigenvector centrality of actor I (see Wasserman and Faust 1994 for more details).

- Table 5 here -

All four measures suggest that the aviation's market knowledge network is most centralized. This is in so far surprising as the aviation networks have more nodes than the space networks, which tends to reduce centralization. It scores particularly high on degree centralization and eigenvector centralization. This implies the presence of few very central nodes. Because of fewer links but the same number of nodes, the numbers are lower for the technological knowledge network. Interestingly, it has a comparatively low value of betweenness centrality, meaning that central actors can be bypassed through alternative nodes. Both networks of the space industry are rather similar, which corresponds to their fairly high correlation. Their centralization scores are also fairly high.

On the basis of these numbers, we can confirm the existence of star-type knowledge networks in both industries. Accordingly, the hub-and-spoke type industry structure seems to shape also the industries' knowledge networks. This is particularly interesting as the largest companies and production facilities in the Dutch aviation and space industry are medium-sized on an international scale. Hence, potential hub actors are relatively small but still able to form the networks accordingly.

4.4. Central network actors

When Fokker went bankrupt in 1996, parts of the company survived as more or less independent firms. The space related activities of Fokker were consolidated in one firm (no 77 in the graphs). Another firm took over the core of Fokker's aviation activities (no 62 in the graphs). This firm has also some business in the space sector. Thus, we consider one Fokker successor in the aviation and two in the space industry. In Section 3, we argued that these actors with a history in the former Fokker company are likely candidates for the most central positions in the knowledge networks.

We use four centrality measures to assess the network centrality of actors: degree, betweenness, eigenvector and closeness. The first three are similar to the centralization measures described above. In contrast to their network wide meaning above, the focus is here on single actors. In addition, we consider closeness centrality, which is defined as the reciprocal of a node's total distances to all other nodes in a network:

$$C_c(n_i) = \frac{n-1}{\left[\sum_{j=1}^{g} d(n_i, n_j)\right]^{-1}}.$$

where $d(n_i, n_j)$ describes the geodesic distance between actors i an j (see for more details Wasserman and Faust, 1994).

Table 6 shows the ranks of the two former Fokker companies among all profit-oriented actors with respect to these four measures. Obviously, the former Fokker company dominates the market knowledge network in aviation with respect to all measures. The same is true for its space related successor. Thus, as expected, in both industries, the successors of Fokker take central network positions. This is even more so in space, despite the fact that the relative size of the Fokker successor in aviation is much larger than its counterpart in space (taking up 18 and 49 percent of total employment in their respective industries). A clear exception is the comparatively weak position of the Fokker successor in the technology network of aviation. While it has a large number of direct links (degree), it has a weak position with respect to Eigenvector and closeness centrality. This corresponds to its rather peripheral location in the network, implying a relatively large distance to the network's core nodes. The firm does well with respect to betweenness though. This implies that, despite its peripheral location, it still has an important network position that connects rather distant and otherwise unconnected parts. This is in line with Broekel and Boschma (2009) who showed that a shared past in Fokker was a driver of knowledge network formation in Dutch aviation. Unfortunately, we lack longitudinal data to test whether the firm used to have a central position but eventually moved out of the center over time. If this is true, the Dutch aviation industry managed to emancipate from the Fokker centered industrial structure in the past. This remains however speculative.

- table 6 here -

4.5. Density

The Figures 1-4 visualize the market and technological knowledge networks in both industries. They look pretty similar. This is confirmed by network correlation coefficients which is 0.59^{***} in case of aviation and 0.74^{***} for space.[3] In Section 2, we were arguing that we expect the space networks to be denser than the networks in the aviation industry. To shed light on this issue, we estimated the networks' densities. The density of a network is defined as the number of observed links divided by the number of possible links. In an undirected network the density is estimated as:

$$D = \frac{g_{obs}}{n * (n-1)/2}$$

[3] Correlation is estimated according to Butts et al. (2001). Significance is based on quadratic assignment procedure by Krackhardt (1992).

In aviation, the 55 nodes and 200 market knowledge and 121 technological knowledge links translate into network densities of 0.13 (market knowledge) and 0.08 (technological knowledge). These outcomes are in line with the findings of Sammarra and Biggiero (2008) on the aerospace industry in Rome (Italy), who found densities of 0.12 and 0.15, respectively. The space industry's knowledge networks are characterized by 33 nodes with 115 market and 87 technological links, which result in a density of 0.22 and 0.16, respectively. The networks of the space industry are thus almost twice as dense. If establishing and maintaining links is associated to costs, the density of networks will decrease with increasing numbers of nodes because an upper limit to the number of contacts of an actor may exist. However, the size difference between aviation and space (in terms of number of nodes) does not seem to be enough to solely explain the density difference. Moreover, the 22 isolates in aviation clearly outnumber the one isolate in space. Thus, as expected, space knowledge networks are indeed denser than those in aviation. We argued before that this may be explained by a higher reliance on synthetic knowledge in aviation which might lower the willingness to collaborate in aviation. Evidence for cut-throat competition among aviation firms is provided by our interviews, during which a number of managers described competition as an obstacle to collaboration. As one manager put it, "there's a lot of mistrust among the companies [in aviation] due to the high competition in the Dutch market". Another manager comes to a similar remark: "sharing of knowledge [in aviation] would be great, but the problem is that most firms are competitors".

- Figure 1 here -

- Figure 2 here -

- Figure 3 here -

- Figure 4 here -

4.6. Network positions of non-profit organizations

Figures 1-4 indicate that non-profit organizations are of immanent importance to the knowledge networks of aviation and space. For a more precise assessment of their network position, we again compute and compare different centrality measures.

Table 7 shows the significant differences in the mean of the centrality measures for different types of actors in the aviation industry. In both networks, firms hold on average less central positions. Research organizations and associations are the most central actors in the market knowledge network, and to a somewhat lesser extent in the technological network. Next in the ranking are universities. The market knowledge network is clearly dominated by one association (no. 117 in the graphs) according to all four centrality measures. However, some research organizations (no. 83 and 71) are also crucial actors. As mentioned before, the Fokker successor is also well positioned. In the technological network, associations are of slightly less importance. Here, in addition, universities (and no. 81 the TU Delft in particular) shape the network's structure. In this network, firms are generally of little relevance, and lack strong ego networks, as demonstrated by the 22 isolates. For aviation, we can conclude that non-profit organizations are of essential importance.

- table 7 here -

In the space industry, the picture is somewhat different, because fewer non-profit organizations are part of this industry. We have too little observations to do a statistically sound comparison of firms with universities and associations. Table 8 highlights the differences in the actors' average centralities between firms and research organizations. As in aviation, firms tend to be less centralized in both networks than research organizations. However, one firm (the successor of Fokker) is the most central actor in the market knowledge network. The next most central actors are two non-profit organizations. Among these is the ESA research facility, whose high score on betweenness suggests it is in a good position of brokering market knowledge flows in this industry. This reflects the importance of the ESA as primary customer, which accounts for about 50 percent of all orders (Dutch Ministry of Economic Affairs, 2009). The other is the Dutch research organization TNO. In contrast to aviation, associations are of minor importance. In the technological knowledge network, the situation is not much different. Most central actor is here TNO followed by the Fokker successor. Other central actors are the TU Delft and some other firms. Hence, in contrast to the aviation, firms are important nodes in the network, although this is still strongly shaped by non-profit organizations.

- table 8 here -

To sum up, public actors are of immense importance in the knowledge networks in both industries. In aviation, this is even more so than in space, where firms serve as brokers as well. As expected, due to the customer structure, associations are crucial market knowledge sources in the aviation industry. In space, research organizations provide access to demand which comes primarily from public agencies.

4.7. Network links between the two industries

We showed earlier that both industries rely to some extent on different knowledge bases. The question then is: to what extent are the knowledge networks of both industries connected?

We begin analyzing the combined market knowledge network of the two industries, which are depicted in Figure 5. The cores of both industries' networks are surely not identical but the networks do seem to be integrated. However, a closer look reveals that there are only two direct links between actors of which one is exclusively active in space, and the other one in aviation. None of these links connects two firms though. Both links exists between a space research center and two universities which are focused on aviation. Whether these organizations are really capable of transferring marked knowledge from one industry to the other is questionable, to say the least.

- figure 5 here -

In addition to these direct links, a number of indirect links exist that connect space or aviation actors to organizations that do business in both industries (so-called hybrid organizations). 49 links connect space with hybrid organizations, 55 links regard relations between aviation and hybrids, and 35 links connect different hybrid organizations. When comparing these numbers to the number of exclusive aviation (34) and space links (27), it becomes clear that these 16 hybrid organizations are key players in the market knowledge networks of both industries. However, it is not clear what type of knowledge is transferred between two hybrid organizations. This is why we will focus on those organizations that have at least one link to an exclusive space as well as to an exclusive aviation organization. Eight of these bridging organizations exist in the market knowledge network. Two of these are firms, two are research organizations, two are universities, and two are associations.

Table 9 compares bridging organizations with non-bridging organizations. Bridging organizations are clearly most central in the market knowledge network. On average, they have more links to both industries as well as to hybrid organizations. However, for five of these bridging organizations, partly based on our interviews, we doubt whether these function as real bridges between the two industries. Universities tend to be segmented. The same applies to the large research organization TNO, which has several sub-divisions. One of the two associations split up in 2009 its aviation related activities and its space activities: the former were integrated into an agency of the Dutch Ministry of Economic affairs, while the latter were bundled into a new exclusively Space focused association. The other association is the Dutch defense industry, which makes the exchange of non-military related market knowledge unlikely through this link. Hence, essentially there are two firms, one research organization, and one association focused on military business that connect the two industries' market knowledge networks. These four organizations account for 25 links to the aviation industry and 18 links to the space industry.

- table 9 here -

In sum, for market knowledge networks, we find that only few direct links exist between the two industries. However, there are substantial indirect links that connect the two industries' networks through hybrid organizations, i.e. organizations active in both industries. In the end, it depends on the extent to which these organizations transfer market information from one industry to the other whether the two networks are really connected. Given that only two of the bridging organizations are profit oriented with a viable interest in market knowledge, we doubt the existence of substantial inter-industry exchange of market information. This is what we expected, but conditional on the assumption that bridging organizations are rather ineffective.

Figure 6 shows the combined technological knowledge networks of the two industries. As compared to the combined market knowledge network, both industries' technological knowledge networks seem to be integrated more strongly. However, like the market knowledge network, only two direct links exist between an exclusive aviation and space organization. Both connect two universities to the same research organization. In contrast to market knowledge, these organizations might be capable of transferring technological knowledge from one industry to the other.

- figure 6 here -

In addition to these direct links, we focus on indirect links. Of the 173 total links, 45 link aviation to hybrid organizations, 47 connect space with hybrid organizations, and 41 links exist between hybrids. Again, these numbers have to be seen in relation to only 15 exclusive aviation and 23 exclusive space links. Hybrid organizations are of key importance for the two industries' technological knowledge networks as well. In a similar manner as for market knowledge, we focus in the following on organizations that bridge the two industries, i.e. those organizations that have connections to an exclusive space and an exclusive aviation organization. There are nine organizations of this kind, of which eight are identical to those identified for the market knowledge network. The additional organization concerns an university.

In Table 9 these bridging organizations' characteristics are compared with those of non-bridging organizations. All these numbers are very similar to the numbers of the market knowledge network and hence, the conclusions are identical. Bridging organizations are clearly most central in the technological knowledge network. For the eight organizations that bridge the market and the technological knowledge networks of the two industries, the same arguments apply regarding their potential effectiveness of their role as bridging organization. The one organization that bridges only the technological knowledge networks is an university and hence, is treated as the other universities. Accordingly, there are two firms, one research organization, and the one military-focused association that truly bridge the two industries' technological knowledge networks. These organizations account for 15 links to the aviation industry and 15 links to the space industry.

In contrast to market knowledge, however, we tend to assign a higher probability of successful internal knowledge transfers to university and research organizations when the content concerns technological knowledge. In particular, the technical university in Delft has often shown its abilities to team up with industrial partners and participate in intensive knowledge transfers (see, e.g., van Burg et al., 2008). University employees are also more likely to participate in the same seminars, meetings and conferences, which aim at the exchange of technological knowledge.

5. Conclusion

The aviation and space industries are frequently treated as a combined aerospace industry. From our Dutch study on knowledge networks in both industries, it becomes clear that one should be cautious to do so, as important differences between the two industries exist. We argue therefore that the aviation and space industry are two separate industries, at least in the Netherlands, despite some similarities.

As expected, our study demonstrated that the two industries rely on different knowledge bases, at least to some extent. Aviation relies more heavily on synthetic knowledge, while space activities draw more on analytical knowledge. The knowledge network in the space industry is much denser than the one of aviation. This difference may be attributed to the use of different knowledge bases, but a number of respondents also hinted at the lack of trust, high levels of competition and weak competences in the case of aviation. In each industry, we also found that different types of organizations take up central positions in the knowledge network. Associations are essential brokers of market knowledge in the aviation industry, while in the space industry, firms are more important players, as well as public agencies from which most demand comes. No direct ties exist between space and aviation firms. What makes the two industries' networks connect are non-profit organizations. This is why we expect that the flow of market information is probably rather weak, but we believe that technological knowledge can pass these organizations (in particular universities) more easily and connect the two industries more effectively.

This study has generated questions that need to be taken up in future research. First, we need to study more carefully how the underlying knowledge bases relate to the structure of knowledge networks. There is little theory on how the use of particular knowledge bases in industries is reflected in the constellation of their knowledge networks, and how this affects the potential for inter-industry knowledge spillovers. Second, more research is needed that investigates the precise role of bridging organizations that connect the knowledge networks of different industries, how public universities are engaged in that process, and how public policy may play a role. Although some organizations like universities seem to perform that role, it is unclear whether they really do in practice, given the fact these are large organizations with many divisions. Third, our study showed that one needs to differentiate between networks based on market and technological knowledge. Studies focusing on either one may miss key characteristics of industries. More importantly, our study raised the demand for further contributions explaining how the type of knowledge impacts on the structure and evolution of knowledge networks. Finally, our study focused on the knowledge networks of the two industries in the Netherlands, but did not explore what links were established with organizations outside the Netherlands. Taking up this topic of local versus non-local knowledge relationships would contribute to a better understanding of how industry's knowledge networks are structured, and why.

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Median (only firms)	*Space*	*Aviation*	*Hybrid*
Age in years	24.5	18	28
Absolute employment	32	40	74

Table 1: Basic actor characteristics, absolute

Variables (only firms)	*Space-Aviation*[1]	*Aviation-Other*[2]	*Space-Other*[3]
Age	6.5	-22	-15.5*
Employment	-8	-45	-53**

[1] Median space – median aviation

[2] Median aviation – median other (only firms)

[3] Median space – median other (only firms)

Wilcoxon test used for significance

Table 2: Basic actor characteristics, relative

Mean (only firms)	*Space*		*Aviation*		*Hybrid*	
Share of scientists	23.1		6.9		14.4	
Share of engineers	60.1		77.2		75.4	
Share of bachelor degree	67.4		19.3		28.3	
Importance of academic journals	2.4		0.9		2.1	
Recruit from university	3.7		2.3		3.3	
Recruit from technical organizations	2.2		2.1		0.9	
Importance external knowledge	46.8		30.6		39.3	
	Market	Techno	Market	Techno	Market	Techno
No. of links to universities	0.07	0.57	0.11	0.31	0.42	1.57
No. of links to research organizations	1.57	1.07	0.22	0.2	1	1.43
No. of links to associations	0.14	0.07	0.71	0.07	0.57	0
All numbers based on joined network of aviation and space						

Table 3: Knowledge base characteristics, absolute

Variables (only firms)	*Space-Aviation*[1]		*Aviation-Other*[2]		*Space-Other*[3]	
Share of scientists	14.5^{***}		-5^{*}		9.5	
Share of engineers	-20		0		-20	
Share of bachelor degree	72^{***}		-7		65^{*}	
Importance of academic journals	2.37^{***}		-0.26		2.11^{**}	
Recruit from university	3.5^{**}		-2		-1.5	
Recruit from technical orga.	1		1		2^{*}	
Importance external know.	20^{**}		-10		10	
	Market	Techno	Market	Techno	Market	Techno
No. of links to universities	-0.05	0.31^{*}	-0.49^{**}	-1.49^{***}	-0.54^{*}	-1.18^{**}
No. of links to research orga.	1.27^{***}	1.05^{***}	-0.77^{**}	-0.8^{***}	0.5	0.25
No. of links to associations	0.13^{**}	0.06	0.71	0.06	0.13	0.06

[1] Median space – median aviation
[2] Median aviation – median other (only firms)
[3] Median space – median other (only firms)
All numbers based on joined network of aviation and space
Wilcoxon test used for significance

Table 4: Knowledge base characteristics, relative

Knowledge networks	*Nodes*	*Degree centralization*	*Betweenness centralization*	*Eigenvector centralization*
Aviation market	55	0.42	0.10	0.41
Aviation techno.	55	0.24	0.03	0.38
Space market	28	0.32	0.08	0.36
Space techno.	28	0.34	0.09	0.32

Table 5: Comparison of network characteristics

Fokker: rankings among firms	*Degree Centrality*	*Betweenness Centrality*	*Eigenvector*	*Closeness*
Aviation market[1]	1	1	1	1
Aviation techno.[1]	3	2	12	5
Space market[2]	2/1	6/1	5/1	7/1
Space techno.[2]	2/1	2/1	10/1	10/1

[1] Aviation successor [2] Aviation successor / Space successor

Table 6: Position of former Fokker firms

Market / techno.	Firms	Research	Universities
Research	-2.56**/-0.27**		
Universities	-0.82**/-0.11**	0.17**/0.15**	
Association	-0.26**/-0.17**	-0.09/0.10	-0.18**/0.05

Mean difference of degree centrality. Similar results are obtained for betweenness, eigenvector, and closeness centrality.[4]
Significance based on Wilcoxon test.

Table 7: Aviation, Differences in network position

Market / techno.	Firms	Research	Universities#
Research	-0.20** /0.17**		
Universities#	-0.12/-0.28	-0.08/-0.11	
Association#	-0.04/-0.02	0.16/0.15	0.07/0.26

Mean difference of degree centrality. Similar results are obtained for betweenness, eigenvector, and closeness centrality.
Significance based on Wilcoxon test.

Table 8: Space, Differences in network position

[4] The presence of a large number of isolates biases the network characteristics of the Aviation industry. This is the reason why we use the mean instead of the median for the network variables because the mean gives more weight to few observations with large positive values.

Variables	*Mean difference: bridge – no bridge organizations*[1]	
Age	38.5	
Employment	772.5[*]	
Share of scientists	2.5	
Share of engineers	23	
Importance outside knowledge	10	
Recruit from university	3.5	
Recruit from technical institute	1.5	
Share with bachelor degree	8.5	
	Technological network[2]	Market network[2]
Degree centrality	0.17[***]	0.18[***]
Betweenness	0.03[***]	0.05[***]
Eigenvector centrality	0.18[***]	0.18[***]
Closeness	0.04[***]	0.02[***]
# Aviation links	3.75[***]	4.27[***]
# Space links	2.63[***]	2.5[***]
# Links to hybrid organ.	6.57[***]	6.3[***]

[1] Only non-profit bridge organizations considered.
[2] All bridge organizations considered.
Wilcoxon test used for significance.
All numbers based on joined network of aviation and space

Table 9: Differences between bridging and not-bridging organizations

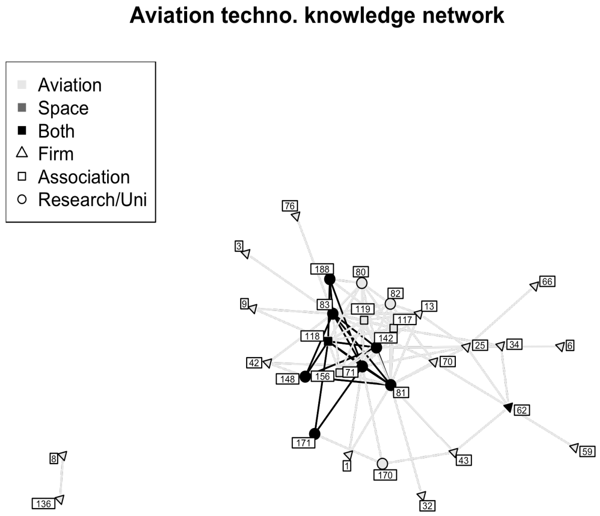

Figure 1: Aviation technological knowledge network

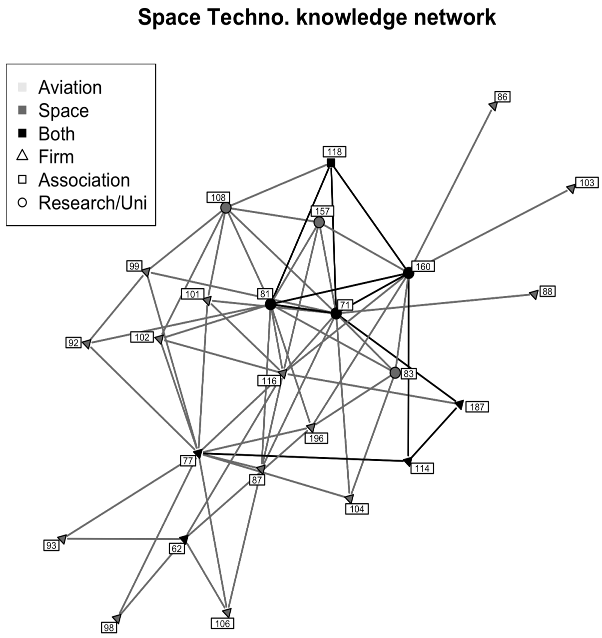

Figure 2: Space technological knowledge network

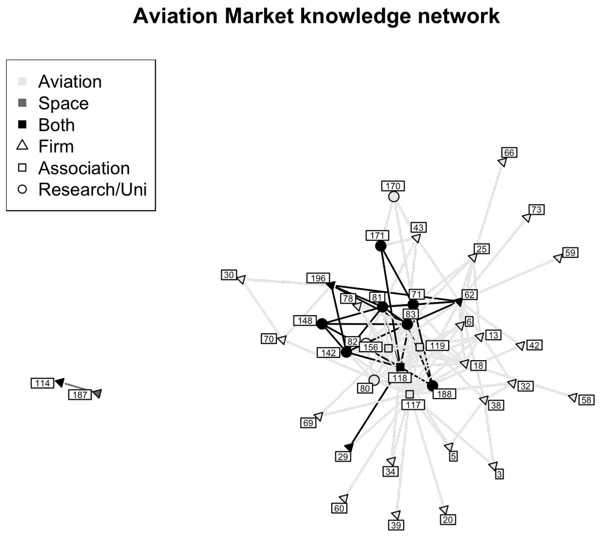

Figure 3: Aviation market knowledge network

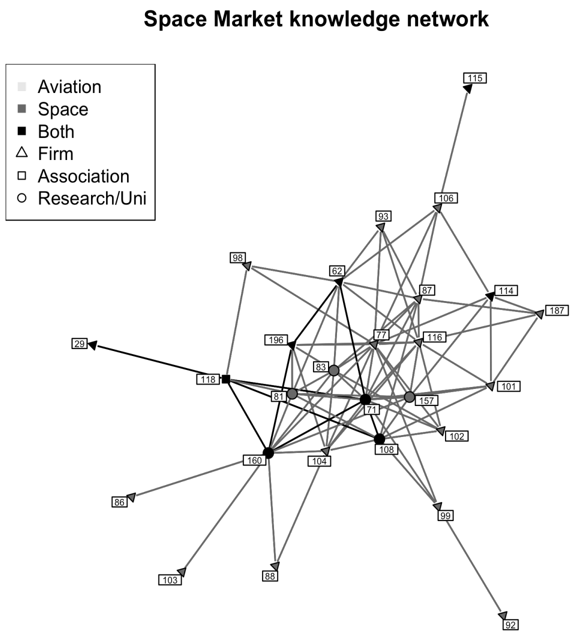

Figure 0: Space market knowledge network

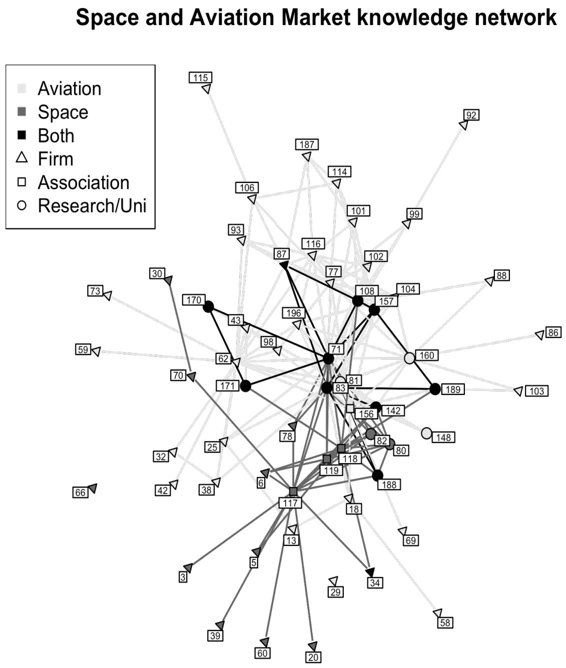

Figure 5: Space and Aviation market knowledge network

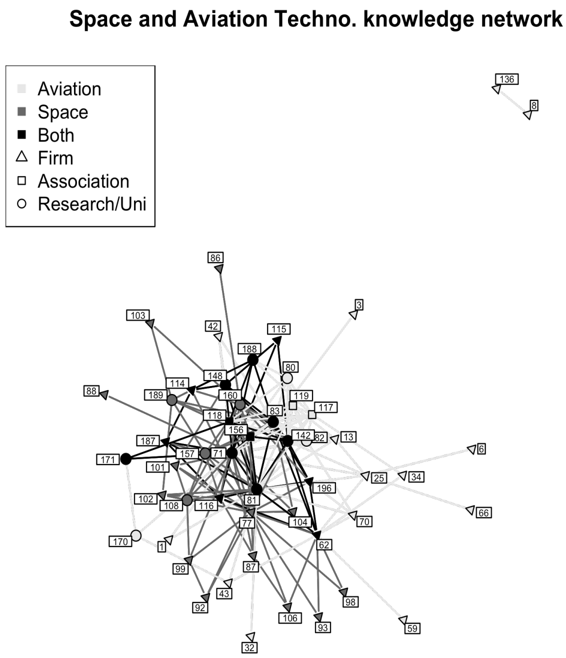

Figure 6: Aviation and Space technological knowledge network