Commercialisation of technology innovations: an empirical study on the influence of clusters and innovation networks

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Abstract: The current body of literature offers contradictory results concerning the role of clusters and innovation networks in the commercialisation of high technology. Whereas several previous studies verify the overall beneficial effects of cluster membership for knowledge-intensive firms, others report that clusters have only little or no influence on technology firms' economic success. The major purpose of this study is therefore to conduct a comparative analysis between small and medium-sized firms within and outside clusters with regard to the commercialisation of their innovations in the emerging nanotechnology sector. Our results reveal several differences in the commercialisation process and activities between firms within and outside of nanotechnology clusters.

Keywords: technology cluster; commercialisation strategies; nanotechnology; cooperation; intellectual property rights; complementary assets; search and bargaining costs.

Reference to this paper should be made as follows: Fiedler, M. and Welpe, I.M. (2009) 'Commercialisation of technology innovations: an empirical study on the influence of clusters and innovation networks', *Int. J. Technology Management*, Vol. x, No. x, pp.xxx–xxx.

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1 Introduction

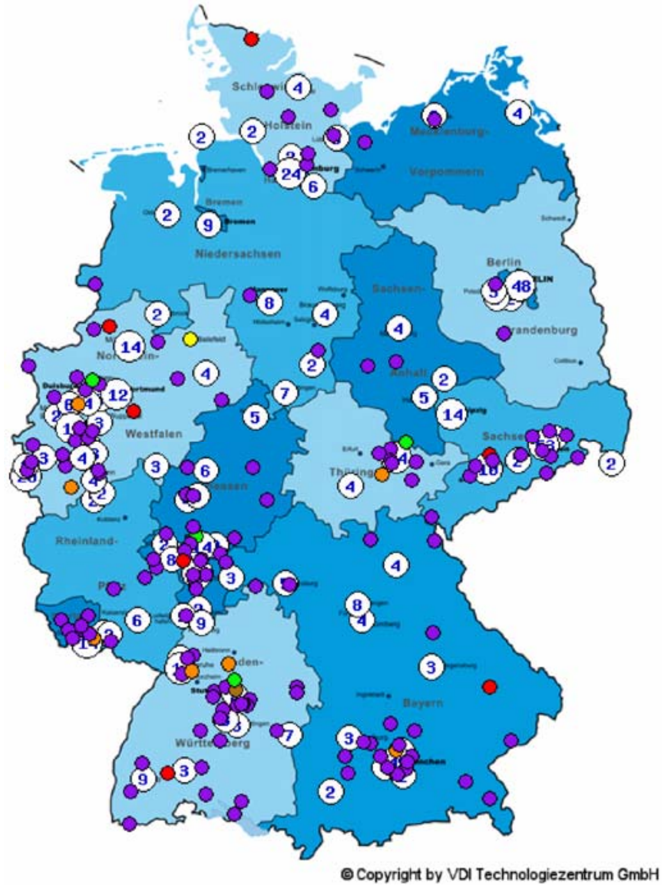
It is widely recognised in the economic literature that the performance of a national economy in terms of innovation and productivity is not only the result of its basic research capabilities and inventions (Gay and Dousset, 2005). It is also strongly influenced by its ability to exploit these inventions commercially and develop them into products (Debackere and Veugelers, 2005). Understanding how scientific knowledge translates into commercially viable products in the marketplace is therefore an important research issue (e.g., Arora et al., 2001; Arrow, 1962; Gans and Stern, 2003; Goldfrab and Henrekson, 2003; Sobrero and Roberts, 2002) and it is common for inventors, policy makers and entrepreneurs to underestimate the difficulty of commercialising science and technology (Bercovitz and Feldman, 2007; Waitz and Bokhari, 2003).

Nanotechnology has emerged from recent scientific advances, which marketers and investors regard as having great commercial potential. For example, it is estimated that the worldwide nanotechnology market will be worth more than US$ 1 trillion in 10–15 years (Roco, 2000). Consequently, policy planners have looked with great interest at this technology, and the transfer of its scientific and technological know-how into valuable economic activity has become a high priority on many policy agendas (Bozeman et al., 2007; Debackere and Veugelers, 2005). Identifying ways to successfully commercialise scientific discoveries is especially important in Europe where the gap between high levels of scientific performance and these discoveries' minimal contributions to industrial competitiveness and new venture entrepreneurship appears particularly large (EC, 2002). This lack of commercial exploitation of technology innovations is also known as the 'European paradox' and empirical evidence suggests that the flow of basic research towards economic exploitation is substantially hindered in Europe (Kaiser, 2003; EC, 2002).

One possible way of supporting technology innovators with their commercialisation is through government support measures and structural policy, such as science parks, clusters and innovation and knowledge networks (Guan and Ma, 2007; Stuart et al., 2007; Narula and Santangelo, 2009; see Beaudry and Schiffauerova (2009) for a review). To a certain extent, this school of thought contradicts the current and increasing globalisation and new internet-based communication technologies that have made global collaboration possible at very low costs, and thus makes the advantages of geographical proximity seem relatively unimportant (Lublinski, 2003; Teck-Young, 2004). Despite the fact that technology-enabled collaboration and communication make cooperation more effortless than before, an inclination towards cluster forming can be observed in technology-intensive sectors (Fuchs and Koch, 2005, p.253; Feldman, 2003, p.314; Henn, 2004, p.5). The distribution of nanotechnology companies in Germany already reveals unmistakable tendencies towards cluster forming, both regarding small and medium-sized companies as well as participant institutions such as, e.g., universities (Figure 1). Figure 1 provides an overview of the local distribution of small and medium-sized nanotechnology firms and related institutions in Germany.

The previous body of literature provides different predictions regarding clusters' role and their success. For example, recent empirical studies on the role of clusters in the commercialisation of science suggest that producers, users, suppliers and public authorities' interactions (Debackere and Veugelers, 2005) are of crucial importance as "technology entrepreneurship is the process of many", and the skills and resources required to take an idea from its inception to commercial use have to be mobilised by drawing upon resources of actors from multiple domains (Bonaccorsi and Thoma, 2007; Garud and Karnoe, 2003). Other generic benefits of clusters are access to employees, suppliers, specialised information, institutions and public goods (Häussler and Zademach, 2007; Steinle and Schiele, 2002; Swann and Prevezer, 1996). Clusters can furthermore improve marketing and enhance the reputation of a particular field. Clusters are also more attractive for customers and investors and promote complementary industries such as, for instance, tourism and transportation. Finally, clusters can be highly motivating and make measurement and comparison of performance between firms feasible (Porter, 1998a).

Figure 1 Overview of the local distribution of German small and medium-sized nanotechnology firms and related institutions (see online version for colours)



② = Conglomerate of more than one firm/institution.

Yellow = Networks.

Orange = Research Centre.

Red = Universities.

Lilac = SME.

Brown = State funded institutions.

Green = Financier.

However, the growing body of literature on the value of clustering for technology-based SME clusters does not provide clear evidence of clusters' effectiveness and is also somewhat contradictory (Hendry et al., 2000). Recent empirical evidence has questioned the significance of regional clustering of new technology-based firms (Lasch et al., 2007). For example, Audretsch (2001) remarks that not all clusters are equally successful at producing commercial success and that many regions have tried to develop a high-technology industry but that many attempts have not proven economically successful. For example, despite clustering, significant commercially successful innovative activities did not emerge in biotechnology in the Lombardy province in Italy (Orsenigo, 1988). Keeble (1994) observes that large and small firms in high-tech industries have been "markedly more dispersed than clustered", which is particularly true of small firms. Moreover, even when firms are concentrated, they may have more relationships outside their domain than within it (Garnsey and Cannon-Brookes, 1993). Audretsch and Feldman (1996) analysed high-tech sectors and showed that in sectors where innovation is based on science, geographic links are weaker. Surprisingly little attention has been devoted to clarifying these contradictory results in previous studies, consequently, the role of clusters in the commercialisation of science-based and technology-intensive nanotechnology sectors is still not well understood. Lasch et al. (2007) find that there is an optimal level of geographical concentration for high technology firms and that 'overagglomeration' can turn into diseconomies.

Furthermore, there has also been minimal research with regard to the organisation of commercial activities within clusters in the nanotechnology industry. To date no research has been found that examines cluster membership's influence on the commercialisation process of nanotechnology innovations that simultaneous compares firms within and outside a cluster. Consequently, there is no knowledge on exactly how the relationships necessary to commercialise an innovation operate within a cluster. Finally, nanotechnology research confirms that the operation of a nanotechnology cluster occurs within geographic proximity. Unlike many other industries, such as IT and electronics, which tend to cluster across geographic regions, the nanotechnology industry focuses on site-specific characteristics. This has a significant impact on nanotechnology clusters' operation and on their influence on technology innovations' commercialisation. For instance, the significant amount of face-to-face contact between members may enable them to access important resources and information more easily (Porter, 1998a).

In order to address the aforementioned research questions, this study is aimed at clarifying: *What influence does belonging to a cluster have on nanotechnology innovations' commercialisation?*

We analyse this question with special emphasis on the nature and characteristics of nanotechnology as a strongly science-based technology. The overall goal of this study is to shed more light on the 'black box' of what happens between science's basic discoveries and their successful transformation into financially successful business applications. The focus of the present analysis will be on the practices that the previous body of literature identified as fostering and hindering the exploitation of basic research. Technology clusters' contribution as a mediating institution to improve the link between science and innovations will be the crux of our analysis.

Empirically, this research is based on a quantitative, in-depth comparison between nanotechnology SMEs inside and outside nanotechnology clusters. Based on Marshall's (1920), Krugman's (1991) and Porter's (1998b) work, we derive 17 hypotheses regarding the commercialisation of nanotechnology innovations. We hypothesise that the commercialisation process and outcome of firms inside a technology cluster differs from the commercialisation process and outcome of firms outside of one. All hypotheses were confirmed.

Our results show several differences between firms inside and outside of clusters. Firstly, firms within clusters are more dependent on other companies' complementary assets to commercialise their innovation. Secondly, as expected, firms within a nanotechnology cluster show significantly higher cooperation with firms in the geographical proximity and use significantly more resources that are geographically close for their nanotechnology innovation's commercialisation than firms that are not located within a cluster. Thirdly, firms within nanotechnology clusters have more informal, personal and face-to-face contact during the commercialisation process. Furthermore, firms inside a nanotechnology cluster find it easier to cooperate with other actors and to license their nanotechnology innovations. Finally, firms within a nanotechnology cluster have significantly higher sales than firms outside one.

Our examination of clusters' influence on technology commercialisation contributes to both the technology management literature and the literature on knowledge and innovation networks. We also contribute to the emerging body of literature on the commercial potential of nanotechnology innovations by developing a conceptual model and testing our hypotheses with regard to clusters' influence on the development of commercial applications' development. Further, as we study clusters' role in the commercialisation of technology-intensive innovations, we seek to address the gap in the existing research literature on the influence of geographical agglomerations by comparing SMEs within and outside technology clusters.

The rest of the paper is organised as follows: The next section defines the phenomenon of cluster influence on commercialisation, reviews the existing literature and develops hypotheses with regard to the differences between firms that are allocated within a cluster and firms that are not. Following the data and methodology section, we present the empirical results. The final section concludes with a discussion and suggestions for future research.

2 Theory and hypotheses

2.1 Clusters, agglomerations and networks

There is a long and well-established tradition with regard to clusters, industrial districts and regional innovation systems as favoured locations for the production of goods, services and knowledge (Audretsch and Feldman, 1996). Broadly speaking, their common underlying denominators are a favourable regulatory regime, advanced research universities connected to the industry, a flexible and mobile work force, mechanisms for maintaining global linkages, formal associations and informal mechanisms.

Two of the most prominent concepts are knowledge clusters and innovation networks. Knowledge clusters are agglomerations of co-specialised, mutually complementary and reinforcing assets in the form of 'knowledge stocks' and 'knowledge flows' that catalyse, accelerate and support the creation, diffusion, sharing, absorption, and use of co-specialised knowledge assets (Carayannis et al., 2006; Keilbach, 2000; Yusuf, 2008). Innovation networks are a real and virtual infrastructure and infra-technologies that serve to nurture creativity, trigger invention and catalyse innovation in a public and/or private domain context (Carayannis et al., 2006; Heinze and Kuhlmann, 2008).

Although clusters and knowledge networks are slightly different concepts, both refer to agglomerations with a myriad of informal contacts, gate-keeping processes and personal industry-science networks (Debackere and Veugelers, 2005). These informal contacts and human capital flows are ways of exchanging knowledge between enterprises and public research that are more difficult to quantify, but nevertheless extremely important and often a catalyst for instigating further formal contacts (Allen, 1977; Matkin, 1990; Hessels and Lente, 2008).

Clusters and agglomerations' advantages for commercialisation can potentially be found on the demand and supply side (Swann and Prevezer, 1996): According to Krugman (1991) and Marshall (1920) on the supply side, specialised labour, specialised intermediate inputs and spillovers of knowledge attract firms to cluster (Tappeiner et al., 2008; Zucker et al., 2007). Spillovers of knowledge are considered to be of particular importance for high-technology industries (Häussler and Zademach, 2007). On the demand side, some high technology sectors' strength comes from clustering with important users in other industries (von Hippel, 1998), or market share gained by moving closer to established firms. However, there are also costs associated with locating in a cluster. On the supply side, these include congestion costs and competition with regard to input markets (Rogers and Larsen, 1984). On the demand side, there is also the cost of locating to a more competitive output market (reduced profitability).

2.2 Importance of local agglomerations for the nanotechnology sectors

Often the literature on clustering implicitly assumes agglomeration to be a general phenomenon applying to most industries. Empirical evidence, however, shows that not all industries are presently in the process of clustering, or at all affected by it (Steinle and Schiele, 2002). Previous literature has identified a number of conditions that need to be fulfilled in order for the commercialisation process to profit from clustering. Common reasons for clustering is the expectancy associated with clustering in industries that are characterised by the availability of implicit knowledge, the presence of network-innovations, rapid transformation, and, particularly, the involvement of multiple actors with distinct competencies in the process of innovation (Steinle and Schiele, 2002). Especially, the emerging character of nanotechnology, the multitude of necessary competencies as well as its yet ambiguous application potential makes clustering an attractive and important option for firms in this area.

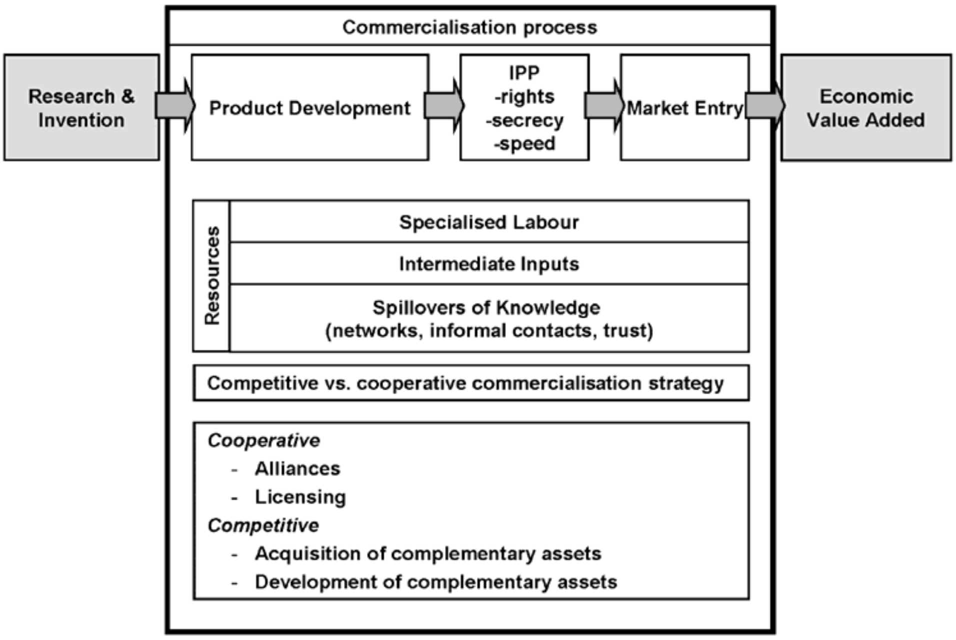
2.3 Conceptual model and hypotheses

Although economic geographers were already paying attention to geographical proximity's significance for an individual company in the 19th century, it is the economist Alfred Marshall who is generally regarded as the founder of the modern concepts regarding the effectiveness of geographical proximity. Marshall (1920) deals with the topic of industries' location and with the factors that influence this choice (Keilbach, 2000, p.42). As identified by Marshall, the three most important reasons for industry's concentration on a certain location, stem from the availability of skilled workers as well as intermediate goods, and the easy transmission and discussion of new ideas and improvements, whether in products, technologies, or organisation (Baptista, 1998, p.17).

In this context, one therefore also speaks of the 'external economies' of industrial clustering, or of 'economies of agglomeration' (Gordon and McCann, 2000, p.516). These agglomeration effects are later further refined and differentiated as 'Marshall-Arrow-Romer externalities' and 'urbanisation economies', with the former describing industry-specific external effects in a specific region and the latter generally positive external effects produced by the urban environment's impact (Feldman, 1999, p.14).

Figure 2 presents this study's conceptual model from which we derive our hypotheses. Following Marshall (1920) and Krugman (Feldman, 1999), specialised labour, specialised intermediate inputs and spillovers of knowledge are key factors of cluster forming (Swann and Prevezer, 1998, p.1142; Carayannis et al., 2006), and are the crux of our model and empirical analysis. We analyse the commercialisation process of SMEs' nanotechnology inventions from the basic scientific discovery and invention up to the successful economic exploitation. We compare product development, the choice of intellectual property protection and nanotechnology SMEs' form of market entry within and outside nanotechnology clusters.

Figure 2 Conceptual model: the commercialisation value chain



2.3.1 Specialised labour within a cluster

Entrepreneurial ventures have to draw on appropriate strategic human resources to devote themselves to entrepreneurial behaviours and activities that pursue success. In the nanotechnology field, specialised labour can be found for the commercialisation of an innovation at service providers, suppliers and competitors (Prevezer, 1998, p.130; Carayannis and Alexander, 2004). The following hypothesis can therefore be postulated:

Hypothesis 1: Companies in a cluster cooperate more with service providers, suppliers and competitors that are within the geographical proximity with regard to commercialisation than those companies that do not belong to a cluster.

2.3.2 Specialised intermediate inputs

Since the commercialisation of nanotechnology is comparatively new and the small and medium-sized enterprises are likewise mostly relatively young, a large number of resources that are required for commercialisation might not be available in enterprises. Know-how, marketing/sales and after-sales services are particularly important with regard to specialised intermediate inputs in the relevant commercialisation context (Porter and Stern, 2001, p.29).

The estimation of the quality that such specialised, mainly intangible, resources could yield, often demands much adaptation, agreement, handling, control and adjustment costs. Hence geographical proximity appears to be transaction cost reducing (Porter, 1998a, p.215; Angel, 2002, p.339). In respect of a cluster's specialised intermediate input, we presume the following relationships:

Hypothesis 2a: Enterprises in a cluster are more inclined to obtain complementary resources from the geographical proximity than enterprises that do not belong to a cluster.

Hypothesis 2b: Enterprises in a cluster can access resources for commercialisation that are more specialised and better adapted to their innovation than enterprises that do not belong to a cluster.

Hypothesis 2c: Enterprises in a cluster are more dependent on the resources of other enterprises for commercialisation than enterprises that do not belong to a cluster.

Hypothesis 2d: Enterprises in a cluster have fewer resources for commercialisation at the moment of readiness for the market than enterprises that do not belong to a cluster.

2.3.3 Spillovers of knowledge

Knowledge transfer is not only crucial in the research and development sectors, but also for commercialisation (Oerlemans and Meeus, 2005, p.92). With regard to the commercialisation of innovations in the nanotechnology sector, Knol emphasises that it requires external knowledge from the organisational environment to commercialise technology successfully (Knol, 2004, p.2). 'Knowledge spillovers' indicate positive external effects produced by the geographical proximity (Darby and Zucker, 2003, p.16). They are granted an important role as a mediator during the transfer of knowledge and in technology transfer (Baptista, 2001, p.43). These knowledge streams, which are absorbed by enterprises, then again confirm their positive effect on the enterprise's competitive advantage (Decarolis and Deeds, 1999, p.955), which can positively influence the introduction of innovations (Bönte, 2004, p.275). Knowledge from the geographical proximity can therefore benefit a company as it can have a supportive effect during knowledge transfer: "Still, certain types of information and knowledge exchange continue to require regular and direct face-to-face contact" (Owen-Smith and Powell, 2004, p.17).

It is the face-to-face interaction between incrementally innovating actors that allows the exchange of implicit knowledge. "Put simply, the more tacit the knowledge involved, the more important spatial proximity is between the actors taking part in the exchange" (Maskell and Malmnerg, 1999; Chen, 2009). Geographical proximity and associated face-to-face contacts can therefore be considered as essential for the transfer of knowledge as well as for knowledge spillovers (Oerlemans and Meeus, 2005, p.95; Swann and Prevezer, 1998, p.7).

A prerequisite for knowledge spillovers to occur is, however, that there should be transparency within the cluster and that the innovator can protect himself, either through concealment or intellectual property rights, against an undesired exploitation of his innovation by other participants in the cluster. A cluster's member organisations are aware of what membership of such a system entails. They adhere to a common set of rules. These 'conventions' can be enforced, as members can be excluded and thus be deprived of the information flow only accessible to those that are members (Steinle and Schiele, 2002). Unlike in virtual communities, members of geographically rooted clusters cannot simply choose to join another group as soon as they have ruined their reputation. Consequently, the costs associated with a bad reputation are so high in a cluster that collaboration based on trust is essential. An actor's information as well as opportunistic behaviour spreads is easily disseminated within a cluster, so that breaking the conventions would endanger all relationships with other cluster members (Steinle and Schiele, 2002). Consequently, the following hypotheses can be derived:

Hypothesis 3a: Enterprises in a cluster have more informal contacts than companies that do not belong to a cluster.

Hypothesis 3b: Enterprises in a cluster have more personal contacts than companies that do not belong to a cluster.

Hypothesis 3c: Enterprises in a cluster trust one another more than companies that do not belong to a cluster.

Hypothesis 3d: Enterprises in a cluster exchange more important knowledge regarding their commercialisation than companies that do not belong to a cluster.

Hypothesis 3e: Enterprises in a cluster have more networks than companies that do not belong to a cluster.

Hypothesis 3f: Enterprises in a cluster collaborate more frequently than companies that do not belong to a cluster.

Hypothesis 4: Enterprises in a cluster move in a more transparent environment than those companies that do not belong to a cluster.

Hypothesis 5: Enterprises in a cluster judge property rights as being more meaningful than companies that do not belong to a cluster.

Since firms establish themselves within a technology cluster to gain competitive advantage (Carayannis et al., 2006), we expect that the positive externalities of cluster membership, besides the advantages of specialised labour, specialised intermediate inputs and spillovers of knowledge, are also directly reflected in improved opportunities for commercialisation. One could presume that companies that establish themselves in a cluster also specifically do so because they are specifically interested in their innovation's commercialisation and anticipate lower search and bargaining costs with regard to a possible commercialisation partner. Also, it has been shown that in industries in which clusters are commonly formed, being outside a cluster leads to a 'periphery discount' on returns (Steinle and Schiele, 2002).

> *Hypothesis 6a: Companies in a cluster regard the commercialisation of their innovation for their enterprise's financial survival as more important than enterprises that do not belong to a cluster.*
>
> *Hypothesis 6b: Companies in a cluster have less expenditure with regard to licensing than enterprises that do not belong to a cluster.*
>
> *Hypothesis 6c: Companies in a cluster are more successful with licensing than enterprises that do not belong to a cluster.*
>
> *Hypothesis 6d: Companies in a cluster have better sales with nanotechnology innovations than enterprises that do not belong to a cluster.*

3 Data and method

3.1 Sample, survey design and data collection

We obtained data through a pre-tested survey of small and medium-sized nanotechnology firms in Germany from November 2005 to January 2006 – as well as 20 follow-up telephone interviews from November 2008 to January 2009. According to the European Union's classification standards for firm sizes, small and medium-sized firms are those with less than 250 employees (European Commission, 2004). The survey approach is appropriate because publicly available financial information does not provide the level of detail that we needed for this study, including fine-grained information concerning these firms' strategy and characteristics.

All data were therefore self-reported, but previous research supports the reliability and validity of self-reported measures in this field (Brush and Vanderwerf, 1992; Gans et al., 2002; Orpen, 1993), especially if other sources are unavailable, as in the study of SMEs, which are often young and privately held small firms (Dess and Robinson, 1984; Lechner et al., 2006). Furthermore, managerial assessment is an opportunity to gather information on firm characteristics and development's multiple dimensions. To ensure that a high proportion of the answers were valid, the questionnaires were addressed to the CEOs and/or founders of the firms, using a key informant approach (Brush and Vanderwerf, 1992; Huber and Power, 1985). CEOs and founders are considered the single most knowledgeable and valid information sources, especially regarding strategic information (Glick et al., 1990). Our survey results reveal that 35% of respondents are founders, 45% are members of the top management team board and 20% are members of the company management, which indicate that the answers are highly valid. We are, of course, aware of the trade-off between objective data collected from secondary sources at various different times and data richness derived from primary sources; given the unavailability of sufficient data, we therefore had to opt for a survey approach of self-report data (Lyon et al., 2000).

We are also aware that all questionnaire data is susceptible to Common Method Bias, which can result in misleading conclusions (Campbell and Fiske, 1959), and we therefore took procedural steps, as suggested by Podsakoff et al. (2003), to control method bias. We first separated the measurement criterion and the predictor variable proximally and psychologically. Secondly, we guaranteed the protection of respondents' anonymity and thus reduced evaluation apprehension. Thirdly, we paid special attention to the wording of the items to avoid ambiguity or complicated syntax, and kept it simple, specific and concise. Furthermore, we asked whether the respondents' firms were part of a nanotechnology cluster right at the end of the questionnaire in order to prevent respondents matching their answers to whether or not there were part of a cluster.

In addition, we examined both the individual variables as well as the relationships between them prior to the statistical analyses, following the procedure recommended by Hair et al. (1998). We paid particular attention to missing data and the identification of outliers, and tested the assumptions for the use of multivariate data (Hair et al., 1998).

In our empirical investigation, we surveyed 336 small and medium-sized nanotechnology firms, thereby addressing the total German population of such companies at the time of the survey. Our survey of the existing nanotechnology firms was based on the European nanotechnology gateway 'nanoforum.org', which includes a comprehensive database of all firms in Europe. Nanoforum.org is a pan-European nanotechnology network founded by the European Union under the Fifth Framework Programme (FP5) to provide information on European nanotechnology efforts and support to the European nanotechnology community. Several sources recommend the nanoforum database as a reliable source for identifying firms active in nanotechnology, among them the Federal Ministry for Education and Research and the VDI (the Association of German Engineers). The nanoforum website provides all users with access to a comprehensive database of European nanoscience and nanotechnology organisations. From the nanoforum database, we selected all firms registered in Germany. In a second step, we validated the information in the nanoforum database by contacting the firms to validate whether they were still in business and considered themselves as active in nanotechnology. Finally, we also collaborated with other researchers who had identified firms in the nanotechnology field. We feel that our database is sufficiently representative (Hair et al., 1998), since to the best of our knowledge it does not contain any *systematic* omissions.

For the mailing process, we used the total design method as suggested by Dillman (1978). The final number of completed surveys for small and medium-sized firms was 98, translating into a response rate of 29%.

3.2 Imputation

When data is collected by questionnaire, subjects may be unwilling or unable to respond to some items, or may fail to complete sections of the questionnaire due to a lack of time or interest (Schafer and Olsen, 1998). These types of lapses, though inevitable, are unintended and uncontrollable by the researcher. Traditional approaches to dealing with missing data include list-wise deletion, pair-wise deletion, mean substitution and the inclusion of an indicator variable. However, none of these constitutes an optimal solution for missing values, except under special circumstances (Acock, 2005), as all of them can result in biases in a positive or negative direction, can increase type II errors, reduce the efficiency of estimates, and neglect correlations and β weights, and thus jeopardise the validity of a study (Allison, 2002; Little and Rubin, 1987). Many of the data sets used in papers appearing in management journals have serious problems with missing values, and often do not report how the researchers have dealt with these. Over the past decades, numerous strategies have been introduced that are innovative improvements traditional approaches. The most common alternative is to impute values for missing data (Schafer and Graham, 2002). To impute complete data for our sample, we used the EM algorithm of NORM (Little and Rubin, 1987), a software program designed to assist researchers in following the multiple imputation guidelines outlined by Rubin (1987), and followed the procedures outlined by Schafer and Olsen (1998). The reader is referred to Acock (2005) for a detailed description of the advantages of this approach and the EM algorithm.

3.3 Variables

Table 1 reports a summary of the statistics of the variables that we used in this study.

Table 1 Descriptive statistics

	N	*Min.*	*Max.*	*Median*	*Mean*	*S.D.*
Cooperation with suppliers	98	1	7	2.00	3.08	2.18
Cooperation with service providers	98	1	7	3.00	3.14	2.02
Cooperation with competitors	98	1	5	1.00	1.50	0.91
Access to resources in geographical proximity: inputs	98	1	7	2.00	2.77	2.17
Access to resources in geographical proximity: know-how	98	1	7	2.00	2.47	1.81
Access to resources in geographical proximity: marketing/sales	98	1	6	1.00	2.17	1.67
Access to resources in geographical proximity: after-sales-service	98	1	7	1.00	1.96	1.54
Specialised resources: innovation-specialised know-how	98	1	7	3.00	3.70	2.34
Dependency on complementary assets	98	1	7	5.00	4.44	2.15
Informal contacts	98	1	7	3.00	3.07	1.77
Personal face-to-face contacts	98	1	7	3.00	3.40	1.97
Mutual trust	98	1	7	4.00	3.41	1.90
Knowledge exchange	98	1	7	3.00	3.12	1.79
Network building	98	1	7	2.00	2.95	1.88
Cooperation building	98	1	7	3.00	3.12	1.80
Transparency	98	1	7	6.00	5.61	1.68
Intellectual property protection	98	4	21	16.00	15.33	3.68
Importance of commercialisation	98	1	7	6.00	5.49	1.85
Effort to license out	98	1	6	2.00	3.28	2.35
Licensing success	98	1	7	5.00	4.84	2.34
Sales in thousand € in 2004	98	20	800.000	2300.00	51.826.28	121.670.09

N = 98. Minimum and maximum values, arithmetic means and standard deviations are displayed.

Missing values were imputed using the EM algorithm of NORM (See Schafer and Olsen (1998), Acock (2005), Allison (2002), Little and Rubin (1987) and Schafer and Graham (2002)) for an overview.

Cluster membership

We asked the respondents to indicate whether they were part of a nanotechnology cluster.[1] 75.5% said that they were not and 24.5% indicated that they were.

Cooperation with suppliers, service providers, competitors

On a 1–7 Likert scale, the respondents indicated the extent to which they cooperated with suppliers, service providers and competitors regarding their nanotechnology innovation's commercialisation.

Access to resources in the geographical proximity

The respondents indicated on a 7-point Likert scale the extent to which they took advantage of the following resources in the geographical proximity to commercialise their innovation at the time of market readiness: inputs, manufacturing equipment/know-how, marketing/sales and after-sales services.

Specialised resources

The extent to which the main cooperation partner's resources (know-how) had to be adjusted to their innovation in the commercialisation process was indicated on a 7-point Likert scale.

Dependency on complementary assets

We asked the respondents to indicate the extent to which they depended on other companies' resources to commercialise the innovation on a 7-point Likert scale.

Informal contacts

The respondents indicated on a 7-point Likert scale the extent to which their commercialisation was influenced by informal contacts.

Personal contacts

The extent to which their commercialisation was influenced by increased personal, face-to-face contacts was indicated on a 7-point Likert scale.

Mutual trust

We asked the respondents to indicate the extent to which their commercialisation was influenced by the establishment of mutual trust on a 7-point Likert scale.

Information/knowledge exchange about commercialisation

The respondents indicated the extent to which their commercialisation was influenced by the exchange of information/knowledge about the commercialisation on a 7-point Likert scale.

Network building

We asked the respondents to indicate the extent to which their commercialisation was influenced by the establishment of networks on a 7-point Likert scale.

Cooperation building

The extent to which their commercialisation was influenced by the establishment of cooperations was indicated on a 7-point Likert scale.

Transparency of environment

We asked respondents to indicate the company environment's level of transparency on a 7-point Likert scale.

Importance of intellectual property protection

The respondents indicated the importance of intellectual property protection measures (intellectual property rights, trade secrecy) for the commercialisation of their nanotechnology innovation on a 7-point Likert scale.

Importance of commercialisation

The respondents indicated the extent to which their nanotechnology innovation's successful commercialisation was necessary for the company's survival on a 1–7 Likert scale.

Effort to license

We asked the respondents to indicate the effort it took to license their innovations on a 7-point Likert scale.

Success of licensing

We asked the respondents to indicate how successful their licensing activities had been on a 7-point Likert scale.

Sales with nanotechnology innovation

The respondents indicated what their revenue for their nanotechnology innovations had been in 2004.

4 Results

4.1 Descriptive results

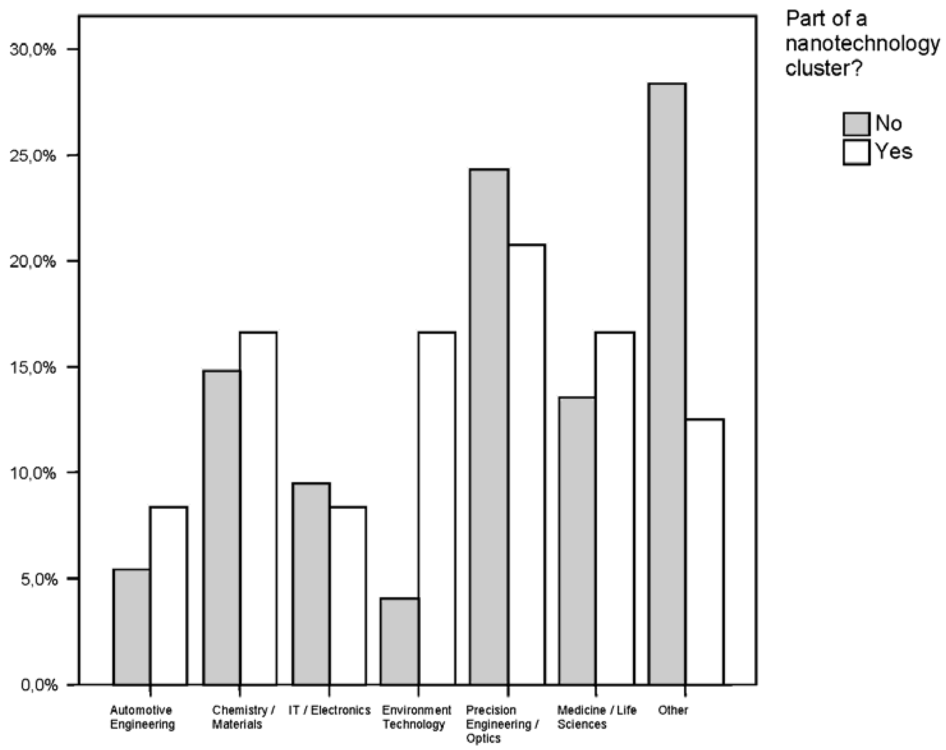
Since nanotechnology is a new and emerging field, few studies have so far looked explicitly at the commercialisation activities of nanotechnology SMEs. The following therefore reports a number of basic results regarding the commercial importance of nanotechnology, nanotechnology firm characteristics, the commercialisation activities of nanotechnology SMEs within nanotechnology clusters and networks in Germany, which is one of the larger players in the nanotechnology field (Porter, 1998b).

Asked what is commercially interesting about the commercialisation of nanotechnology inventions, the majority of companies from both samples mentioned that nanotechnology makes *miniaturisation* possible, which in turn offers new possibilities in the areas of:

- production processes such as new ways of constructing IT/wafer structures, optics and surface coating (thus offering less friction, abrasion and improved scratch resistance)
- new products and applications, based on materials' new attributes such as self-cleaning/easy-to-clean, catalysis, nano-composits, nano-imprint machines, in-vivo marking, lithography, metrology, mono-structuring and new ways of drug delivery
- improved possibilities for analytics and measurement on the nanometre scale and increased precision, which paves the way for technological differentiation and new markets.

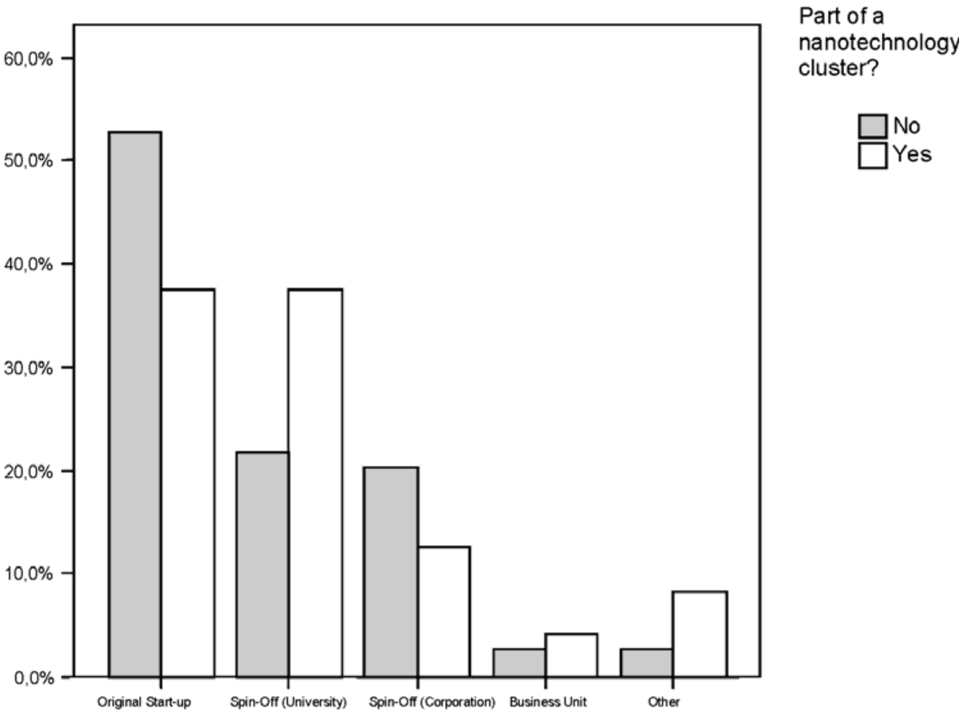
However, many respondents also made it clear that in the present stage of development, nanotechnology mostly offers commercial opportunities to improve existing products and technologies in an incremental way. Radical innovations such as 'nano-bots' were not mentioned by any of the responding firms and some respondents strongly suggested that such revolutionary innovations would not appear on the market within the next ten years. Nanotechnology is a cross-sectional technology and the distribution of the industries in our sample reflects this: SMEs within nanotechnology clusters frequently and largely come from automotive engineering, chemistry and materials management, medicine and life sciences and, especially, from energy and environment technologies. Firms outside clusters come from the IT and electronics as well as the precision engineering/optics and other industries (see Figure 3).

Figure 3 Industries within and outside the nanotechnology cluster



The majority of the firms in our sample developed from start-ups (50%), while 26% are from a university or a research institution, 18% are spin-offs from a company and 3% are a company branch. As Figure 4 reveals, spin-offs from universities and research institutes are over-represented in a cluster, whereas start-ups and spin-offs from corporations and business units and subsidiaries are over-represented outside clusters (see Figure 4).

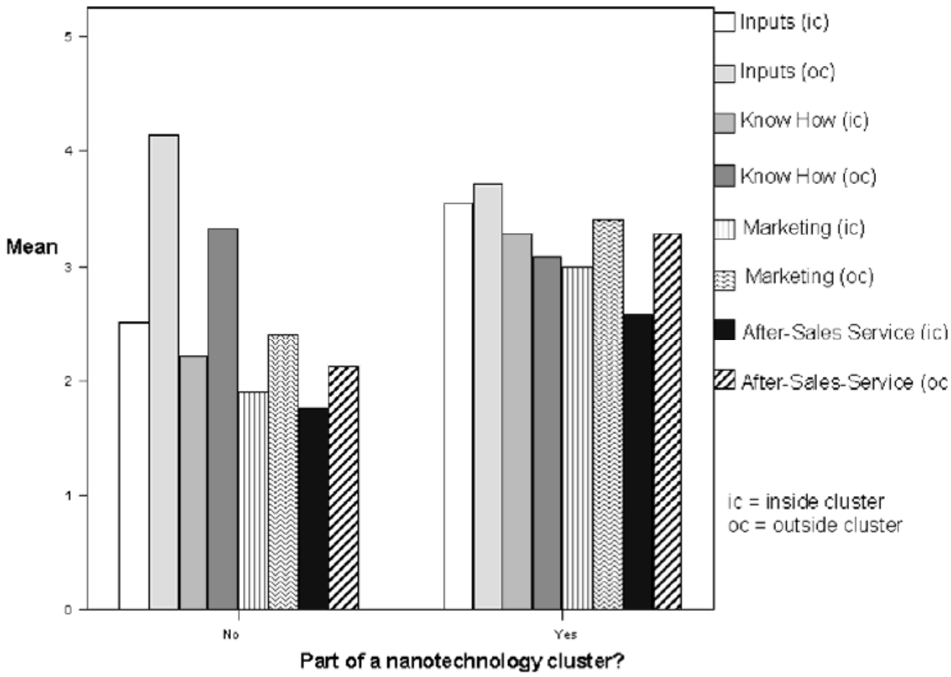
Figure 4 Firm origin



The greater majority (82%) of the firms in our sample already have sales of nanotechnology innovations based on their own research and 20% have already awarded licences for their nanotechnology innovation. This concerns both product innovations (57.1%) and process innovations in the nanotechnology field (42.9%) that took an average of 3.8 years of development until they were ready to be launched on the market. The percentage of nanotechnology innovations to the companies' total sales was on average 54% per year. On average, the firms obtained 9.5 patents and awarded 1.9 licences. SMEs in our sample (in and outside clusters) reported on the importance of their nanotechnology invention's successful commercialisation for their economic survival (Ø 5.51 for SMEs), which indicates the generally high importance of the nanotechnology-based innovations' economic success.

Two-thirds of the respondents indicated in the questionnaire that geographical proximity is important for an innovation's commercialisation. As expected, there are large differences in the number of cooperation partners within geographical proximity. On average, firms within clusters cooperate with 21.2 companies, while firms outside clusters do so with only 2.6 firms. Firms within clusters access resources for commercialisation more strongly, both in respect of resources within the geographical proximity as well as the geographical distance, whereas firms outside clusters primarily access resources within the geographical distance (see Figure 5).

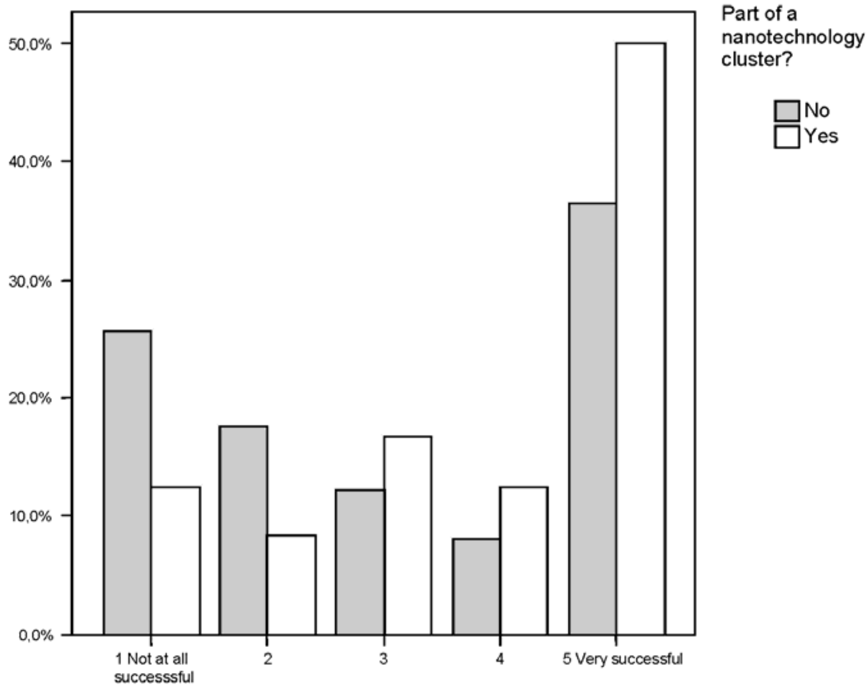
Figure 5 Resources use for commercialisation



In 2006, SMEs in clusters had fewer employees (an average of 75.29) than SMEs outside clusters (an average of 97.76) – this difference is, however, not significant. Asked in what way the geographical proximity in the cluster has influenced their commercialisation, the companies answered that the trust between firms in a cluster as well as the social interaction of the companies' employees has had a particular influence on their commercialisation. It appears that cluster SMEs exchange informal knowledge and practical know-how to a greater degree than firms outside the cluster ($p < 0.001$). Furthermore, SMEs within a cluster are more likely to build a patent portfolio (4.29) than firms outside a cluster (3.74). Companies inside a cluster assess their licensing success higher (5.54) than firms outside a cluster (4.61) (see Figure 6).

Furthermore, SMEs within a cluster to a greater degree indicate that the one-sided exploitation of cooperation could lead to a loss of image (6.17 vs. 5.43, $p < 0.5$) than firms outside a cluster do. Building cooperations with other companies is less laborious for firms inside (4.46) clusters than for firms outside of them (5.03). Companies inside clusters cooperate significantly more with their main cooperation partner on research and development (5.92 vs. 5.11, $p < 0.5$). Companies outside a cluster also cooperate distinctly more with regard to manufacturing facilities and know-how. Other sectors of cooperation (marketing, concessions, after-sales service, reputation/brand name and experience with legal regulations) are similar between companies inside and outside clusters.

Figure 6 Success of licensing



In answering the question how research institutes and universities had contributed to innovation commercialisation, the SMEs indicated that it had especially been access to the universities' expertise and know-how that had been important (3.86), followed by access to specialised employees (3.60) and research-related advice services (3.63). Universities play an outstanding role in recruiting employees within the geographical proximity in comparison to other organisations such as competence centre suppliers, customers, competitors and other companies.

When we called the survey participants three years later and asked them again about the importance of geographical proximity they confirmed the above results by stating that being part of a cluster helps in winning contracts, bundling resources, reaching a critical mass and trusting the partner. Especially small firms stated that they profit from finding partners to manufacture and market the nanotechnology inventions with very little cost and that they rely on word-to-mouth marketing. They also said that clusters help in being more credible in the eyes of the client since it is easier to offer a wider variety of products and services. About two thirds of the telephone interview partners stated that they intend to commercialise their innovation with a stand-alone strategy and want to keep the know-how inhouse but are very dependent on specialised resources from their partners.

4.2 Multivariate results

Table 2 shows the results of the hypotheses tests when comparing firms within a nanotechnology cluster with firms outside a nanotechnology cluster using parametric one-tailed independent *t*-tests and non-parametric Mann-Whitney-U-tests. Both tests delivered the same results regarding the significance of the hypotheses tests.

Table 2 *t*-test for independent samples

	Inside cluster	*Outside cluster*	*t*	*p*	*Results*
H1: Cooperation with suppliers	4.63 (2.22)	2.58 (1.93)	–4.34	0.000	Confirmed
Cooperation with service providers	4.29 (1.94)	2.77 (1.91	–3.38	0.000	Confirmed
Cooperation with competitors	1.92 (1.14)	1.36 (0.79	–2.21	0.018	Confirmed
H2a: Inputs	3.54 (2.30)	2.51 (2.08)	–2.05	0.022	Confirmed
Know-how	3.29 (1.97)	2.20 (1.69)	–2.64	0.005	Confirmed
Marketing/sales	3.00 (1.98)	1.91 (1.48	–2.50	0.009	Confirmed
After-sales-service	3.29 (1.80)	1.76 (1.40)	–2.01	0.024	Confirmed
H2b: Innovation-specialised know-how[b]	2.67 (2.14)	4.04 (2.31)	2.57	0.006	Confirmed
H2c: Dependency on complementary assets[c]	3.25 (2.05)	4.82 (2.06)	3.26	0.001	Confirmed
H2d: Resources at market maturity	15.67 (4.50)	18.11 (4.60)	2.27	0.013	Confirmed
H3a: Informal contacts	3.88 (1.80)	2.81 (1.71)	–2.63	0.005	Confirmed
H3b: Face-to-face contacts	4.13 (2.0)	3.16 (1.92)	–2.12	0.019	Confirmed
H3c: Mutual trust	4.13 (1.90)	3.18 (1.86)	–2.17	0.017	Confirmed
H3d: Knowledge exchange	3.96 (1.94)	2.85 (1.67)	–2.71	0.004	Confirmed
H3e: Network building	3.71 (1.90)	2.70 (1.82)	–2.33	0.011	Confirmed
H3f: Cooperation building	3.96 (1.70)	2.85 (1.76)	–2.70	0.004	Confirmed
H4: Transparency	6.17 (1.20)	5.43 (1.78)	–2.33	0.012	Confirmed
H5: Intellectual property protection	17.50 (3.00)	14.62 (3.63)	–3.52	0.000	Confirmed
H6a: Importance of commercialisation	6.17 (1.40)	5.27 (1.93)	–2.50	0.009	Confirmed
H6b: Effort to license out	2.50 (2.21)	3.53 (2.35)	2.00	0.029	Confirmed
H6c: Licensing success	5.54 (2.02)	4.61 (2.02)	–1.90	0.034	Confirmed
H6d: Sales in thousand € in 2004	113800.00[a] (219629.92)	31726.69[a] (52917.47)	–1.82	0.041	Confirmed

One-tailed *t*-test for independent samples were used. Using the non-parametric Mann-Whitney-U-Test revealed no differences in the significance of the results.

N = 24 for firms inside a cluster; *N* = 74 for firms outside a cluster. Standard deviations are shown in parentheses.

Missing values were imputed using the EM algorithm of NORM (See Schafer and Olsen (1998), Acock (2005), Allison (2002), Little and Rubin (1987) and Schafer and Graham (2002) for an overview.

[a]Median values for the sales variable are 1500,00 (in thousand €) for firms outside of a cluster and 10.000,00 (in thousand €) for firms within a cluster.

[b]Lower values on this item indicate that the resources for commercialisation had to be less adjusted and were therefore more specialised and better adapted to the innovation.

[c]Lower values on this item indicate that the commercialisation of the innovation was more dependent on the resources of other firms.

Table 2 reveals that firms within nanotechnology clusters report higher informal contacts ($p < 0.01$), face-to-face and personal communication ($p < 0.05$), mutual trust ($p < 0.05$), exchange of informal and practical knowledge ($p < 0.01$), networking ($p < 0.05$) and cooperation ($p < 0.01$) than firms outside the cluster, confirming Hypotheses 3a–3f. Firms inside a nanotechnology cluster also report greater transparency in their environment regarding of cooperation partners' opportunistic behaviour, confirming Hypothesis 4. Hypothesis 5 argues that firms within clusters place greater importance on intellectual property protection and this is confirmed ($p < 0.001$). Firms inside clusters also consider the commercial success of their nanotechnology innovation as vital to the survival of their company ($p < 0.05$), confirming Hypothesis 6a. Hypothesis 6b is also confirmed; firms within nanotechnology clusters do find it easier to license their innovations. Similarly, the result that nanotechnology firms evaluate the commercial success of their licensing agreements more favourably than firms outside clusters is also significant and Hypothesis 6c therefore only confirmed. Hypothesis 6d that argues that firms within a nanotechnology cluster have stronger sales is confirmed.

5 Discussion and conclusion

Against the background of the recent scientific developments in nanotechnology, this paper deals with geographical proximity and clusters' impact on nanotechnology innovations' commercialisation. We have aimed to provide a concise characterisation and full statistical analysis of the commercialisation activities and process of technology SMEs. Marshall's (1920) and Krugman's (1991) key views as well as views that build on them (Porter, 1998a, p.216; Porter, 1998b, p.81; Zeller, 2001, p.135; Cooke, 2001, p.9; Decarolis and Deeds, 1999, p.965; Robinson et al., 2007) in respect of the factors that make cluster membership economically advantageous, are confirmed with regard to nanotechnology in Germany.

All of our hypotheses are confirmed and we find a number of differences in the commercialisation process between firms within and outside of technology clusters. Cluster firms cooperate significantly more with firms in the geographical proximity in respect of resources, such as human capital, and specialised intermediate inputs such, as manufacturing equipment/know how, marketing/sales, after-sales service, for their nanotechnology innovation's commercialisation process than firms that are not located within a cluster. Furthermore, firms in nanotechnology clusters report a higher degree of knowledge spillovers, such as more informal contacts, information exchange, networking and cooperation than firms outside the cluster. Geographical proximity apparently decreases transaction costs in this regard. Firms inside a nanotechnology cluster also report that they experience less effort when licensing out their innovations and significantly higher sales of their nanotechnology innovation than firms outside a nanotechnology cluster.

We see the following picture arise from our results: Firms within clusters are simultaneously more successful in the commercialisation of innovation and also more dependent on cluster membership and other firms and resources. A possible interpretation is that firms within clusters pursue more complex network innovations that need specialised inputs and require collaboration. Also, firms within clusters tend to be smaller and financially dependent on their nanotechnology innovation's commercial success. A possible interpretation is that these are young and highly specialised firms that pursue entrepreneurially risky projects. Overall our results add to the thesis that technology clusters help to gain competitive advantages and help in the commercial exploitation of technology and the creation of economic value.

The results of our study are in line with some of the findings from the previous literature. Through our comparative analysis, we are able to confirm that in a clustered environment isolated companies suffer from a periphery discount, which can amount to 40% lower returns as suggested by Fabiani and Pellegrini (1998). The results of our study are also consistent with previous literature that has argued that in high-technology sectors the technology and knowledge necessary for innovation may lie outside a firm's traditional core competence (e.g., Avenel et al., 2007; Lasch et al., 2007). Our results clearly point to technology SMEs' need for inter-firm alliances for their innovative activities. Although our results emphasise the importance of universities within clusters, we also underline Hendry et al.'s (2000) finding that not all SMEs make use of university resources In our sample, 25% did not cooperate with universities at all. Those SMEs that do cooperate, report that the university or research institution is their main cooperation partner, which generally adds to the image of science-based and research-driven innovations within clusters (Häussler and Zademach, 2007; Welsh et al., 2008). Furthermore, our study demonstrates that SMEs within a cluster to a greater degree indicate that the one-sided exploitation of cooperation could lead to a loss of image than firms outside a cluster do. This finding is in line with Steinle and Schiele (2002) who emphasise the importance of reputational effects in geographically rooted clusters.

Our paper alerts regional planners to the nanotechnology industry's need to cluster for successful commercialisation. Policy makers may use our study for the promotion of local network building in the nanotechnology industry (Laranja et al., 2008). Although many regulatory issues continue to be constituted on a national level, the support of cluster formation is a concrete measure that policy makers can actively pursue to foster technology innovation in the emerging nanotechnology sector. For technology entrepreneurs, our study highlights those steps in the commercialisation value chain that are affected by cluster membership. It should thus help entrepreneurs in their choice of company location.

Since nanotechnology is still in an early stage and commercialisation is only beginning, one can assume that nanotechnology clusters' importance will increase greatly in the following years. This reasoning is based on the examination of clusters' varying phases, depending on where they are in their evolutionary development (Pouder and St. John, 1996, p.1193). A cluster formed by pioneering companies has a pull effect that attracts other production and service organisations and start-ups (Stuart and Sorenson, 2003, p.250; Audretsch and Keilbach, 2005, p.19). It therefore requires a critical mass, which one can also equate with positive network effects (Picot et al., 2003, p.64), to fully develop the advantages and effect mechanisms that have perhaps not as yet been achieved with regard to nanotechnology (Klocke, 2004, p.107). Häussler and Zademach (2007) show that the ability to change network composition over time is crucial for cluster success. This school of thought is also further enriched by the hierarchical cluster concept that, on the basis of clusters built as a result of entrepreneurship, envisages various stages during cluster forming and the associated increasing interactions between local firms and institutions (Litzenberger and Sternberg, 2005, p.262–264). In view of the strong structural and political measures at the national and regional level (Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie, 2006, p.7), it can be assumed that the current cluster forming and geographical proximity's effect mechanisms will in future increase rather than decrease or even out.

In view of the early development stage of nanotechnology's commercialisation, our results are helpful with regard to other research endeavours and provide insight for subsequent examinations of selected phenomena. The roles of, for example, universities and research institutes as well as external financiers and venture capitalists could be further examined. The latter appear to play a particularly important role in nanotechnology innovations' commercialisation, as they also do in biotechnology (Rothaermel and Thursby, 2007; Welpe and Kollmer, 2006), although this could also be a result of politically influenced measures (Kaiser, 2003, p.854). Small and medium-sized companies experience a lack of financial means as a barrier to innovation (Zukünftige Technologie Consulting der VDI Technologiezentrum, 2004, p.218), therefore further research efforts can focus specifically on the role that geographical proximity plays in the financing process. In addition, a further examination of both the disassociation of an intrinsic meta-perspective as well as a differentiated examination of a few sectors or types of company development seems worthwhile. These specific groups exhibit differences that could, against the background of cross-section technology, also be traced back to certain branch-specific trajectories, offering. Additional premises for further research.

It would also be helpful to examine which roles adopt soft location factors besides the classic infrastructure, and the roles that, for example, current social networks, e.g., entered into during university study, play. Whether firms profit in different ways and to different extents from cluster membership with regard to the commercial exploitation of basic research results should also be investigated. Finally, the organisational structure of clusters and their knowledge transfer abilities and knowledge development could be a rewarding field for future research. There is also risk that clusters may have negative spin-offs. Externally, technological discontinuities and shifts in buyer needs may result in irrelevant resources. Internally, clusters may be prone to groupthink and collective inertia (Häussler and Zademach, 2007). Furthermore, over-consolidation, cartels or trade unions may stifle internal competition (Porter, 1998a). It is therefore important to acknowledge that clusters may have negative consequences. To date, no studies have identified any evidence of clusters' negative impacts (for example, a clash of customer needs), which provides a fruitful area for future research. Häussler and Zademach (2007) and Lechner et al. (2006) emphasise cluster and network dynamics. Therefore, future research should also take a dynamic perspective in studying the influence od clusters on company development.

This paper is a starting point for the examination of geographical proximity's impact. It offers, as does nanotechnology, many possible perspectives for further views. How the development of nanotechnology will be shaped in future and whether it, as a further cycle in Kondratieff's sense and as key technology of the 21st century, is able to persevere is eagerly awaited. Further empirical research devoted to nanotechnology phenomena and, against the background of increasing globalisation, to the somewhat paradoxical geographical proximity phenomenon offer equally exciting fields.

Overall, our study contributes to the ongoing discussion on whether and when clusters add to the creation of economic value. Our results point to the fact that economic success in knowledge-intensive services often hinges on the creation of networks, social interaction, and local-based tacit knowledge. Thus, our results support the notion that local geographic agglomerations such as clusters and networks can serve as catalysts and accelerators of technology commercialisation and trigger the successful exploitation of science-based inventions. We have therefore shed light on how cluster membership can impact the commercialisation of science-based innovations.

Acknowledgements

The authors would like to thank Martin Vetter and Oliver Widman for their help in collecting the data and Ilse Evertse for her help in editing the manuscript.

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Note

[1]Examples of the clusters in our study include Biomet, Nanobionet, NanoBioTechnologi, Optonet, GITZ, GKSS-FZ.

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