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IDENTIFYING NANOTECHNOLOGICAL LINKAGES IN THE FINNISH ECONOMY - AN EXPLORATIVE STUDY

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ABSTRACT: Nanotechnology, as an emerging science-based technology, is seen to have great potential both in scientific as well as economic terms. In this paper the focus is on identifying the technological linkages between the Finnish nanotechnology community and the industrial incumbents. These technological link-ages are first observed at a broader level in comparison with the technological strengths of the Finnish industries, and then in greater detail at the level of companies. In addition, the absorptive capacity of the incumbents is discussed to illustrate their ability to take advantage of external sources of knowledge. The descriptive analysis shows that the R&D activities of the Finnish nano-community are linked up to the technological specialisation of Finnish industry in broader sense and that there are potential technological linkages to various industrial sectors. Further, the nano-related incumbents are characterised by a higher level of absorptive capacity. The conclusion is that nanotechnology is connected to traditional and 'high-tech' industries. The nano-related incumbents might also exhibit an ability to utilise external sources of knowledge, and can possibly provide commercialisation paths for the smaller nano-dedicated companies. The future will tell whether the incumbent companies will play a key role in the commercialisation of nanotechnology in Finland.

KEYWORDS: nanotechnology, Finland, general purpose technology, technology life cycle, absorptive capacity
JEL: O33, O30

CONTENT

1. INTRODUCTION

1.1. Background

Nanotechnology has been hailed as a new revolutionary science-based technology that has the potential to have a significant impact on how we live our lives (Lipsey et al. 2005; Shea 2005; Bozeman et al. 2007). But before the technological revolution has an impact, there must be advances in the underlying sciences and in the diffusion of this new emerging technological field. There are many unanswered questions related to nanotechnology with regards to, for example, safety, standards and societal aspects. However this paper addresses the diffusion of nanotechnology in terms of the economic and technological potential. The emergence of nanotechnology and related industrial activity requires an understanding about how technologies link up to the existing economy. Only through such analysis can the potential impact of this new science-based technology on the overall economy be assessed.

Nanotechnology is sometimes associated with the concept 'general purpose technology' (Lipsey et al. 2005; Palmberg and Nikulainen 2006; Youtie et al. 2007). General purpose technologies (GPTs) can be viewed as great leaps of innovation that affect the entire economy. Unlike many incremental technological developments, GPTs are drastic advancements that potentially redefine the whole society. Nanotechnology shows some signs of becoming a GPT (Palmberg and Nikulainen 2006; Youtie et al. 2007). It is important to recognise that nanotechnology, at least in its current form, is mostly an enabling technology. Such technology is not an end-product in itself but rather is becoming integrated with other existing manufacturing technologies. More importantly, nanotechnology is not an industrial sector *per se.* It is associated with various industries quite unrelated in technological terms. Although there are existing and potential links between nanotechnology and a variety of industries, it is often difficult to identify commercialisation paths for these new and possible radical innovations (for a case-study on the use of nanotechnology in the construction industry see Palmberg (2007a)). For nanotechnology to have a significant impact on society, it needs to be used in a broad range of products and processes, and diffused in a variety of industrial sectors. The success of this diffusion determines the true impact of nanotechnology.

This paper focuses on understanding the technological linkages between different actors who have key roles in the evolution of Finnish nanotechnology. As these new technologies are often based on scientific advancements and only slowly start to generate industrially viable applications, the technological linkages between existing industry and new entrants is often unclear. Therefore, it is crucial to observe to what extent the technological capabilities of traditional Finnish industries match the R&D activities of the Finnish nano-community. These existing and potential technological linkages are prerequisites for a broader diffusion of nanotechnology. Another important aspect of the diffusion of nanotechnology is the absorptive capacity of incumbent companies since this will determine the degree to which they are able to utilise these new external sources of knowledge.

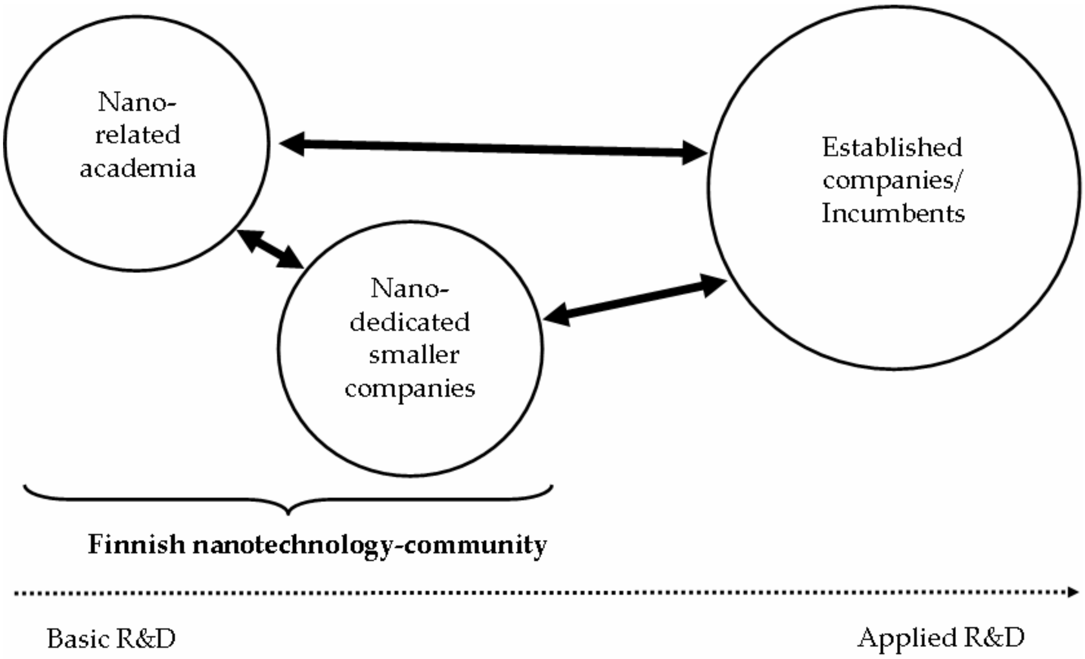
1.2. Aim and structure of paper

The aim of this paper is to identify and analyse the nanotechnological linkages throughout the Finnish economy. The relevant actors in this study are the science- and technology-community consisting of smaller nano-dedicated companies and nano-related academia, and the larger incumbent companies. To analyse the technological linkages between the different actors this paper addresses the following questions:

1) *What is the extent of technological linkages between nanotechnology and the broader technological specialisation of Finland?*
2) *Which types of established companies and industries are technologically linked to Finnish nanotechnology?*
3) *Do incumbents have the absorptive capacity to utilise the related external sources of knowledge?*

To answer these questions different theoretical frameworks are used. Several data sources are utilised based on earlier empirical results. Approaching the research questions from various viewpoints allows both the general industry-level and more detailed company-level perspectives to be analysed. The technological linkages analysed in this paper are illustrated in Figure 1.

Figure 1. Technological linkages between nanotechnology S&T-community and incumbents



The paper is structured as follows. Section 2 provides an analytical framework by discussing the relevant literature. Section 3 focuses on the methodologies used for identifying nano-related technological linkages and also discusses the data. Section 4 consists of the empirical analysis. Section 5 concludes the paper with a synthesising discussion, and discusses the limitations of the study and possible future research directions.

2. CONCEPTUAL FRAME

The theoretical framework of this paper draws upon various different, although connected, streams of literature. The discussion of general purpose technologies provides insight into why technological linkages between various actors of the economy are important during the evolution of a new technological field (e.g. Lipsey et al. 2005). Another relevant research area is the literature related to technology life cycles (e.g. Tushman and Anderson 1986), and especially the role of large established companies (e.g. Teece 1986; Teece 2006). These discussions are also related to the importance of industrialists during the commercialisation of technology (e.g. Carlsson and Eliasson

2003) and the absorptive capacity of companies (e.g. Cohen and Levinthal 1990). In the following the most relevant contributions in each research area are reviewed to provide a conceptual frame for this paper.

2.1. GPT

Many technologies possess some of the elements of GPTs but only a few have managed to actually evolve to that stage. The criterion for a technology to be identified as a GPT varies to some degree in the literature. In the following the criteria of a GPT are presented based on some of the earlier contributions (see in particular Helpman and Trajtenberg 1994; Bresnahan and Trajtenberg 1995; Lipsey et al. 2005). First, a GPT must have *significant scope for improvement* along with economically relevant dimensions of merit so that its cost of operation will fall over time. Related to this, the second criterion is that a GPT has a *widening variety of uses* as it develops and the costs decline. In other words, it is applied in an increasing range of products and processes. Third, it also has to have a *wide range of different uses in various industries*, in the sense that a large share of the production activity in the economy uses the technology. Fourth, it has to generate a range of other new *complementary technologies and innovations*.

The criteria presented above are based mostly on theoretical work although for some technologies, such as electricity and ICT, empirical evidence supports these conceptual efforts (David 1990; Lipsey et al. 2005). As discussed earlier in this paper it is very difficult to identify GPTs before substantial time has past from the first key innovations. Nonetheless, Youtie et al. (2007) provide the first empirical evidence that nanotechnology is more 'general' when measured through patent statistics. In other words, the core inventions in nanotechnology are applied in a broader range of application areas. According to Youtie and al. (2007) nanotechnology exhibits a similar level of generality compared with ICT. This can be seen as an indication that nanotechnology at least has the potential to become a GPT.

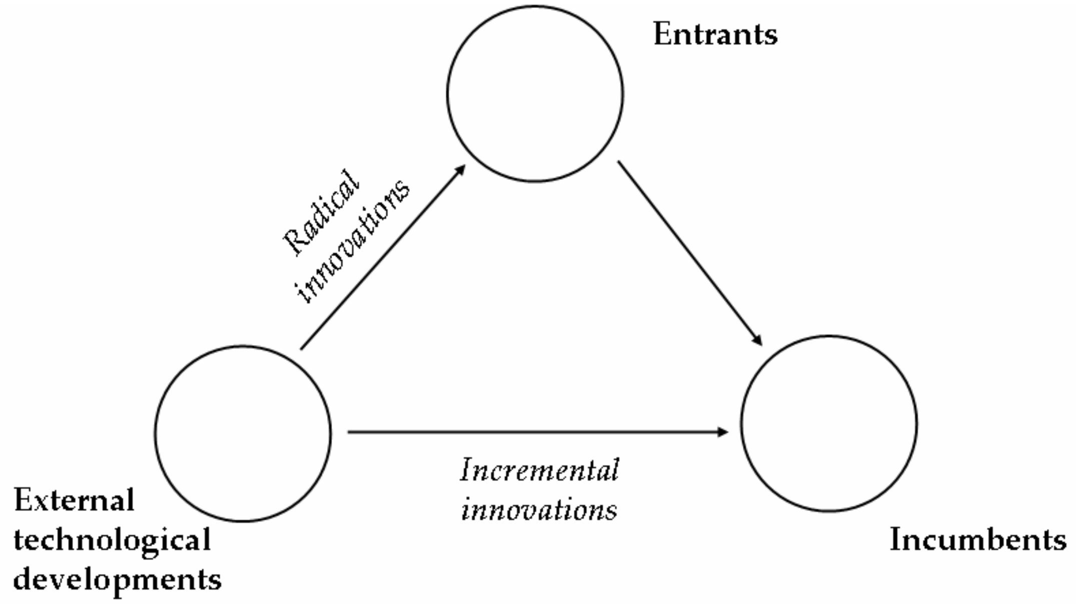
In the present study the focus is mostly on the second and third criteria of GPT. The second criterion stated that a GPT has a widening variety of uses. For this statement to be true a potential GPT should exhibit this variety at a fairly early stage to facilitate the technological diffusion. One area where this should be evident is the technological characteristics of a potential GPT. It should rely on a variety of technologies, which might be an indication of a broad range of potential uses. The third criterion argues that a GPT must have a wide range of different uses in various industries. In other words, the diffusion of the related technology must establish linkages (or at least have the potential to do so) over the whole economy from industries to consumers. In the present paper, this issue is addressed by looking at how nanotechnology is linked to other technologies and existing industries.

It is important to note that identifying GPTs is possible only after a relatively long time has passed from the emergence of the core innovations in the technology field in question (David 1990). Good examples are electricity and ICT, which are both viewed as GPTs. These technologies started to show signs of their technological and economic potential a considerable time after their initial discovery. Hence, when discussing the potential of nanotechnology to become a GPT, it is far too early to make drastic verifying conclusions, although a predictive discussion is nonetheless important.

2.2. Technology life cycles

The second related stream of literature discusses technology life cycles and the role of large companies during the commercialisation of new technologies. When technology life cycles are observed, the nature of the related technological innovations is a key issue. By distinguishing between incremental and radical innovations, the impact of these technological innovations on industry structures and the different roles of entrant companies and incumbents can be identified. Incremental innovation builds on existing knowledge and relies on existing competences. Hence, incumbent companies are quick to adopt such innovations. On the other hand, radical innovations build on new knowledge and can sometimes be viewed as competence-destroying innovations. The new science-based entrants master these radical innovations and are stronger in the market, while incumbents might have difficulty utilising the full potential of these new technologies. This has raised various questions regarding the profit distribution, the industrial organisation and the division of labour among incumbents and new entrants during the early phases of the emergence of a new technology field. Figure 2 illustrates a simplified version of a technology life cycle.

Figure 2. Technology life cycle with different types of innovations



Teece (1986, 2006) discussed the importance of larger and older incumbent companies and what role they play with respect to new emerging entrants who introduce radical innovations. The main conclusion of this discussion is that the role of incumbent companies depends on its complementary assets (Mitchell 1989, 1991; Tripsas 1997; Hill and Rothaermel 2003). These complementary assets can, for example, relate to distribution channels, marketing or knowledge of market dynamics. These complementary assets can be either generic or specialised. Generic complementary assets are available to all incumbent companies while specialised complementary assets are unique to a specific incumbent.

A majority of the theoretical and empirical contributions in this field mostly focus on traditional industries. A notable and relevant exception is Rothaermel and Boeker (2007). They analyse the role of incumbents and entrants in the biotechnology industry. In their study the research methods used in biotechnology are viewed as a radical competence-destroying innovation. They find that larger incumbent companies lack the technological expertise, but through their complementary assets (e.g. knowledge of drug approval processes, sales channels and marketing) the incumbents are able to profit from these technological innovations. Thus the success and profit distribution among incumbents is determined by the specific complementary assets they possess.

Nanotechnology in its current form still lacks the characteristics of a radical innovation. The majority of contemporary applied R&D in nanotechnology builds on prior knowledge and is thus more incremental by nature (Igami and Okazaki 2007; Youtie et al. 2007). The radical nature of nanotechnology is most likely linked to the emergence of innovations that build on 'bottom-up approaches', where the innovations rely on molecular level manipulation rather than the current advances in miniaturisation. The R&D efforts related to bottom-up approaches are still mostly basic research orientated, while more applied research is predicted to emerge in the mid- to long-term (Hullman 2006). Although nanotechnology has so far remained a non-radical technology, one can still assess whether there are technological linkages between the incumbents and new science-based entrants.

Recent empirical research compares biotechnology to the emerging activities in nanotechnology (Rothaermel and Thursby 2007). Rothaermel and Thursby (2007) observed if nanotechnology follows a similar pattern in industrial application compared with biotechnology. They argue that nanotechnology has the potential to affect a broader range of industrial sectors than biotechnology. One reason could be that biotechnology focuses on new organic materials, while nanotechnology allows the development of organic and inorganic materials. Rothaermel and Thursby (2007) find that nanotechnology and biotechnology exhibit similar evolutionary patterns in technology life cycles. In the light of these findings, it seems that, both in bio- and nanotechnology, the incumbent companies as industrialists play a key role in the commercialisation of innovation introduced by the smaller science-based companies (see also Luukkonen and Palmberg (2007) and Carlsson and Eliasson (2003)).

2.3. Absorptive capacity

Many of the aspects discussed above are related the concept of absorptive capacity (Cohen and Levinthal 1990). This term has been coined to illustrate the capabilities of companies in the acquisition and utilisation of external knowledge. It measures a company's ability to value, assimilate and apply new knowledge. With respect to the present study this term is useful in assessing the capabilities of the incumbents in the field of nanotechnology. Although establishing technological linkages between different actors in the field is important, the ability of incumbents to actually utilise these connections ultimately depends on their absorptive capacity.

Absorptive capacity can be studied on many levels (e.g. individuals, companies and countries). It consists of prior knowledge (such as knowledge stocks and knowledge flows) and the ability to use this prior knowledge in utilising external sources of knowledge. It is usually studied through a company's innovation performance, aspiration level or organisational learning. Absorptive capacity is one of the reasons companies invest in R&D instead of simply buying the results (e.g. patents). In empirical and theoretical studies internal R&D spending is often considered a proxy for the absorptive capacity of a company. Thus R&D investments have a dual role. Firstly, it enhances the company's ability to bring new products to market, and secondly allows relevant external sources of knowledge to be identified.

Based on these conceptual and empirical contributions, it is clear that merely establishing technological linkages between different actors fails to capture the ability of incumbents to absorb the surrounding new knowledge. Therefore, in the present paper the absorptive capacity of nano-related incumbents, with respect to other incumbents in the respective industry, is addressed by using simplified quantitative proxies.

3. METHODOLOGIES AND DATA

3.1. Methodology

Empirical contributions of direct relevance to the present paper are scarce in the existing literature. New suitable empirical methods therefore need to be used to address the research questions presented earlier. The issue of technological linkages is approached on two different levels. On the first level, the focus is on a broader country and technology level, where indexes based on relative patenting in different technological classes are utilised. At the second level, a more specific company-level approach is used to identify possible technological linkages based on patenting in similar technologies. In addition, the differences in absorptive capacity between nano-related and other incumbents are assessed.

The revealed technological advantage (RTA) indexes, used in this study for the broader approach, were originally developed to analyse technological specialisation of countries (see e.g. Soete 1987). This paper utilises a specific approach used by Cantwell and Iammarino (2000). Cantwell and Iammarino (2000) identified the technological advantages (based on patenting activity) of different regions in the U.K. and matched these regional results with the technological advantages of foreign-owned multinational companies. The methodology of this paper is based on a slightly modified version of this RTA index where companies, instead of regions, are used as reference groups. The following definition of RTA is used in the present study:

Revealed technological advantage (RTA):

$$RTA_{ij} = \left(\sum P_{ij} / \sum P_i\right) / \left(\sum P_{wj} / \sum P_w\right)$$

where *P= number of patent applications*
i = company group
j = technological class
w = total in the world or Finland

The modified RTA index will be used to identify the technological advantages of large incumbent companies, and small nano-dedicated companies. In addition to these science-based companies, the technological advantages of nano-related academia are calculated to see if it links to the actors in the private sector. The underlying assumption of this methodology is that the potential linkages are measured through the co-occurrence of patents in the same technological class. Through identifying the technological advantages of these different groups, it should then be possible to establish how well these science-based technologies link to the existing technological advantages of larger incumbents.[1]

The more detailed analysis of technological linkages is based on identified similarities in patenting activity across these different groups. In the prior literature the most interesting and relevant empirical research is Rothaermel and Boeker (2007). Rothaermel and Boeker (2007) discuss the switch from older to newer technologies, and their impact on complementary assets, technological similarities and alliance formation, in the context of bio- and nanotechnology companies in the US. They find that

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[1] This study aims to identify *potential* or *established* linkages between smaller nano-dedicated companies and incumbents. The study does not aim to observe, which type of technological linkage is in question but merely tries to identify similarities.

incumbents with relevant complementary assets (such as production and commercialisation competencies) are more likely to be partners in alliances with small entrant companies. In addition, they observe that technological similarity, based on patent cross-citations, increases the likelihood of alliance partnerships. As their exercise is currently unrepeatable due to data restrictions in this paper the technological linkages are analysed in somewhat looser terms. The technological similarity (or linkages) is observed here by comparing which incumbent companies have had patenting activity in the exact same technological classes as the smaller nano-companies.

The two methods described above are here proposed as a means to identify potential, and perhaps also established, technological linkages across the different groups, but they fail to take into account the issue of absorptive capacity. To address this important aspect in the diffusion of nanotechnology, more standard research methods are employed. As suggested above the previous empirical literature on absorptive capacity views that company's level of R&D investments indicates its ability to value, integrate and apply new external knowledge. In the present paper this statement is analysed by comparing the R&D intensity of incumbents, which are identified as having potential or established technological linkages with smaller nano-dedicated companies, with respect to other incumbents in the same industries.

3.2. Data

Patent data is used to identify the technological activity of the different actors in this analysis - large incumbents, small nano- and bio-companies and nano-related academia. While patenting activity fails to recognise all innovative activity (e.g. process and other non-patentable inventions), it is generally viewed as a viable proxy for such activities (Griliches 1990). The analytical methods applied here, identify the technological areas in which the different groups have relative advantages and in which these different actors have technological linkages at least potentially. In addition to patent data, company-and industry-level data on sales and R&D investments are used to analyse the absorptive capacity of the nano-related incumbents.

The EPO patent application data were collected for each of the groups used in our analysis: total in the world, total in Finland, small nano-dedicated companies in

Finland, small bio-dedicated companies in Finland and Finnish nano-related academia (a more detailed description of data collection is in Appendix I).[2] The number of published patent applications in the EPO is illustrated in Table 1.

Table 1. Distribution of patent applications across different groups

Group	**# of patents**
World	3,936,306
Finland	24,019
Nano-companies	167
Nano-academia	262
Bio-companies	255

Note: Data collected from Delphion in July, 2007

It is clear that the patenting activity between the comparison groups is very different. The number of EPO patent applications is around 4 million and about 24,000 have Finland as the priority country. The number of company assigned nano- and biotechnology EPO patent applications is quite low, which is explained at least to some degree by the novelty of these technological areas. One interesting finding is that the number of patent applications having an academic researcher as an inventor is higher than the number of patent applications assigned to small nano-dedicated companies. As some of the smaller nano-dedicated companies are based on inventions made in academia and they still might have strong links to universities, there is an overlap in patenting between these two groups. Some of the academic patents are also included in the nano-dedicated company patents. In addition, the number of academic patent applications might be an underestimation of the inventive activity in the field because for academic researchers the incentive is to publish research findings rather than to patent them (see e.g. Stephan 1996).

Another important aspect in using patent data in industry-level analysis is that technologies do not always map into industries one-to-one basis (Pavitt 1984). Al-

[2] An important note here is that the total patent applications in Finland is seen as representing patenting by the larger incumbents. The reason for this presumption is that the small companies only have a minor share of the patents granted in Finland while the medium-sized and large companies are responsible for 88% of Finnish patenting activity (calculations based on ETLA's FEPOCI-database).

though some industries rely on a single technological platform, it is more common that they utilise several different technologies in their innovation activities. It has been also noted that companies have to manage a wide range of technologies in order to develop and produce products and services (Granstrand 1998).

To analyse differences in the absorptive capacity of incumbents, company level data are utilised. Those incumbents identified as having links to nanotechnology are compared with other incumbents who assumedly have no such clear connection to the field. The company-level data comes from a dataset that focuses on the 500 largest companies in Finland (Talouselämä 500 - TE500). This dataset comprises mainly financial data and includes some other company specific data such as R&D investments.

4. RESULTS

As discussed earlier in this paper the aim is to analyse the technological linkages between the nano-community and incumbents at different levels. The patent data are used in the analysis in two different ways: 1) to calculate the RTA index and 2) to identify potential technological linkages between the smaller nano-dedicated companies and larger incumbents subject to the assumptions discussed above.

4.1. Revealed technological advantage - RTA

By using the RTA index the technological advantage of different reference groups is identified. These advantages are based on the relative patenting in the same patent classes with respect to different groups. As discussed earlier these groups are: the world, Finland, small nano-dedicated and bio-dedicated companies in Finland, and Finnish nano-related academia. By using these reference groups, one can measure the relative advantages that the groups have in relation to each other.[3] The results are presented in Table 2.

[3] See Figure 1 for the illustration of the relationship between different actors.

Table 2. The Revealed Technological Advantage (RTA)

		Finnish nano-community		
	Finland vs.World	Small nano-comp. vs. Finland	Nano-academia vs. Finland	Small bio-comp. vs. Finland
	n= 24 019	*n= 167*	*n= 262*	*n= 255*
Electrical engineering	**1.53**	0.21	0.28	015
Instruments	0.68	**2.81**	**3.02**	**2.45**
Chemicals & pharmaceuticals	0.42	**2.08**	**2.89**	**5.54**
Process engineering	**1.49**	**2.01**	**1.34**	0.62
Mechanical engineering	0.93	0.15	0.12	0.07
Cons. goods and civil eng.	**1.10**	0.09	0.22	0.06

Note I: Technological classification is based on OECD (1995) and Mancusi (2003)

Note II: The more disaggregate version of technological classes is in Appendix II.

It is evident that Finland (and especially incumbents based on the assumptions presented above) is technologically specialised in electrical engineering, process engineering, consumer goods and civil engineering when the world patenting is the reference group. When the distribution of nano- and bio-patenting is compared with Finland as the reference group, it is evident that nanotechnology is spread over a broader range of technological areas, as the literature on GPTs and nanotechnology suggested (Palmberg and Nikulainen 2006; Youtie et al. 2007). Smaller nano-dedicated companies are specialised in instruments, and chemicals & pharmaceuticals, as well as in process engineering. In the other technology classes, the smaller nano-companies are less specialised, but exhibit at least some level of activity. The role of instruments can be explained by the fact that major nanotechnology developments are currently focused on improvements in instrumentation (Hullman 2006). Overall nanotechnology seems to be innovative in areas where Finland has comparative technological advantages. In comparison, biotechnology exhibits slightly more narrow specialisation and in technologies where Finland is less specialised.

Finnish biotechnology is specialised in only a few technological areas. It is specialised in instruments, chemicals & pharmaceuticals and somewhat in process engineering. However, biotechnology fails to have significant levels of activity in other areas and its strengths are in technological classes were Finnish industry is not very specialised. The strength in chemicals & pharmaceuticals in both nano- and biotechnology also suggests that there is a connection between these two technologies.

Nano-related academia exhibits a pattern very similar to the smaller nano-companies in its technological specialisation. This can be seen as an indication that these two groups are, at least potentially, fairly connected in their technological R&D activity. One reason for this result is the overlap between these groups as some patents assigned to the nano-dedicated companies have academic inventors.

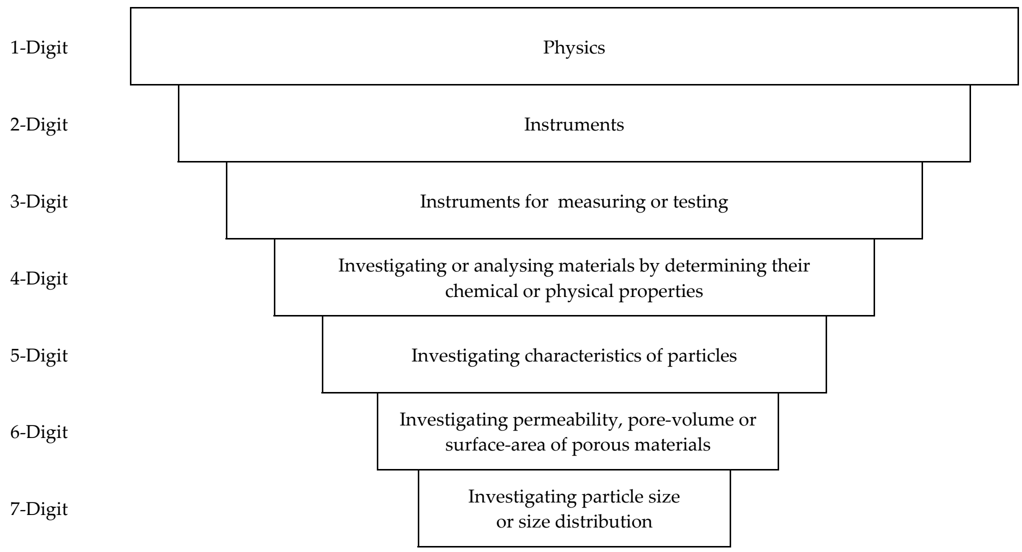
Four conclusions can be drawn from the RTA based descriptive analysis: 1) the innovative activity in Finnish nanotechnology seems to technologically broader than biotechnology, 2) the smaller nano-companies and nano-related academia are very similar in their technological specialisation patterns, 3) the technological specialisation of the nano-companies matches the technological advantages of Finland to a greater extent than biotechnology, and 4) the more general technological profile of nanotechnology suggests that it can indeed potentially become a GPT.

The analysis of RTA indexes provides interesting insights into the technological specialisation of different groups and their potential linkages. The results suggest that for nanotechnology to become a GPT there must be evidence that it is related to various production activities in a variety of industrial sectors. The RTA indexes focus on technologies rather than production activity, and hence a connection needs to be established between the technology field and industry. The company-level R&D activity can be viewed as the pre-stage for future production activity. As nanotechnology is still clearly in the R&D phase rather than the production phase, the results indicate that nanotechnology is related to a range of technologies feeding into a variety of industries. This finding supports the statement about the generality of nanotechnology (Shea 2005; Palmberg and Nikulainen 2006; Youtie et al. 2007).

4.2. Technological linkages

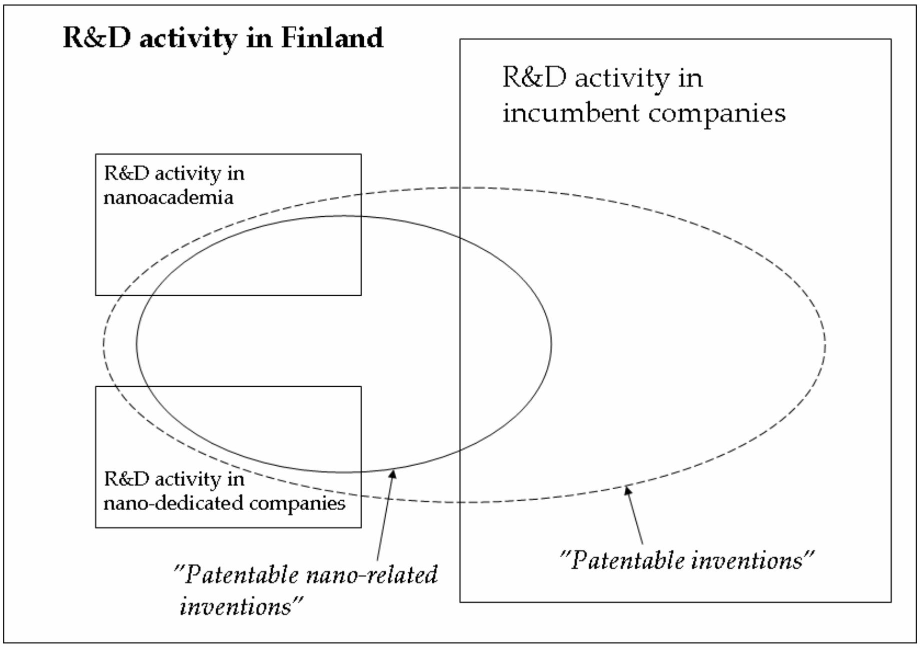
The general analysis provides some insights into the technological relations through the RTA indexes, but leaves some questions still unanswered, especially regarding the potential technological linkages between the large incumbent companies and the smaller entrant companies. To shed more light on this, these two groups were matched on the basis of the IPC classification (International Patent Classification). The idea was to identify the patent classes of the smaller nano-companies and then identify which other Finnish companies have patenting activity in the exact same patent class. The underlying assumption of this methodology is that the potential linkages are measured through the co-occurrence of patents in the same technological classes. The rationale for these linkages is based on the knowledge proximity of knowledge bases. The patent classes were identified on a seven-digit level. An example of one of the IPC classifications is in Figure 3 below.

Figure 3. IPC classification of G01N 15/02



Based on this patenting activity in the same patent class, a potential technological linkage is established between the two groups. This approach provided a list of companies having the exact same patent classes. It should be recognised that having a patent even in exactly the same patent class does not necessarily mean that the incumbent patents are related to nanotechnology. These potential technological linkages are illustrated in Figure 4.

Figure 4. R&D activity and technological linkages



The larger context for this analysis is the R&D activity in Finland. It comprises various innovative activities either patentable or protected in some other fashion (such as secrecy, lead-time or complexity). The three relevant components for the current study are the larger incumbent companies, the small nano-dedicated companies and nano-academia. The share of patentable nano-related innovations is higher in the latter two groups, while incumbents only operate marginally in nano-related activities. In the present study the interest is on the technological linkages of small nano-companies and incumbents. The activities of the nano-companies are most likely more applied-oriented, and therefore more relevant for the diffusion of nanotechnology than the activities of the nano-related academia. In this stage of the matching, no differentiation is made between incumbents and other smaller companies. The technological linkages between companies are merely established while later the focus will be on the basic characteristics of incumbents. Table 3 summarises these results.

Table 3. Patent applications in the same IPC-classes

Technological class	# of nano-company patents	Total # of Finnish patents in the class	Most patenting companies (including incumbents)
Electrical engineering	13	31	Fortum (4) ASM Microchemistry (2) Licentia (2) Metso Paper (2) Nokia (2)
Instruments	48	193	Thermo Fisher Scientific (27) Wallac (18) Metso (13) VTT (12)[4] Vaisala (7)
Chemicals & pharmaceuticals	35	121	Orion (12) Valio (5) Kemira (4) Licentia (4)
Process engineering	66	464	Metso (183) Kemira (19) Partek (16) UPM-Kymmene (12) M-real (11)
Mechanical engineering	4	30	Metso (8) M-real (2) Wallac (2)
Consumer goods & civil engineering	1	3	U-H Rakennus (1)
Total	167	842	

Note I: Technological classification is based on OECD (1995) and Mancusi (2003)

An important note here is that patent classifications are not evenly distributed. The number of overall patents in each class varies greatly and thus comparisons between technology classes must be carefully interpreted. Nano-related patenting occurs mainly in three classes – instruments, process engineering and chemicals & pharmaceuticals. The same patent classes are also populated by the larger incumbent companies. This indicates that in these classes patenting is quite frequent. The last column in Table 3 indicates the most patenting companies in each technological class. Only the most patenting companies in each class are shown.[5]

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[4] A unique characteristic of the Finnish innovation system is that the research institute efforts are mostly conducted in VTT (Technical Research Centre of Finland). In other countries such activities are usually distributed across various research institutes. Research institutes are often R&D providers for companies and in the present paper they are considered to belong to the group of larger companies.

[5] The complete list of companies and associated technology classes are in Appendix III

Even more interesting is the proportion of nano-patents with respect to the overall patenting by these technologically linked incumbents. The results indicate that potentially nano-related patenting accounts for 8.8% of the incumbent patenting activity.[6] If this result is compared to the overall patenting activity in Finland, potentially nano-related patenting accounts for 2.8% of all Finnish patent applications. Hence, these results indicate that nanotechnology potentially links up to a surprisingly large fraction of overall innovative activity in Finland.

While patenting provides relevant insights into the Finnish innovative activity in the field of nanotechnology, understanding which types of larger incumbent companies are possibly technologically linked to the smaller nano-companies is an interesting question. These larger incumbents are often multinational companies, which are key components in sustaining the overall economic performance of Finland. By understanding to what extent nanotechnology can provide new methods to enhance the industrial renewal of the larger incumbents.

Table 4. The industrial affiliation of all nano-relevant incumbents (based on TE500)

Industry	**# of companies**	**%**
Electronics	3	6
Foodstuff	4	8
Energy	1	2
Chemical and pharma	9	18
Metal engineering	12	24
Paper and forest	5	10
Miscellaneous	6	12
Packing	1	2
Construction	4	8
Textiles	1	2
Wholesale	2	4
Services	2	4
Total	50	100

To answer this question, the attention turns to the largest companies in Finland. Table 4 describes the industrial affiliation of these companies that were identified as having to possible technological linkages to nanotechnology. The company level data

[6] Note: 7666 EPO patent application in total – data from Delphion

comes from the TE500 database, which contains industry classifications, financial data and other related details for the 500 largest companies in Finland and does cover all of the nano-relevant larger incumbents.

It is evident that many of the nano-related incumbents are from traditional industries, such as metal engineering, paper and forest, and construction. There are also connections to 'high-tech' industries, such as electronics and chemicals and pharmaceuticals. Thus it is clear that nanotechnology potentially has technological linkages to various industries with various degrees of R&D activity. This finding also supports the earlier statement that nanotechnology shows signs of becoming a GPT. To illustrate the differences between the nano-relevant incumbents and other incumbents the level of sales for the companies and the number of personnel are shown in Table 5.[7]

Table 5. Incumbent characteristics

		# of companies	**Mean**	**Median**	**Std. Dev.**	**Min**	**Max**
Nano-relevant	Sales (million €)	50	2526.0	533.7	5675.1	58.08	34191
	Personnel	50	7771.0	1330.0	12905.4	147	56900
	R&D (million €)	50	108.96	9.1	580.8	0.13	3825
Other	Sales (million €)	143	438.3	142.5	999.0	54.15	9974
	Personnel	143	1804.6	668.0	2883.8	87	21200
	R&D (million €)	143	6.56	2.5	13.0	0.01	116

The incumbent characteristics show that they are diversified not only by their industry and in their technologies, but also in their size, employment and level of R&D activity. The incumbent characteristics in general are skewed as there are many medium-sized companies and few large multinationals. A good example is the number of personnel. While the smallest identified companies are still relative small (147 employees), the largest are multinational companies (the largest being Nokia). When the nano-relevant incumbents are compared with the other incumbents it is clear that the former group includes the largest companies in Finland. This indicates that Finnish nanotechnology is potentially linked to the most significant companies in Finland. Again this supports the discussion of a variety of uses in various industries, but the ability of these incumbents to utilise surrounding knowledge is still unclear. To understand this

7 The number of observations is limited to 193 (out of 500) as R&D investments were not available for the excluded companies. The R&D investments were available for all the nano-relevant incumbents.

aspect in greater detail, the absorptive capacity of these nano-relevant incumbents must be reviewed.

4.3. Absorptive capacity

As discussed in the analytical framework absorptive capacity relates to the ability of companies to utilise external sources of knowledge. This capacity is somewhat difficult to measure and therefore one of the common methods is to approach the question through case-studies. However, in the present paper a rough assessment is used, pending on future case studies.

Empirical research has used company level R&D intensity as a proxy for companies' absorptive capability (Cohen and Levinthal 1989; Rothaermel and Hill 2005). Using the same approach, information on R&D intensity of the identified incumbents is used and compared with the industry-level average.[8] The results are interesting as it seems that the nano-related incumbents have a higher average level of R&D intensity when compared with the respective industry in general.[9] In particular the share of nano-relevant incumbents having a higher R&D intensity than the industry average is ~72% compared with ~59% for the other large companies in the respective industries. This indicates that nano-relevant incumbents might have higher absorptive capacity than other incumbents. It should be noted that absorptive capacity is more than just internal investments in R&D. Accessing external sources through different modes of interaction and the challenges emerging for this collaboration especially when related to nanotechnology have an impact on the absorptive capacity (Palmberg 2007b). Another important aspect is that the interaction among companies, and between companies and academia, is based on individual level communication. Thus, individual characteristics and motivations play a crucial role in facilitating the interaction between different actors in the field (for industry-academia interaction in Finnish nanotechnology see Nikulainen (2007)).

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[8] Data from Statistics Finland

[9] R&D intensity varies by industry and company (Griliches 1990), and hence industry specific characteristics are taken into account in this study by dividing the company R&D intensity with the overall industry specific R&D intensity.

Although this analysis takes into account industry specificities, a more detailed industry level analysis could provide further insight into the questions of absorptive capacity and the related incumbents connected to nanotechnology.

5. DISCUSSION AND CONCLUSIONS

5.1. Summary

In this exploratory paper the aim was to identify linkages in nanotechnology between larger incumbent companies and the Finnish nano-community. This community consists of smaller nano-dedicated companies and nano-related academia. It was suggested that nanotechnology exhibits some signs of becoming a general purpose technology. This paper focuses on assessing two of the criteria associated with GPTs. A technology must have a wide range of uses and should be used in a variety of industries to have the potential to be a GPT. The proposed research questions of nanotechnology and its potential to become a GPT were linked to the literature of technological life cycles and absorptive capacity. This framework provided guidelines for the methodological analysis. The wide range of uses and usage in a variety of industries were observed through patent analysis, where potential technological linkages were identified between incumbents, nano-dedicated entrants and nano-related academia. The concept of absorptive capacity was then introduced to the discussion in order to assess the capabilities of these larger incumbents.

Some general conclusions can also be drawn with respect to whether nanotechnology might become a GPT. The Finnish nano-community is technologically linked to various technologies and to various industries. The link between the strengths of Finnish innovative activity in general and the somewhat matching specialisation profile of nanotechnology promises opportunities for broad technological diffusion. However, it is important to remember that identifying GPTs requires substantial time between the first innovations and the broader diffusion of technology.

The descriptive analysis provided a range of interesting results. Firstly, based on revealed technological advantage indexes the smaller nano-dedicated companies are technologically more diversified when compared with counterparts in the field of biotechnology. At the same time, the nano-related academia exhibits a similar technological specialisation profile as the dedicated nano-companies. Furthermore, the profile of nanotechnology in Finland is relatively well linked to the technological advantages of Finland in a broader sense. Secondly, the technological linkages between smaller nano-companies and incumbents yielded results showing that nanotechnology is not only technologically diversified but also exhibits a similar pattern across technologies with respect to the larger incumbents. This last result is interesting as the company level analysis indicates that the absorptive capacity of nano-related incumbent companies is higher than the capacity in companies unrelated to nanotechnology. This could suggest that the incumbents related to nanotechnology might have the ability to facilitate the technological diffusion in this new emerging technology field and could thus also realise the linkages for productive use. If these linkages *de facto* exist, it might also provide the smaller entrants with potential commercialisation paths for their innovations.

5.2. Limitations

Assessing new emerging technologies is a difficult task. The technological trajectories are only emerging and a dominant technological design is still missing. The availability of relevant data is also a problem. Therefore, this paper utilises all the relevant quantitative data available. As evident from the analysis above, the level of R&D activity in nanotechnology is still emerging. So this study should be seen as a first attempt to analyse nanotechnology in the context of linking different actors in this technological field. When nanotechnology is more established and there are fewer technological uncertainties, a more detailed and comprehensive analysis should provide insight into the research questions presented here.

5.3. Future research and extensions

The analysis of nanotechnology and the roles of different companies and academia should be given more attention. Although the newness of this technological field limits the opportunities to study many relevant aspects of nanotechnology, some new directions could be taken. A more qualitative approach to answering the questions of industry dynamics and technological linkages would provide insight into the current activity in the field. In addition, through interviews some of the quantitatively hard questions, (e.g. the absorptive capacity of incumbents), could be answered in greater detail taking into account the possible industry specific characteristics of nanotechnology.

The quantitative approach used in the present study could also be extended to a more detailed analysis of the companies' knowledge bases and the knowledge relatedness in nanotechnology. The analysis of the role of the similarity in the knowledge stock of the companies could be approached through patent citation analysis. Rothaermel and Boeker (2007) used patent cross-citations in analysing the technological similarity of incumbents and entrants. This approach would allow an interesting analysis of the technological linkages between companies. Another aspect is the knowledge relatedness within the companies related to nanotechnology, both in the smaller nano-dedicated companies as well in the larger incumbents. This approach could follow the methodology introduced by Breschi et al. (2003) as they analysed to what extent different technologies are related within companies. With respect to nanotechnology this is a very interesting question, as it is regarded as a multidisciplinary technology. It would be interesting to study what types of knowledge are related in nano-related companies compared with other companies with fewer ties to nanotechnology.

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APPENDIX I - Data collection

RTA index

For the RTA index based analysis, the patent data consist of patent applications at the European Patent Office (EPO). The data were collected from Delphion online patent dataset in July 2007. Thus the data consist of all the published patent applications before that time. The EPO application data provides us with most updated information of the codified innovative activity of our comparison groups. The EPO patent application data were collected for each of the groups used in the analysis: total in the world, total in Finland, small nano-dedicated companies in Finland, small bio-dedicated companies in Finland and Finnish nano-related academia. The patent data were then stratified to the respective technological classes based on the International Patent Classification (IPC). An important note here is that the total patent applications in Finland is seen as representing the patenting by the larger incumbents. The reason for this presumption is that the small companies only possess a minor share of the patents granted in Finland while the medium-sized and large companies are responsible for 88% of Finnish patenting activity (calculations based on ETLA's FEPOCI-database).

The relevant groups for data retrieval were identified based on the following criteria. The total patenting in the world is based on the number of patent applications at the EPO. The total number of Finnish patents in different technological classes is identified based on the priority country (country of first patent filing) in the patent application document. The smaller nano- and bio-companies were identified based on public sources and expert opinions. A more detailed description of the identification of nano-companies is available in Palmberg and Nikulainen (2007). The size of the nano-companies was controlled to be less than 65 employees. This ensures that the activities of these companies can indeed be assumed to relate to nanotechnology. Larger companies are more difficult to associate with nanotechnology as it is still an emerging and enabling technology. The bio-companies were identified based on the official register of Finnish bio-industry association (Finnish Bioindustries – FIB), which keeps track of the activities in the field. The large companies were also excluded from the biotechnology company list. These exclusions of larger companies allow us to make a clear distinction between incumbents and new entrants. In addition, the interest was in the new (and usually smaller) entrants in the field. For the small companies identified all their patent applications were collected regardless of their relation to nano- or biotechnology. In this way all the patenting activity of the groups were acknowledged, thus providing a better understanding of their overall knowledge base.

To identify patenting by the Finnish nano-academia, the data retrieval was approached from a slightly different perspective. This approach consisted of identifying associated individuals in the nano-academia from patent data, which was collected with an advanced keyword search algorithm (more details are found in Palmberg and Nikulainen 2006). The data provided the information of the relevant inventor names, although it did not reveal their affiliation. Therefore, in order to identify the individuals working in academia, a survey conducted among the nano-community in Finland was used to establish the affiliation of each individual (see Palmberg et al. 2007). For these identified academics all patent applications (regardless of the assignee of the patent application) were collected.

Technological linkages

The relevant patent classes were identified based on the patents assigned to the nano-dedicated companies. This provided us with a list of main patent classes of each of their patents. To avoid duplicates, only patent applications in the EPO were used. In case of several versions of the patent application based on modifications to its content, only the last version was taken into account. These main patent classes of the patents assigned to nano-companies were then used in data collection for identifying similar patenting by other Finnish companies. Here relevant patent applications were identified if they had Finland as the priority country and the identified main patent class in any of the patent classes (main, secondary or inventive) in the patent application. This provided a slightly less stringent definition of the connection between the patent applications, thus taking into account all the relevant technological linkages.

APPENDIX II - The Revealed Technological Advantage (RTA) on disaggregate level

	RTA Finland vs.World	RTA Nano-comp. vs. Finland	RTA Bio-comp. vs. Finland	RTA Nano-academia vs. Finland
Electrical engineering				
Elec. devices & elec. eng.	0.79	0.63	0.17	0.56
Audio visual tech.	0.63	0.00	0.00	0.17
Telecommunications	3.22	0.07	0.06	0.13
Information technology	0.84	0.00	0.71	0.30
Semiconductors	0.19	7.65	1.00	6.83
Instruments				
Optics	0.21	5.62	0.00	2.05
Control & measurement tech.	0.96	3.16	2.18	3.05
Medical tech.	0.58	0.97	3.96	3.24
Chemicals and pharmaceuticals				
Organic chemistry	0.24	2.34	8.68	2.48
Macromol. chem. & polymers	0.49	1.40	0.76	0.89
Pharma & cosmetic	0.25	4.53	15.48	3.85
Biotechnology	0.40	2.82	10.82	5.91
Materials & metallurgy	0.58	1.71	0.56	4.90
Food & agriculture	1.52	0.96	2.72	1.43
Process engineering				
Chemical engineering	0.58	0.84	1.65	3.47
Surfaces	1.33	0.75	1.30	0.71
Materials processing	1.93	23.61	0.00	20.52
Thermal processes	2.21	2.75	0.26	1.25
Oil & Basic material chem.	1.66	0.47	0.15	0.30
Environmental tech.	1.15	1.21	0.53	0.00
Mechanical engineering				
Machines & tools	1.06	0.49	0.00	0.31
Engines & pumps	0.58	0.00	0.00	0.00
Mechanical elements	0.82	0.24	0.16	0.00
Handling	1.36	0.00	0.14	0.07
Food processing	1.06	0.00	0.00	0.72
Transport	0.70	0.00	0.00	0.00
Nuclear engineering	0.60	2.44	0.00	0.00
Space technology	0.57	0.00	0.00	0.00
Consumer goods and civil eng.				
Consumer goods	0.85	0.00	0.13	0.25
Civil engineering	1.45	0.16	0.00	0.20

Note: Technological classification is based on OECD (1995) and Mancusi (2003)

APPENDIX III - Complete list of companies and technological classes

Note: Group 'Unknown' is either assigned to individuals or to companies without registration (YTJ).

	Nano-related companies	# of patent publications
Electrical eng.	Fortum	4
	ASM Microchemistry	2
	Licentia	2
	Metso Paper	2
	Nokia	2
	Anturilaakso	1
	Atmel	1
	Draka NK Cables	1
	ICS Intelligent Control Systems	1
	Teknoware	1
	Vaisala	1
Instruments	Unknown	29
	Thermo Fisher Scientific	27
	Wallac	18
	Metso	13
	VTT	12
	Vaisala	7
	Nokia	5
	Orion	5
	Kone	3
	Medix Biochemica	3
	Bio-Nobile	2
	Liqum Paper	2
	Biofons	1
	Cyflo	1
	Fortum	1
	Glaston Finland	1
	Labmaster	1
	Lappeenrannan Tek. Yliopisto	1
	Liqum	1
	M-real	1
	Nordkalk	1
	Optoelectronics Research Centre	1
	Outokumpu	1
	Rautaruukki	1
	Saint-Gobain Isover	1
	Savcor Process	1
	Slo	1
	Stresstech	1
	Suominen Kuitukankaat	1
	Temet	1
	TR-Tech Int.	1
Chem. & pharma	Unknown	17
	Orion	12
	Valio	5
	Kemira	4
	Licentia	4
	Finnzymes	3
	Karyon	3
	VTT	3
	Alko	2
	Fortum	2

	Jurilab	2
	Leiras Finland	2
	MAP Medical Technologies	2
	Raisio	2
	Biohit	1
	Boreal Kasvinjalostus	1
	Danisco Sweeteners	1
	Faron Pharmaceuticals	1
	Finnfeeds Finland	1
	FIT Biotech	1
	Hormos Medical	1
	Huhtamäki	1
	IPSAT Therapies	1
	LAB Pharma	1
	Labmaster	1
	Metso	1
	Nextrom	1
	Nor-Maali	1
	Novagent	1
	Oulun Yliopisto	1
	PediPharm	1
	RNA-Line	1
	Santen	1
	Thermo Fisher Scientific	1
	UPM-Kymmene	1
	Wallac	1
	Vetcare	1
Process eng.	Metso	183
	Unknown	26
	Kemira	19
	Partek	16
	UPM-Kymmene	12
	M-real	11
	Conenor	10
	Raisio	10
	Stora Enso	8
	ASM Microchemistry	5
	Aga	4
	Ahlstrom	4
	Fortum	4
	VTT	4
	X-TEC	4
	Andritz	3
	Bio-Nobile	3
	Finnish Chemicals	3
	Keskuslaboratorio KCL	3
	Nextrom	3
	Orion	3
	Uponor	3
	Diamond Blade	2
	Dynea Chemicals	2
	FP-Pigments	2
	Lohja Rudus	2
	Natural Colour K. Kirjavainen	2
	OMS Optomedical Systems	2
	Outokumpu	2
	Parma	2
	Thermo Fisher Scientific	2
	Wärtsilä Finland	2
	Astra Zeneca	1
	Ciba Specialty Chemicals	1

	Corenso United	1
	Cultor	1
	Cuycha Innovation	1
	Draka NK Cables	1
	Drivetec	1
	Ekokem	1
	Elematic	1
	EV Group	1
	Finnfeeds Finland	1
	Finninno	1
	Foster Wheeler Energia	1
	Fotocomp	1
	Glaston	1
	Honeywell	1
	Inventio	1
	Kautar	1
	Liqum	1
	Loparex	1
	Metsä-Botnia	1
	Myllykoski	1
	Nalco Finland	1
	Nokia	1
	POM Technology	1
	Process Team Finland	1
	Pöyry	1
	Tamfelt	1
	Termorak	1
	Timson	1
	Vaahto	1
	Vaisala	1
	Wallac	1
	Wihuri	1
	Zeus Ultrastructures	1
Mechanical eng.	Metso	8
	Unknown	4
	M-real	2
	Wallac	2
	Ahlstrom	1
	Borealis Polymers	1
	Lännen Tehtaat	1
	Orion	1
	Outokumpu	1
	Oxford Instruments Analytical	1
	Planmed	1
	Thermo Fisher Scientific	1
	UPM-Kymmene	1
	Uponor	1
Cons.goods & civil eng.	U-H Rakennus	1
	Unknown	1

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