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HOW GENERAL ARE GENERAL PURPOSE TECHNOLOGIES?

– Evidence from nano-, bio- and ICT-technologies in Finland

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ABSTRACT: General purpose technologies (GPT) have a significant impact on economic activity through radical technological change and wide technological diffusion. This paper aims to address the generality of technologies associated with the GPT concept. Information and communications technologies (ICT), biotechnology and nanotechnology are viewed as existing or potential general purpose technologies, but there is a lack of empirical evidence of their generality. This paper addresses the argument by using patent, industry and company level data from Finland. The results provide evidence that ICT, as expected, is a GPT. Nanotechnology shows signs of being potentially widely applicable, but for biotechnology the channels of technological diffusion seem to be fewer and more focused on areas where Finnish companies are less active. The results and discussion are also reflected on the newly formed innovation policy instrument in Finland - SHOKs (Strategic centres for science, technology and innovation), which aim to direct a large share of the Finnish public R&D subsidies towards more demand-based and incumbent-driven innovation activity.

Keywords: general purpose technology, technology diffusion, science-based technology, ICT, biotechnology, nanotechnology, SHOK

JEL: O30, O33, O38

1. INTRODUCTION

1.1. Background

Technological change has been one of the key drivers of economic growth in the latter part of the 20th century (Romer 1990) and is becoming even more important in the 21st century. Advances in science have driven technological progress, creating completely new industries. These new industry-creating, science-based technologies are sometimes referred to as general purpose technologies (henceforth GPT). GPTs have, due to their enabling generic nature, strongly influenced the development of economic activities, and many have had a significant impact on how industries and even individuals operate (Lipsey et al. 2005).

Examples of historical GPTs are the steam engine, electricity and mass production (Lipsey et al. 2005). A common feature in all of these technologies is that they have fulfilled the following criteria:

1. The technological development related to the initial invention(s) has been rapid, which indicates that there has been room for technological improvement.
2. The technologies are eventually used in many industries across the economy.
3. The technologies are used in many ways within industries.
4. There are eventually both technological and organisational complementary innovations.

The main challenge in identifying a GPT is the long lag between the emergence of the core innovation(s) and associated economic activity. Evidence from information and communication technology (ICT) suggests that even several decades passed between the core innovations and their economic impact (David 1990). However, both findings of time lag, as well as the difficult identification process, are often related to underlying methodological choices.

A typical approach is to use time-series, where the connections between innovative activity (for example, R&D investments or patents) and productivity is analysed. This approach has several challenges, in particular as to how the desired connection is isolated from other factors affecting productivity. This is also one reason why economic literature lacks empirical evidence on GPTs. Thus, a traditional approach requires complementary ways of identifying GPTs when analysing new technologies that might have the potential to become GPTs in future.

The focus in this paper is on modern GPTs that have all emerged from advances in science. The most widely recognised modern GPT is ICT. It has seen a rapid technological change since the emergence of the transistor in the 1950s, which is seen as the starting point for the development of ICT related technologies. Computers have evolved from large bulky mainframes to hand-held devices, and related development of software from stand-alone versions to applications used over the Internet. ICT has developed rapidly, it is used in many industries, in many ways, and it has also led to major complementary innovations such as the Internet.

Other science-based technologies that are discussed as potential future GPTs are biotechnology and nanotechnology. Whereas ICT is a GPT, biotechnology and nanotechnology are still in the fairly early stages of technological development and hence their potential in economic terms is still uncertain.

Biotechnology relates to technological applications that use biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use (OECD 2005). Biotechnology is most often applied in agriculture, food science and medicine. Biotechnology emerged as its own distinct field in 1970s, and has now become a very relevant source for new products and processes, in particular in pharmaceuticals being one of the first adapting industries. The expectations on biotechnology have in recent years diminished as it has been claimed that its major contributions are mainly related to the development of new pharmaceuticals (Hopkins et al. 2007). It is, therefore, somewhat questionable whether biotechnology can be considered a GPT, albeit there is some evidence that the uses of biotechnology is broadening into other application areas such as bio-fuels (NSF, 2008).

Nanotechnology emerged in the 1980s and, compared to biotechnology, it is in an even earlier and more uncertain phase of evolution. Nanotechnology refers to a field whose theme is the control of matter on an atomic and molecular scale (structures of the size 100 nanometers or smaller), and involves developing materials or devices within that scale. It is a multidisciplinary field, ranging from organic to inorganic research areas. It is still unclear what the potential impact of this field is, but it is estimated that the market for nanotechnology based products and processes is large due to its general definition enabling diverse application areas in a variety of industries (Hullman 2006; Nikulainen 2007; Youtie et al. 2008).

As the literature on GPTs argues that all of these three technologies are or have the potential to become a GPT (Lipsey et al. 2005), it is worthwhile addressing the generic nature of these technologies by identifying their existing and potential diffusion paths. Thus, in this paper the generality of these technologies is analysed and discussed. In addition, the public policy efforts related to the further development of these science-based technologies are addressed.

1.2. The aim of the paper

The aim of this paper is to address the generality of modern science-based technologies using Finland as an example of a small open knowledge-intensive economy, where the process of industrial renewal plays an important role also in the future development of the economy. The role and generality of these science-based technologies is established by assessing the role of different actors and their interactions when commercialising scientific knowledge. This allows potential diffusion paths between technology innovators and applying industries to be identified. As GPTs are by definition widely used, it is also relevant to understand how generic and generally applied ICT-, bio- and nanotechnologies are.

This paper contributes to the existing empirical evidence on the generic nature of GPTs by addressing the generality from a technological diffusion perspective. The study complements earlier patents analysis where patenting trends and patent citation indicators have been discussed (for example Youtie et al. 2008). The approach used here highlights the role of larger established companies and their importance in the commercialisation of scientific knowledge. While this paper does not provide insights into the productivity discussion related to GPTs, it introduces aspects related to the potential impact of the emerging GPTs.

The rest of the paper is structured as follows. Section 2 presents the analytical framework addressing aspects related to identifying GPTs and discusses the context of the analysis. Section 3 presents the data and highlights methodological considerations. Section 4 focuses on the results and discusses the analysed GPTs with respect to ongoing innovation policy reforms in Finland. Section 5 draws conclusions.

2. ANALYTICAL FRAMEWORK

The theoretical and methodological framework of this paper relies on earlier work focusing on nanotechnology (Nikulainen 2007). In this paper the perspective is broadened to biotechnology and ICT. The theoretical framework draws upon various different, although connected, streams of literature.

2.1. General purpose technologies

Many technologies possess some of the elements of GPTs but only a few have managed to evolve to finally embody all the characteristics of GPTs. The criterion for a technology to be identified as a GPT varies to some degree in the literature, and the criteria used in this paper build on these earlier contributions (Bresnahan and Trajtenberg 1995; Helpman 1998; Lipsey et al. 2005; Palmberg and Nikulainen 2006). First, a GPT must have *significant technological scope for improvement* so that its operating cost will diminish over time. Second, it also must have a *wide range of users in many industries*, in the sense that a large share of the production activity in the economy uses the technology. Third, a GPT has a *widening variety of uses within industries* as it develops and the costs decline. In other words, it is applied in an increasing range of products and processes. Most scholars also argue that there is a fourth criterion for a GPT, which states that a GPT has to generate a range of other new *complementary technologies and innovations*.

The present study focuses especially on the second criterion of a GPT; a GPT has a wide range of users in many industries. For this statement to be true, a potential GPT should exhibit this variety at a fairly early stage to facilitate the technological diffusion. The present paper addresses this issue by looking at how modern GPTs (ICT, biotechnology and nanotechnology) are technologically linked to existing industries.

The criteria discussed above are based mostly on theoretical work although for some technologies, such as electricity and ICT, empirical evidence supports these conceptual efforts (for example David 1990; Lipsey et al. 2005). While there is some empirical evidence of the impact and general purpose nature of ICT, empirical research is scarce for nano- and biotechnology. Youtie et al. (2008) provide the first empirical evidence that nanotechnology is 'general' when measured through patent statistics. The core inventions in nanotechnology are applied in a broad range of application areas. According to Youtie et al nanotechnology exhibits a similar level of technological generality compared with ICT. This can be seen as an indication that nanotechnology at least has the potential to become a GPT. However, it is far too early to draw any final conclusions.

Youtie et al. (2008) also found that biotechnology, when applied in the field of pharmaceuticals, has lower technological generality than nanotechnology or ICT. This finding is supported by the general development in the field towards drug development and by the relative significance of this one application area over others (see for example Hopkins et al. 2007). Conversely, other potential application industries of biotechnology have received surprisingly little empirical interest.

For this paper these scarce, but insightful, findings suggest that it may be useful to look at the technological generality through a complementary way to Youtie et al. (2008). The generic nature can be explored by identifying technological linkages or similarities between different actors in the process of commercialising science-based technologies. This alternative approach directs the attention to the discussion on the diffusion of technologies and the role of technology life cycles, and, in particular, the different roles that different actors have in this process.

2.2. Technology life cycles and diffusion of science-based technologies

The second related stream of literature discusses technology life cycles and the role of large established companies (incumbents) 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 and incumbent companies can be identified. Incremental innovations build on existing knowledge and rely on existing competences. Hence, incumbent companies are quick to adopt such innovations (Teece 1986). Radical innovations instead build on new knowledge and can sometimes be viewed as disruptive and competence-destroying (Tushman and Anderson 1986). The new science-based entrants master these radical innovations and are stronger in technological competences, 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 (Teece 1986; 2006).

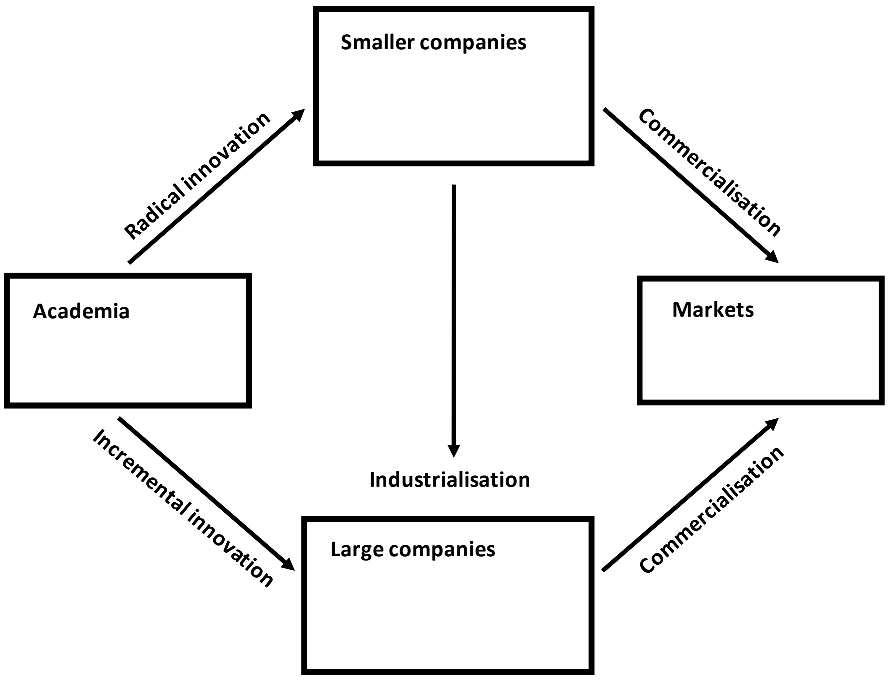
Teece (1986; 2006) has discussed the importance of larger and older incumbent companies and what role they play with respect to new emerging entrants who introduce radical innovations. The main conclusion of this discussion is that the role of incumbent companies depends on its complementary assets (see also 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.

A majority of the empirical contributions in this research area focus on traditional industries. A notable and relevant exception is Rothaermel and Boeker (2007). They analyse the role of incumbents and entrants using biotechnology applications in the pharmaceuticals industry. In their study, the research methods used in biotechnology are viewed as a radical competence-destroying innovation as they do not build on existing knowledge on the identification of potential pharmaceuticals. They find that larger incumbent companies lack the technological expertise, but through their complementary assets (for example 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.

Another recent and somewhat connected empirical study is by Rothaermel and Thursby (2007), in which they assessed whether nanotechnology follows a similar pattern in industrial application as compared to biotechnology. They argue that nanotechnology has the potential to affect a broader range of industrial sectors than biotechnology. One reason for this is that biotechnology focuses on new organic materials, while the definition of nanotechnology includes 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, can play a key role in the commercialisation of innovations introduced by the smaller science-based companies (see also Carlsson and Eliasson 2003; Luukkonen and Palmberg 2007).

The discussion of technology life cycles, radical and incremental innovations and the different roles that actors have in the diffusion of technologies is summarised in Figure 1. Academia is the source of science-based innovations, both radical and incremental, which diffuse to different actors based on the innovation's characteristics. Smaller technology orientated companies develop the "radical" innovation further and can choose either commercialising the innovation themselves or interacting with incumbents, who might have the necessary complementary assets for the commercialisation of the innovation and thus can act as industrialists. If the innovation is incremental by nature, it might be that academia is a direct source for incumbents, who have expertise in the related area. In such a set up, smaller companies do not provide value-added by further developing the innovation. This paper approaches the reasoning above by focusing on the interaction between the smaller technology orientated companies and the incumbents.

Figure 1. The role of different actors in commercialisation



Adapted from Hermans et al. (2009)

2.3. Absorptive capacity

Many of the aspects discussed above are related to 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 relates to the company's ability to value, assimilate and apply new knowledge. With respect to the present study this term is useful in discussing the capabilities of the incumbents to utilise the above-mentioned GPTs. 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 (for example 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 (Cohen and Levinthal 1990). Absorptive capacity is one of the reasons companies invest in R&D instead of simply buying the results, for example patents. Thus R&D investments have a dual role. Firstly, they enhance the company's ability to bring new products to market, and secondly allow relevant external sources of knowledge to be identified. Based on existing literature, it is clear that merely establishing technological linkages between different actors fails to capture the ability of incumbents to absorb the surrounding new knowledge.

To take into account the role of absorptive capacity, after establishing potential linkages between different actors with respect to the science-based technologies addressed, the diffusion of these technologies with a recently introduced innovation policy initiative in Finland is discussed. Strategic centres for science, technology and innovation (henceforth SHOK) are recently formed joint ventures focussing on strategic long-term research meeting the demands of the main industries in Finland. The participants in these ventures include the incumbents in each industry along with universities. One of the main purposes of SHOKs is to facilitate the diffusion of scientific knowledge to companies by bringing the main actors, large companies and universities, closer to co-operation on a long-term basis (Nikulainen & Tahvanainen 2009).

3. METHODS AND DATA

3.1. Methods

The underlying assumption in this paper is that the potential and existing technological linkages between different actors can be measured through the co-occurrence of patenting activity in the same specific technological field. This study aims to identify *potential* linkages between smaller companies and incumbents. By identifying these linkages between different groups, it is possible to assess to what extent the science-based technologies link to the existing technological competences among the larger incumbents.

In the prior literature the most interesting and methodologically relevant empirical research is by Rothaermel and Boeker (2007). They discuss the switch from older to newer technologies and its impact on complementary assets, and technological similarities and alliance formation, in the context of bio- and nanotechnology companies in the US. They find that 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 similarity of patent citations between smaller companies and incumbents, increases the likelihood of alliance partnerships. In this paper the technological linkages for nano- and biotechnology are analysed at a more general level: by comparing which incumbent companies have had patenting activity in the exact same technological classes as the smaller companies.

As ICT is a more established technological field compared to bio- and nanotechnologies, a slightly different method for analysis is employed. Patent classification systems, in particular IPC (International Patent Classification), are well-established in this technological area and, thus, companies active in the field can be directly identified. When this patent information is linked to industry classifications, the companies developing ICT related technologies and the industries they represent can be identified. However, this approach also creates a dilemma that needs to be addressed. Only technological inventions can be patented in Europe (at the European Patent Office), which means that only inventions related to hardware can be identified if patent data is used. Patent analysis reveals only part of the development in ICT, as developments related to software are largely ignored. A complementary approach is clearly needed. Using input-output data on industrial production, the significance of software for different industries can be identified. This is possible as the National Accounting measures the output of the software industry as an input to other industries.

3.2. Data

The data used in this paper comes from several different sources. The data source for patent information varies depending on the technology in question. For nano- and biotechnology an online patent database was used (Delphion-online), which allows efficient identification based on similarities in IPC classifications. For ICT, the source for patent information is PATSTAT database, which is a stand-alone database development and managed by EPO on behalf of OECD (the version used in this paper is the April 2008 edition). The PATSTAT database allows more efficient analysis of larger data, which is necessary when analysing activities in ICT and especially in Finland due to the large size of the ICT related industry.

The smaller companies related to nanotechnology were identified through secondary data sources (publically available documents collected and analysed in June 2007 – see Nikulainen 2007). The biotechnology related smaller companies were identified from the Finnish Bioindustries website (accessed in December 2008), which is the association for Finnish biotechnology related companies and represents most biotechnology companies in Finland. The ICT related companies are recognised solely from the patent data by identifying companies active in ICT related IPC patent classes as discussed above. To highlight the changes within the ICT, company level data from Statistics Finland is also used to indicate the change from hardware development to software development.

The results for nanotechnology, as applied from Nikulainen (2007), represent the situation in the summer of 2007. For biotechnology and ICT the data was collected and analysed in December 2008. In addition, the input-output data, used to highlight the use of software in different industries, is from Statistics Finland for year 2005.

4. EMPIRICAL EVIDENCE AND DISCUSSION

4.1. Industries and linkages

RTA indexes

The main context for the 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). It should also be noted that many of the incumbent companies only operate marginally in the GPT related R&D activities (the exception being the ICT related industry). In the present study, the interest is on the technological linkages of smaller companies and incumbents. But, before going to the actual analysis it is worthwhile highlighting an earlier related finding by Nikulainen (2007) where the revealed technological advantage of Finland and, in particular, bio- and nanotechnologies are discussed (Table 1). By using the Revealed Technological Advantage (RTA) index (see Soete 1987 for more details) 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. The groups are: the world, Finland, smaller Finnish bio-companies, and smaller Finnish nano-companies. By using these reference groups, (papers should be impersonal) the relative specialisation that the groups have in relation to each other can be measured.

Table 1. The Revealed Technological Advantage (RTA)

	Finland vs. World	Small nano-comp. vs. Finland	Small bio-comp. vs. Finland
	n= 24 019	*n= 167*	*n= 255*
Electrical engineering	**1.53**	0.21	0.15
Instruments	0.68	**2.81**	**2.45**
Chemicals & pharmaceuticals	0.42	**2.08**	**5.54**
Process engineering	**1.49**	**2.01**	0.62
Mechanical engineering	0.93	0.15	0.07
Cons. goods and civil eng.	**1.10**	0.09	0.06

Note: An RTA index higher than 1 indicates that the group is more specialised in the particular technology area than the comparison group.
Source: Nikulainen (2007)

It is evident that Finland is technologically specialised in electrical engineering, process engineering and consumer goods and civil engineering when the world patenting is the reference group. This shows that ICT (within the 'Electrical engineering') has had significant impact on the technological landscape of the Finnish industry.

When the distribution of bio- and nano-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. 2008). Smaller nano-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 specialisation. Finnish biotechnology is specialised in instruments, chemicals & pharmaceuticals and has some activities in process engineering. However, biotechnology fails to have significant levels of activity in other areas, and its strengths are in technological classes where the Finnish industry shows no specialisation. The strength in chemicals & pharmaceuticals in both nano- and biotechnology also suggests that there is a connection between these two technologies.

Matching company patents

RTA indexes provide interesting insights into the technological specialisation of different groups and their potential linkages. However, the indexes focus on technologies rather than company activity, and hence a connection needs to be established between the technology fields and industries. To that end smaller biotechnology and nanotechnology orientated companies are matched based on the IPC classification (International Patent Classification) of their patents with other Finnish companies that have patenting activity in the exact same patent class. The underlying assumption of this methodology is that potential inter-industry linkages are reflected in a co-occurrence of patents in the same technology classes (Nikulainen 2007). The rationale for these linkages is based on the proximity of knowledge bases. The patent classes were identified on a very detailed five-digit level.

Based on this patenting activity in the same patent class, a potential technological linkage is established between dedicated bio- and nanotechnology companies and larger incumbents.[1] For ICT, patent classes

[1] It should be recognised that having patenting activity even in exactly the same patent class is only a potential linkage, not necessarily an established one.

are directly used to identify the larger incumbents as this field is more established than the other two fields.

The incumbents linked to GPTs are often multinational companies, which are key components in sustaining the overall economic performance of Finland. It is important to understand to what extent disruptive technologies can provide new methods to enhance the industrial renewal of the larger incumbents. Table 2 shows industry linkages to the respective GPT. It should be noted that for ICT the results are for established linkages, whereas for the still emerging bio- and nanotechnologies the linkages are consequently mostly potential rather than established.

Table 2. The number of large Finnish companies associated to GPTs based on patenting activity

Industry	**Nanotechnology**		**Biotechnology**		**ICT**	
	Potential links		*Potential links*		*Established links*	
	# of companies	%	*# of companies*	%	*# of companies*	%
Electronics	4	8.2	7	13.0	17	34.0
Foodstuff	5	10.2	7	13.0	0	0.0
Energy	1	2.0	2	3.7	1	2.0
Chem. and plastics	11	22.4	13	24.1	4	8.0
Metal and machinery	13	26.5	4	7.4	9	18.0
Paper and Forest	6	12.2	5	9.3	3	6.0
Miscellanous	1	2.0	0	0.0	1	2.0
Construction	5	10.2	1	1.9	1	2.0
Textiles	1	2.0	0	0.0	0	0.0
Services	2	4.1	3	5.6	2	4.0
Telecom. & software	0	0.0	12	22.2	12	24.0
Total	**49**	**100.0**	**54**	**100.0**	**50**	**100.0**

Source: Statistics Finland

For nanotechnology 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 plastics (including pharmaceuticals). Thus it is clear that nanotechnology potentially has technological linkages to various industries which have various degrees of R&D activity. This finding also supports the earlier findings that nanotechnology shows signs of becoming a GPT (for example Youtie et al. 2008).

Interestingly, biotechnology has links to electronics, metal engineering and, most interestingly, telecommunications and software. These links are based on a single company creating methods and hardware to model organisms in a systemic way. Thus, the company is active in the same patent classes as the ICT cluster. If the companies linked only to this single outlier company were to be excluded from the discussion, the number of linked incumbent companies drops from 54 to 31. The remaining companies have more obvious links to biotechnology. Chemicals and plastics (including pharmaceuticals), foodstuff and forest industries are areas where biotechnology is either applied or where there is a significant amount of interest to create biotechnology based solutions. While biotechnology seems to be somewhat more focused on specific industries than nanotechnology, it does have a fairly wide potential application base.

In ICT, the established linkages are existing, not only potential. This explains the somewhat surprisingly low number of identified incumbent companies. The most related industries are electronics, metal engineering and telecommunications and software. This finding highlights that the analysis is on hardware, such as development of components. ICT is also related to software, which can be seen as a complementary innovation to the initial development on the hardware side. As software cannot be patented in Europe, the results clearly underestimate the widespread impact of ICT. Only a limited number of incumbents are operating with the development of hardware, but many can be assumed to develop or use software. Therefore, the role of software and its usage needs to be addressed separately.

Software use in different industries

Input-output data is used to highlight the role of software in selected industries. The inputs from the software industry (NACE 72) to other industries are derived from the National accounting. Table 3 shows the distribution of software inputs across different industries. The NACE classification and its definition are in the first and second column. The third column indicates the volume of inputs from software industry to other industries, and the fourth column shows the overall employment for the industry in question. In the fifth column the relative use of software with respect to the industry employment is presented, and finally in the fifth column the 'intensity' of the use of intangibles is categorised as 'high' (dark gray shading) if the software input is more than twice the total intensity in the economy (> 2.16), 'medium' (light gray shading) if between the twice and the total, and 'low' (no shading) if below the total (<1.08).

The results provide an indication of the role of software in various industries. The industries with high software intensity include, in order of intensity, energy production, energy sources, electrical machinery & telecommunications equipment, computers services, financial services, pulp & paper, basic metals, and publishing & printing. Other industries exhibit lower levels of intensities, but over all a clear conclusions emerge. Software is widely applied in varies industries and, while not measured here, most likely also applied extensively within these industries in various ways.

The increasing importance of the software industry is also evident from the number of new start-ups as indicated in Figure 2. It shows that the economic significance of hardware vs. software industries has dramatically changed in recent years when assessed through the number of new companies per period and by industry.

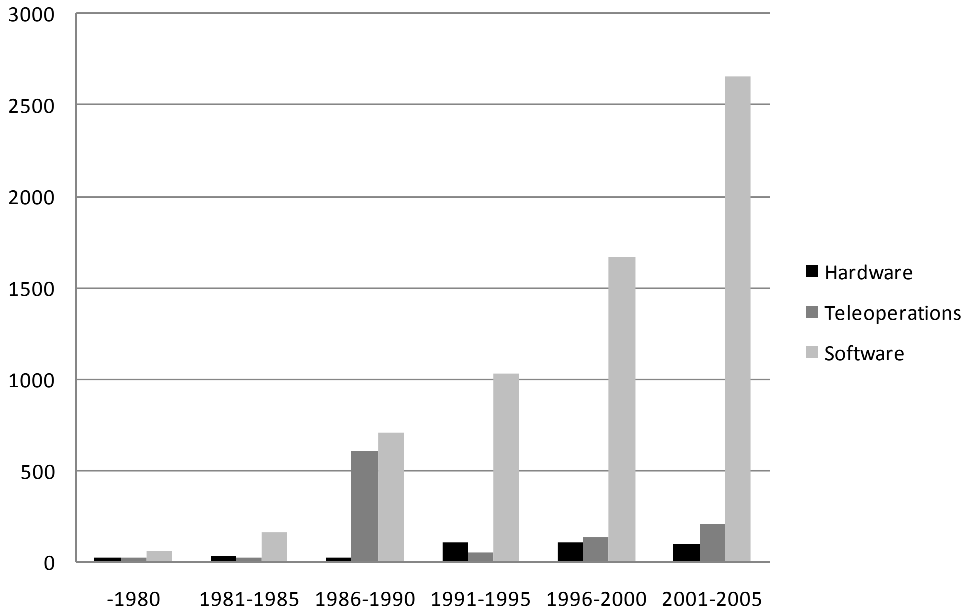
Table 3. The role of software in the Finnish economy

NACE	NACE definition	Software input / mil. euro (2005)	Employment in 1000s (2005)	Software input / Empl. 1000s	Level of intensity
1-5	Agriculture & forestry	8	100.69	0.08	L
10-14	Mining	4	4.28	0.93	L
15-16	Food & tobacco	42	38.63	1.09	M
17-19	Textiles & leather	7	15.59	0.45	L
20	Wood products	19	27.77	0.68	L
21	Pulp & paper	93	35.25	2.64	H
22	Publishing; Printing and recording	72	30.97	2.32	H
23	Energy sources	16	2.24	7.15	H
24	Chemicals	36	17.32	2.08	M
25	Plastics	14	17.88	0.78	L
26	Other non-metal	18	15.16	1.19	M
27	Basic metals	37	15.35	2.41	H
28	Metal products	27	38.40	0.70	L
29	Machinery	113	56.19	2.01	M
30-33	Electr. mach.; Telecom. eq.	337	65.28	5.16	H
34	Vehicles	5	7.45	0.67	L
35	Other transport	12	13.70	0.88	L
36-37	Furniture & recycling	11	16.27	0.68	L
40-41	Energy production	109	15.10	7.22	H
45	Construction	18	118.54	0.15	L
50-52	Trade & repair	167	249.49	0.67	L
55	Hotels & restaurants	7	60.60	0.12	L
60-63	Transport & travel	85	111.17	0.76	L
64	Post and telecommunications	39	42.66	0.91	L
65-67	Financial services	172	43.63	3.94	H
70	Real estate	61	31.69	1.92	M
71	Leasing	4	3.25	1.23	M
72	Computer services	137	34.42	3.98	H
73	R&D	19	15.09	1.26	M
74	Other services	80	142.78	0.56	L
75	Public administration	192	120.88	1.59	M
80	Education	101	141.25	0.72	L
85	Health and social work	85	294.34	0.29	L
90-93	Other social services	51	98.84	0.52	L
ALL		2198	2042.15	1.08	

Note: the 'intensity' of the use of intangibles is categorised as 'high' (dark gray shading) if the software input is more than twice the total intensity in the economy (> 2.16), 'medium' (light gray shading) if between the twice and the total, and 'low' (no shading) if below the total (<1.08).

Source: Statistics Finland

Figure 2. Number of new companies per period by industry



The results show that hardware is a stable or even declining industry in Finland, while the software industry is experiencing a growth trend. This suggests that the nature of ICT as a GPT is changing from technological solutions towards services, of which software is one manifestation. This finding is similar to earlier results looking at labour flows between industries (Maliranta and Nikulainen 2008).

So far the results provide evidence of the generality of the science-based technologies in Finland. The analysis is concluded by addressing the ability of incumbents to absorb developments in these fields. In the following the absorptive capacity aspect is discussed by linking the above results to the recently introduced innovation policy instrument in Finland - SHOKs.

4.2. SHOKs and technological linkages

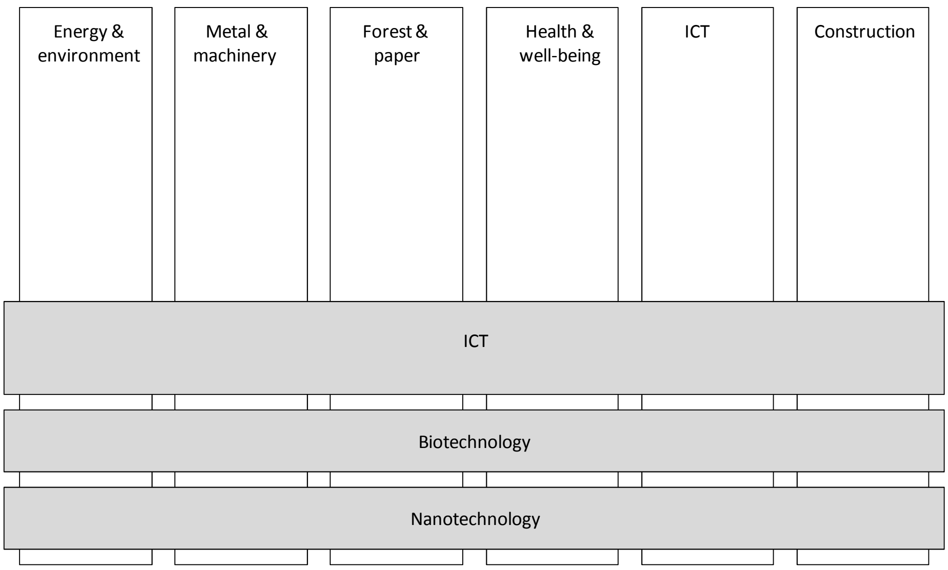
The Strategic Centres for Science, Technology and Innovation (SHOKs) are public-private joint ventures, which consist of selected companies, universities and research institutes. The creation of SHOKs is based on a Finnish government initiative, which aims to promote science and technology in fields deemed vital for the future of the Finnish economy. The process of selecting the industries for the creation of SHOKs is still partially ongoing. By August 2009 the following SHOKs -and the underlying joint ventures- have either been established or will be established: 1. Forest and paper, 2. Metal and machinery, 3. Energy and environment, 4. ICT, 5. Healthcare and well-being, and 6. Construction and maintenance. The idea behind establishing these SHOKs was to bring together different actors in related fields of industry, technology and science in order to set up long-term research agendas that would cover the R&D needs of the companies for 5-10 years.

The research agenda of SHOKs will be on a strategic level focusing on industry needs rather than specific company needs; they can be viewed as supporting public policy efforts towards demand-based innovations. The goal is to promote R&D collaboration between industry and academia on a long-term basis rather than the current situation where most collaboration is often short-term and mostly focused on specific industry needs. Through SHOKs it is hoped that universities would be more able to understand industry needs while at the same time maintaining their academic freedom for research (Tahvanainen 2009). While the claims are controversial, in the data the discussion is limited to the above identified technological linkages and their connection to SHOKs. For more in depth discussion of the SHOKs see Nikulainen and Tahvanainen (2009).

As a novel policy instrument SHOKs might have a significant impact on the future public and partially private investments into the SHOK-specific technologies. As GPTs by definition are widely used, it is relevant to understand how general the technologies are, and what their potential role is for each of the SHOKs.

The research set up illustrated in Figure 3 highlights the different nature of the modern GPTs as nano- and biotechnology are more enabling technologies and ICT is an industrial sector on its own.

Figure 3. SHOKs and GPTs



Similarly, mainly enabling technologies are commercialised by industrialists, whereas others such as ICT are directly taken to the market. In the Finnish context biotechnology aimed towards sector-level activity, but instead emerged mostly as external R&D labs (Rothaermel and Thursby, 2007) for pharmaceutical firms, and nanotechnology as an enabling technology and most likely will not be a sector on its own (provides tools, methods and materials for existing industries). Table 4 provides more details of the companies, related SHOKs, and the total number of companies associated with each SHOK.

Table 4. Linkages between ICT and SHOKs

ICT	**Construction**	**Energy & environment**	**Forest & paper**	**Health & well-being**	**ICT**	**Metal & machinery**
Associated large firms (top 10 by employees, when applicable)	Hartela	ABB* Fortum* Vacon	Alma Media Dynea Chemicals Gemalto Metso Paper M-real UPM Raflatac UPM-Kymmene	GE Healthcare Planmeca Wallac	ABB Comptel EADS Secure Networks Elisa* F-Secure Nokia* Nokia Siemens Networks* Powerwave Comtek TeliaSonera Finland* Tellabs	ABB* Honeywell Metso* Patria Vehicles Polar Electro Rautaruukki* Vacon Vaisala VTI Technologies Wärtsilä Finland
# of companies	2	11	14	7	115	40
# of large comp.	1	4	8	3	24	11

*The company is a member of the SHOK in question

It should again be noted that for the ICT existing linkages are discussed rather than potential ones, as is the case for the bio-and nanotechnologies. As expected ICT, in this case of hardware, is linked to the ICT and metal and machinery SHOKs. However, linkages between forest and paper industries can also be seen suggesting ICT also has an impact on this sector. As with the previous analysis, the role of software is underrepresented and it could be expected that most SHOKs are linked to ICT through the usage or development of software. Thus, it can be said that the developments in ICT are strongly connected on all SHOKs.

Table 5. Linkages between biotechnology and SHOKs

Biotechnology	**Construction**	**Energy & environment**	**Forest & paper**	**Health & well-being**	**ICT**	**Metal & machinery**
Associated large firms (top 10 by employees, when applicable)	FCG Planeko* KWH Pipe Lassila & Tikanoja Paroc Uponor	CIBA Finland Fortum* Kemira* Neste Oil*	Alma Media Huhtamäki KCL Metso* M-Real* Stora Enso* UPM-Kymmene*	Alko Bayer Schering Pharma HK Ruokatalo Instrumentarium Leiras Oriola Orion Thermo Fisher Scientific Valio Wallac	Comptel Digita Elisa* L M Ericsson* Nokia* Perlos Tecnomen Teliasonera Finland* Tellabs Vaisala	ABB* Ahlstrom Kone* Metso* Oras Outokumpu*
# of companies	6	13	8	154	61	13
# of large comp.	4	4	6	21	15	4

*The company is a member of the SHOK in question

In Table 5 above the linkages between biotechnology and SHOKs are presented. Similar to ICT, the one outlier company links biotechnology much more broadly than expected, in particular to ICT and metal and machinery SHOKs. For the other SHOKs there is a wide range of potential users for biotechnology related research. Health and well-being, forest and paper, energy and environment, and construction SHOKs have links to biotechnology suggesting that it could potentially be applied in a variety of areas, in particular when chemical processes are concerned. Particularly interesting findings are the linkages to foodstuff companies and to forest and paper, where the development of biotechnology based processes and products has been ongoing for some time (Hermans et al 2006, Hermans et al 2007, Luukkonen et al 2004).

Table 6. Linkages between nanotechnology and SHOKs

Nanotechnology	Construction	Energy & environment	Forest & paper	Health & well-being	ICT	Metal & machinery
Associated large firms (top 10 by employees, when applicable)	Glaston Lohja Rudus Nordkalk Partek Savcor Teknoware Uponor Saint-Gobain Isover	Dynea Fortum* Foster Wheeler* Kemira*	Huhtamäki KCL Metsä-Botnia* M-real* Myllykoski* Pöyry Stora Enso* UPM-Kymmene*	Astra Zeneca Ciba Finland Danisco Sweeteners Leiras Finland Orion Raisio Santen Thermo Fisher Scientific Valio Wallac	Honeywell Nokia*	Ahlstrom Andritz* Kone* Metso* Outokumpu* Rautaruukki* Tamfelt Vaahto Vaisala Wärtsilä Finland*
# of companies	13	9	14	45	6	16
# of large comp.	8	4	9	15	2	11

*The company is a member of the SHOK in question

Table 6 shows that also nanotechnology has a wide range of linkages to SHOKs. Of particular interest is the limited number of linkages to the ICT SHOK, which could be due to the enabling nature of nanotechnology. Currently, nanotechnology might relate to process technologies rather than end-products. Thus the role that nanotechnology plays in the ICT SHOK might emerge from the future development of components for ICT related companies. For other SHOKs it can be seen that nanotechnology links particularly to metal and machinery, health and well-being, forest and paper, and construction. This suggests that nanotechnology might be as generic as proposed in the literature, but as with biotechnology, it should be noted that both of these technologies are still in a fairly early stage of technological evolution.

5. CONCLUDING DISCUSSION

This paper aimed to identify some indication of the technological generality of ICT, biotechnology and nanotechnology with respect to the Finnish industries. These results were then linked to the discussion of SHOKs. Overall the results provide an interesting insight into the generality of these technologies. It can be concluded that ICT is a GPT, with a wide range of application areas on the hardware side and, in particular, on the software side. For biotechnology the potential diffusion paths seem to be somewhat more limited as biotechnology is focused on areas where the industrial activity in Finland is more limited, such as pharmaceuticals. At the same time there are linkages to areas, such as foodstuff and forest and paper industry, where development work is ongoing [and the potential biotechnology is still uncertain]. Compared to biotechnology, nanotechnology exhibits a somewhat broader set of potential diffusion paths in areas where the Finnish industries are active such as the metal and machinery and the forest and paper industries.

When assessing the association between technologies and SHOKs, a variety of linkages can be found between the science-based technologies and SHOKs. While there seems to be existing and potential linkages, it should be noted that the generic nature of the GPTs poses challenges for the SHOKs.

Firstly, SHOKs are built around industry needs focused more on problem solving than advancing scientific knowledge. Thus there is a potential gap between the different actors in identifying the potential uses for these generic technologies. Secondly, the research efforts in these science-based technologies might require some coordination between SHOKs not only to reduce the potential duplication of research efforts, but also to identify potential applications in areas related to SHOKs other than in the one the research was conducted. Thirdly, in the current form SHOKs mostly exclude the SMEs from participating in the formulation of the research agendas. In fact, in most SHOKs smaller companies are even excluded from participating directly as a result of high initial monetary entry investments. This is an issue that may hinder the diffusion of more radical technologies. Fourthly, SHOKs are designed to direct the innovation policy towards industries and applications rather than technologies (as was the case to some extent in the past). This may create a problem where the R&D investments are too application oriented and, thus, widen the gap between basic science, applied science and commercial applications. Fifthly, SHOKs have their own R&D agendas focusing on the industry specific needs, and their operation is financed mostly by Tekes (The Finnish Funding Agency for Technology and Innovation). In addition, Tekes finances technology specific programmes, such as programmes related to nanotechnology (such as FinNano programme), and has had bio-related programmes. The current plan is to increase the SHOK funding and decrease the funding for technology programmes. This might create a problem for generic technologies, such as the GPTs discussed above, as their funding base is decreasing, and at the same time many of the innovations might not be industry specific as are the SHOK R&D agendas.

There are naturally limitations to this study. First, the analysis is mostly descriptive and focuses on foresight rather than providing statistical evidence on the impact of these technologies on industries. It could be argued that to understand the potential impact of these technologies it is necessary to make some assumptions and explore potential paths of future development. Second, when interpreting the results, it should be noted that patents are more related to product innovations than to process innovations, which are very relevant for some of the SHOKs, such as construction, and forest and paper. These aspects are left for future studies that may resort to more qualitative methods to provide a more in-depth analysis on the roles of different types on innovations within the SHOKs.

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