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MODES, CHALLENGES AND OUTCOMES OF NANOTECHNOLOGY TRANSFER

– A Comparative Analysis of University and Company Researchers*

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ABSTRACT: Nanotechnology has been proposed as the next general purpose technology and engine for growth for the 21th century. Increasing public R&D investments are foremost reflected in the growth of scientific publications, while nanotechnology still is in an uncertain phase of development with various directions of commercialization pending. This paper focuses on the challenge, modes and outcomes of nanotechnology as an emerging science-based field in Finland. The paper contributes by interrogating how challenges and modes of nanotechnology transfer differ across universities and companies and determine outcomes broadly defined. It uses an extensive survey data covering university and company researchers in the Finnish nanotechnology community. The results show significant differences in the perceptions of researchers across these organisations, and highlight specific challenges and modes as determinants of outcomes. The specificities of nanotechnology are also assessed in this context.

KEYWORDS: nanotechnology, technology transfer, Finland, survey data

JEL: O31, O32, O38

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TIIVISTELMÄ: Nanoteknologiasta povataan tämän vuosisadan seuraavaa yleiskäyttöistä teknologiaa ja talouden kasvun moottoria. Mittavat maailmanlaajuiset T&K-investoinnit nanoteknologiaan näkyvät kuitenkin etupäässä alan tieteellisten julkaisujen kasvuna, kaupallistaminen on vielä varhaisessa vaiheessa ja nanoteknologian sovellusmahdollisuuksia kartoitetaan parhaillaan. Tässä tutkimuksessa keskitytään nanoteknologian siirron haasteisiin, muotoihin ja tuotoksiin. Tutkimus pohjautuu laajaan kyselyaineistoon, jonka avulla voidaan huomioida suomalaisten yliopisto- ja yritystutkijoiden erilaiset näkemykset nanoteknologian siirtoon ja näiden vaikutukset patenttien ja uusien tuoteideoiden syntymiseen. Tulosten mukaan yliopisto- ja yritystutkijoilla on selvästi erilaisia näkemyksiä nanoteknologian siirron haasteista ja teknologian siirron muodoista, ja nämä näkemyserot vaikuttuvat osittain myös tuotosten saavuttamiseen. Tutkimuksessa käsitellään lisäksi nanoteknologian erityspiirteitä teknologian siirron kannalta.

AVAINSANAT: nanoteknologia, teknologian siirto, Suomi, kyselyaineisto

JEL: O31, O32, O38

CONTENT

1. Introduction

1.1. Background

Since the seminal paper by Arrow (1962) on the appropriability of basic research it is well understood that private sector incentives for R&D investments are below the social optimum because of the public good character of knowledge. This is particularly the case for science-based technologies in which small companies lack research instrumentation, manpower and other resources. Larger companies might also be reluctant to invest, especially when technologies are in their early and uncertain phase of development. In this context the role of government funded R&D undertaken in the university is important, and the transfer of technology from the university to companies becomes paramount.

The importance of technology transfer has been widely discussed in policy circles. The productivity slowdown of the 1970s and 1980s in the US was partly considered a result of slow rates of commercialization of university research. Various reforms were introduced, the most publicized of these being the Bayh-Dole Act of 1980 allowing universities to own the intellectual property rights (IPRs) of their publicly funded research. The ATP-program, facilitating research venturing between universities and companies, is another much cited example from the US.

In Europe the EU also initiated new programmes, such as the Framework Programme, to boost collaboration between universities and companies (Poyago-Theotoky et al., (2002)). Today most highly developed countries have developed various intermediating structures to support technology transfer. Over the last twenty years a `third role´ of universities has emerged alongside research and teaching. Universities are to a greater extent expected to interact with the broader society, in effect also enforcing upon them a more entrepreneurial stance towards the commercialisation of science (Etzkowitz et al., 2000; Miettinen et al., 2006).

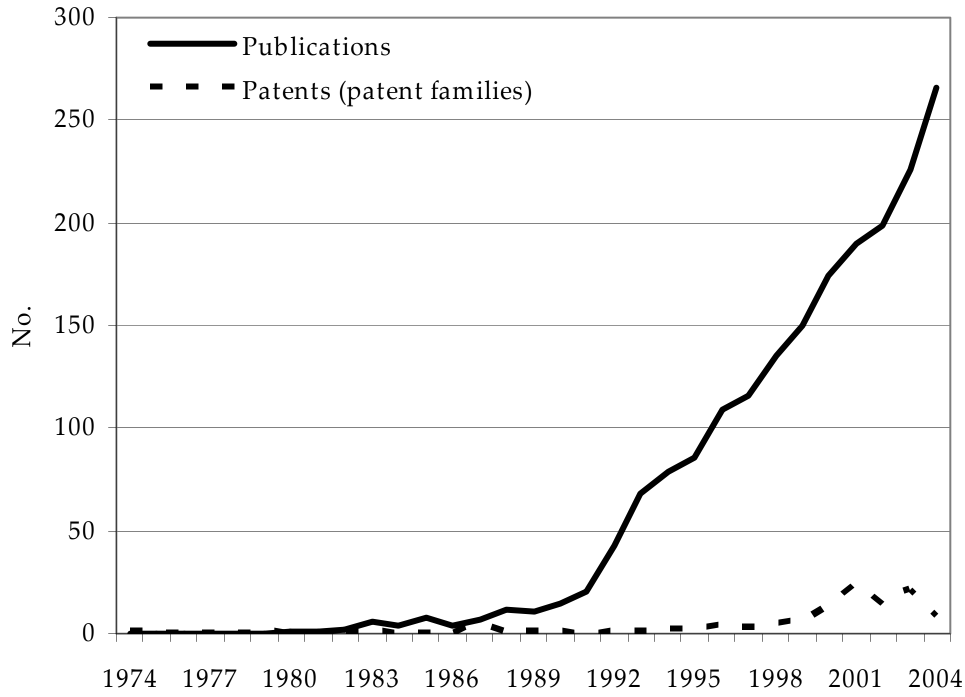
This paper focuses on the transfer of nanotechnology from the university to companies in Finland. Nanotechnology is an important example of an emerging technology field that still is primarily basic research oriented, but for which there are huge – and partly hyped – commercial expectations. Nanotechnology might indeed develop into a general purpose technology (GPT) and engine of growth for the 21th century (Lipsey et al., 2005; Palmberg and Nikulainen, 2006; Youtie et al., 2007). Nonetheless, nanotechnology is still in an early and uncertain phase of development with various directions of commercialization pending. This immaturity and uncertainty might lead to contrasting perceptions of universities and companies during technology transfer on top of those that already characterize the interactions between the universities and companies generally (see Bozeman (2000), Valentin (2000) for reviews of this literature, see also Audretsch et al. (2002)). In particular, very little is yet known about favourable conditions for the transfer of nanotechnology to industry, as well as how universities and companies different perceptions of the modes and challenges of technology transfer affect the development and commercialization of this emerging field.

1.2. Aim and structure of paper

In Finland technology transfer is at the core of innovation policies, due to the various technology programs that are initiated to facilitate interactions between universities and companies (Ylä-Anttila and Palmberg, 2007). Nanotechnology has raised high expectations also in Finland and this field is being promoted by two dedicated programs (the FinNano-programs) and various other initiatives, adding up to the approximate total of approximately 100 million euros of ear-marked public funding by the end of this decade. This is a noteworthy amount also in international comparisons.

Even though Finland is comparatively strong in the field as measured by the number of scientific publications as in most other countries, commercialization activities are in a very early phase, at least when judged by patenting (Figure 1). One key question for the Finnish utilization of, and competitiveness in, nanotechnology is therefore how the scientific knowledge base residing at universities might be better capitalized also in the commercial sphere through technology transfer.

Figure 1. Finnish nanotechnology publications and patents 1990-2004



Source: INPADOC and SciSearch databases

This paper uses a new and unique survey data covering individual researchers at universities and their counterparts in companies in Finland with documented R&D activities in nanotechnology and related fields. It aims to interrogate how perceptions of university and company researchers differ in terms of technology transfer from the viewpoint of challenges, modes of interactions and outcomes. It also aims to analyse how these different perceptions determine the outcomes of technology transfer through multivariate analysis.

This paper contributes to the empirical literature by using new survey data covering individual researchers (evidently such individual-level data is rarely available and used in extant research, for a couple of similar datasets see especially Landry et al. (2005), Brennenraedts et al. (2006), as well as Louis et al. (2001), Agrawal and Henderson (2002)). Another unique feature is that this data can be analysed comparatively across universities and companies to test how companies perceptions of technology transfer differ in the dimensions mentioned above, as well as how these differences affect outcomes. Further, it contributes to the specific literature on the economics of nanotechnology that hence far still is scant and mostly conceptual, and that has primarily relied on aggregate science and technology indicators (see e.g. forthcoming Special Issue on Nanotechnology in Research Policy, Youtie et al. (2007), Meyer (2000) for an early contribution).

This paper is structured as follows. Section 2 presents the analytical framework and discusses extant research in the context of nanotechnology to frame and motivate the empirical part. Section 3 moves to the empirical analysis, starting off with univariate analysis of the different perceptions of universities and companies and ending with a multivariate analysis of how challenges, modes of interaction and various control variables affect outcomes when the affiliation of researchers is taken into account. Section 4 concludes the paper. The survey data is presented in greater depth in Palmberg et al. (2007).

2. Analytical framework and extant research

2.1. Challenges in technology transfer

Technology transfer can be discussed in relation to theoretical models that highlight the interactive feature of innovation (Kline and Rosenberg, 1986; Miettinen et al., 2006). In these models technology transfer covers the processes whereby companies draw on external scientific and technological developments in universities (and public research institutes) during innovation, especially in science-based industries. The models highlight the continuous nature of this interaction between companies and universities, and also suggest that industrial innovation can provide new ideas for scientific developments (Kline and Rosenberg (1986), see also Franzoni (2006)).

Bozeman (2000) notes that the definition of technology transfer is tricky in practice and requires consideration about what one means with `technology', and how technology differs from `knowledge'. Consideration is also required about the definition of the organisational boundaries that technology is to cross during its transfer. In this paper we define technology transfer as the *"…active interaction between researchers from universities and private sector companies. It covers the transfer of research information* *and results from the university to private companies and the related knowledge in a broader sense"* (for a further discussion see Palmberg et al. (2007)).

One long-lasting discussion has been about how and why universities and companies differ in their incentives to engage in technology transfer, and how these differences affect the outcomes (for an extensive discussion on the incentive structures of scientists see Stephan (1996)). Universities and companies are two very different environments. As interactive models of innovation suggest the main objective of companies is to carry out applied research for realizing innovations. In contrast, universities are of tradition focused on basic research for the general advancement of knowledge and academic degrees. This still applies even though universities have been given their new third role.

Set against these fundamental differences between universities and companies several empirical studies highlight specific challenges during technology transfer. We refer here to the review by Valentin (2000), updated with some new contributions. First of all, *companies might place restrictions* on research topics chosen by university researchers. These restrictions might relate to mismatches in the basic research orientation of university researchers and the applied needs of companies (see e.g. Schartinger et al. (2001)). Companies might also impose restrictions on the publication of results in so far as these infringe with secrecy and IPR issues. In contrast, university researchers are under pressure to make public their research in scientific journals as soon as possible.

Related to IPR issues, the possibilities *to appropriate research results* will also vary and is dependent on the particular legislative regime that different countries and universities impose on their researchers. There is, for example, a large literature on the effects and lessons of the Bayh-Dole Act on technology transfer in the US (see e.g. Mowery and Sampat (2004)). It should also be noted that legislative regimes surrounding IPRs over academic research differ across countries. For example, in Sweden researchers still own patent rights over their publicly funded research while Germany, Finland and most other countries have transferred this right to the university.

Communication problems might also arise. Extant research has considered how the degree of codification of knowledge and different modes of interaction relate to challenges and outcomes of technology transfer (Schartinger et al. (2001); D'Este and Patel

(2005)). The transfer of knowledge of more tacit nature tends to require human mobility across organisational boundaries or other more intense and direct modes of interactions with companies Zucker et al. (2002). Valentin (2000) also highlights a general lack of interest of companies as a challenge, while universities might be sometimes be perceived as taking a passive role towards companies at the outset.

Cultural issues are often highlighted even though these are difficult to capture in empirical analysis. Universities and companies operate according to different ethical codes. The former prioritizes common ownership of scientific knowledge, freedom to publish research results also of more critical and sensitive nature, professional prestige and independency. In contrast companies obviously tend to protect the secrecy and privacy of research that feeds into new technologies, products or processes, companies invest in research to obtain shorter-term and commercial benefits (although they sometimes also do so to enhance their absorptive capability vis-à-vis university research). Further, universities are almost per default more bureaucratic in their organisational set-up, and less flexible to rapid shifts in research needs than companies (Valentin, 2000).

2.2. Modes, contexts and outcomes of technology transfer

Extant research has stressed that one should take a broad viewpoint on the outcomes of technology transfer. Not only patents, licensing of research results for new products and processes should be considered. Technology transfer also involves the related knowledge whereby companies receive ideas that only subsequently, with a time lag, lead to new products and processes, increasing market shares and profitability. This viewpoint is indeed in the spirit of interactive models of innovation that highlight the continuous nature of interactions between universities and companies (Bozeman, 2000; Landry et al., 2005).

In extant research, where a broader viewpoint on the outcomes of technology transfer is adopted, an econometric set-up is often used in which explanations are sought for why some university researchers interact more intensively with companies through particular modes than others. Thus, distinctions are made between participation in conferences involving companies, R&D consulting, contract research with companies, science and technology programs involving companies, human mobility and temporary employment at companies. It is often assumed that the latter ones represent more intensive modes of interactions and joint idea generation, while the former represent looser and more occasional modes. Patenting, licensing, commercialization and various types of research based spin-off activities are also considered although not stressed too much. (Bonaccorsi and Piccaluga, 1994; Schartinger et al., 2001; Landry et al., 2005; d'Este and Patel, 2005).

Extant research has foremost been concerned with technology transfer between universities and companies in quite narrowly defined research fields while especially the diversity of sectoral context for the application of research has not been considered (Schartinger et al. (2002) appears to be one of the only exceptions). The nature of the research field involved in technology transfer as well as the sectoral contexts of application industries are especially important to consider in the case of nanotechnology. As suggested nanotechnology already now bears some of the hallmarks of a general purpose technology, the clearest ones being its potential applicability in a wide range of industries as well as its multipurpose nature (see Lipsey et al. (2005); Palmberg and Nikulainen (2006); Youtie et al. (2007)). Accordingly nanotechnology transfer might also be subject to various different types of modes and challenges depending on the specific industrial context in which applications are sought.

Nanotechnology is tricky to define, and it is still largely in a pre-paradigmatic and science-driven phase of development where researchers are exploring different approaches, instruments, materials and phenomena. A short-hand definition commonly used is as follows *"R&D at the atom-, molecular- or macromolecular level of 1-100 nanometres, at which new or existing structures, appliances or systems are used in a controlled setting in order to give them new characteristics and functions due to their small size"* (see Palmberg & Nikulainen (2006), the National Nanotechnology Initiative (NNI) in the US *http://www.nano.gov/*).

The common denominator in most definitions of nanotechnology is the requirement of R&D directed at phenomena below the 100 nanometre scale where materials yield new – and as of yet poorly understood – properties in terms of chemical reactivity, optical, electronic and magnetic behaviour. Another vantage point is to refer to `top-down'- or `bottom-up´-approaches to nanoscale engineering. The former covers the use of lithography, cutting, etching or grinding technologies that already are in use, for example in the electronics industry. The latter one is more radical and still very scientist-driven, with linkages also to modern biotechnology. It concerns the synthesis, characterisation and modelling of individual atoms and molecules to construct larger entities such as crystals, thin-films, tubes and other components. Thus, nanotechnology might be defined as both application-oriented, through the `top-down´ approach, and science-based through the `bottom-up´ approach (Ratner and Ratner, 2003).

3. EMPIRICAL ANALYSIS

3.1. The survey data

For the identification of the survey population we have relied on a nanotechnology keyword search algorithm originally developed by Fraunhofer Gesellschaft, Institute of Systems and Innovation Research (FhG-ISI) in Germany, to identify nanotechnology-related patents and scientific peer reviewed journal articles published before January 2006. The Finnish nationality of these publications and patents were defined based on the information that at least one of the researchers or inventors had a Finnish affiliation, although foreigners naturally also often participated (see Noyons et al. (2003); Palmberg and Nikulainen (2006) for further description and use of this algorithm).

It should be stressed that the population of researchers and inventors that we have identified through this methodology are involved in nanotechnology with various intensities. This is also reflected in the original distribution of publications and patents which is highly left-skewed with a longer left tail of authors having only 1 publication. For identification of the survey population we therefore applied a threshold level of 3 publications (1 publication was considered enough for inclusion in the case of patents). It should also be noted that the researchers and inventors might have numerous other publications or patents in fields not captured by this keyword search algorithm.

An exercise of checking for duplicates and misspelled names was undertaken during February-April 2006, followed by an identification of the contact information using the Internet (email, telephone, address, link to their www-page). This exercise resulted in the identification of 1002 individuals for which verified contact information was available. Care was taken to enhance the user-friendliness of the survey as well as to facilitate the inclusion also of researchers and inventors at companies, in practice by branching the survey according to whether the respondent mainly conducted research or development activities at a university or research institute setting, or in a company. The survey design was finalized and piloted during August 2006, and sent out as a web-based one during September-November 2006 along with two reminders. In Table 1 we present the basic structure of our survey data as a whole.

Table 1. The structure of the survey data by affiliation of respondents

		Universities	Research institutes	Firms	Other	Total
No response	N	195	96	94	14	399
Response	N	397	116	79	11	603
		67%	55%	46%	44%	60%
Total	N	592	212	173	25	1002

The response rate after two reminders is 60%, resulting in 603 responses with few item non-responses. From Table 1 it is also clear that the survey foremost covers researchers (some of which also have filed patents) affiliated to universities as we expected. The share of respondents affiliated to research institutes and companies is also sufficiently large for comparative analysis. We capitalize on this here by focusing in a comparative set-up on the perceptions of university researchers and their counterparts in companies while omitting those affiliated to research institutes. We thus have 465 responses at our disposal, 378 of which are affiliated to universities and 87 to companies. We can also note that 56% of the respondents report `quite a lot´ or `very much´ involvement in nanotechnology by the above mentioned common definition of nanotechnology, the share being 59% for the university researchers and 56% for those at companies.

It should be noted that those affiliated to companies belong to the nanotechnology community in Finland by the methodologies we used for identifying them. Nonetheless, even though we also know from other sources that the included companies are recipients of nanotechnology transfer in Finland, and appear to be representative of this population in terms of size and industry, we cannot establish individual interactive pairs of university researchers and their counterparts in companies.

3.2. Challenges and modes of nanotechnology transfer

Already in the design of the survey we acknowledged that researchers from universities (and research institutes) and companies have quite different perceptions. These differences were facilitated by branching the survey depending on the present primary affiliation of the respondent. While these two branches contained a couple of different questions and answer options we took care in retaining some similar key questions concerning the challenges, modes and outcomes of technology transfer to enable a comparative analysis across both university and company researchers.

The first perspective discussed here concerns responses about the degree to which the covered researchers have considered various *challenges as inhibiting factors* when disseminating research information or results to companies, i.e. from the viewpoint of the university respectively the company affiliation. The answer options covered relate to perceptions of the nature of the university researchers, the basic research orientation of the field, IPR issues, communication problems, university researchers lack of business or market skills as well as the lack or underdevelopment of production technologies in industry. Table 2 gives the percentage share of respondents giving a high score for these items, i.e. inhibiting `quite a lot´ or `very much´ on an ordinal scale from 1 to 4, along with the mean scores, across the two different affiliations of researchers.

Table 2. Challenges inhibiting technology transfer across the affiliations

	University		Company			Total	
	% giving a high score	Mean value	% giving a high score	Mean value	t-test p-value	% giving a high score	Mean value
Passiveness of university researchers	9%	1.412	28%	2.068	0.000***	12%	1.527
Basic research orientation of field	52%	2.609	46%	2.358	0.029**	51%	2.563
Identification of commercial opportunities	41%	2.279	62%	2.684	0.001***	45%	2.355
Communication problems	15%	1.750	27%	1.976	0.031**	18%	1.793
IPR issues	17%	1.754	37%	2.235	0.000***	21%	1.846
University researchers lack of business or market skills	35%	2.167	50%	2.475	0.009***	38%	2.227
Underdeveloped production technologies	28%	1.975	50%	2.436	0.000***	32%	2.066

Statistical significance: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Overall, the basic research orientation of the field, the identification of commercial opportunities and university researchers' lack of business or market skills are the biggest challenges. With reference to the analytical framework, the results here clearly also point to rather different perceptions on challenges between university and company researchers. These surely reflect the fundamental differences that universities and companies have concerning their incentives to interact with each other and engage in technology transfer (compare with Stephan (1996); Schartinger et al. (2001)).

Considering first the nature of university research groups, company respondents consider them as significantly more passive when compared with university researchers themselves. Company researchers highlight the identification of commercial opportunities as a main challenge, and here we also find a significant difference across the affiliations. Conversely, university researchers view the basic research orientation of the field as a somewhat bigger challenge than company respondents.

When moving downwards in table 2, researchers at companies generally give significantly larger scores to challenges when compared with university researchers. The differences are especially clear concerning IPR issues and the lack or underdevelopment of production technologies. These are naturally issues that are of primary concern for companies. University researchers are more focused on activities further upstream almost per default. Moreover, the lack or underdevelopment of production technologies might be a natural consequence of the immature nature especially of `bottom-up´ approaches to nanotechnology. However, communication problems do not appear to be noticeable.

This paper proposes to make a clearer distinction between the modes and outcomes of technology transfer. Further, it acknowledges that various modes and intensities of interactions will also contribute in different ways to the outcomes. Thus, the second perspective concern responses about the degree to which the covered researchers have been engaged in different *modes of interaction* with companies respectively universities. The answer options intended to cover the continuum of looser and tighter forms of interactions, ranging from conferences or seminars, supervision and joint publications to joint research facilities and temporary employment at companies respectively universities. Table 3 again gives the percentage share giving a high score for these items, i.e. `quite frequent', or `very frequent´ modes on an ordinal scale from 1 to 4, along with the mean scores, across the affiliations of researchers.

Table 3. Modes of interaction during technology transfer across the affiliations

	University		Company			Total	
	% giving a high score	Mean value	% giving a high score	Mean value	t-test p-value	% giving a high score	Mean value
Conferences, seminars	46%	2.430	64%	2.837	0.000***	50%	2.505
Supervision of thesis	14%	1.578	28%	2.047	0.000***	17%	1.665
Joint publications	18%	1.698	34%	2.163	0.001***	21%	1.784
R&D consultation	26%	1.889	55%	2.640	0.000***	31%	2.028
Public R&D-programs	47%	2.441	57%	2.651	0.098*	49%	2.481
Bilateral R&D projects	28%	1.851	66%	2.977	0.000***	35%	2.061
Joint facilities	5%	1.298	27%	1.988	0.000***	9%	1.425
Temporary employment	6%	1.234	20%	1.744	0.000***	9%	1.329

Statistical significance: * p<0.1, ** p<0.05, *** p<0.01.

Before moving to the modes an institutional context worth highlighting is the FinNano-programs initiated in the field in Finland. Finland is renowned for close university-company collaboration and the active initiation of science and technology programs, of which the FinNano-programs are a good example. Especially the technology programs, commissioned by the Finnish Funding Agency for Technology and Innovation (Tekes), seek to facilitate technology transfer between universities and companies, arrange numerous workshops and conferences, and require university research groups to link up with companies (see Ylä-Anttila and Palmberg (2007)).

In this data 55% of all university researchers have applied for funding from the FinNano-programs, while the share is 43% amongst company respondents. The active stance towards the FinNano-programs is bound to be reflected also in these results. Thus, overall conferences and seminars, as well as public programs, show up as the most common modes of interaction. Again we see quite different modes of interactions across university and company researchers, as also verified by the t-tests. Further, the overall results appear to be in line with extent research (see especially Landry et al. (2005) and Brennenraedts et al. (2006)).

Researchers at companies report significantly more interactions by all the different modes when compared with university researchers. These company researchers might of course also interact with researchers outside the nanotechnology community, as well as with researchers abroad that we have excluded through our methodologies for identifying survey respondents. This observation seems particularly relevant when looking at tighter modes of interactions where companies fund R&D directly through e.g. R&D consultancy, bilateral R&D projects, and joint R&D facilities. Temporary employment at universities also appears to be more common when compared with university researchers receiving temporary employment at companies. The only less significant difference concerns public R&D programs. This is in line with the practices of technology programs in Finland where university-company collaboration is often implied.

3.3. Outcomes of nanotechnology transfer

As discussed in the literature various modes and intensities of interactions can be understood as outcomes if it is assumed that not only the `technology´ but also the related knowledge in using the technologies is transferred (see especially the discussion in Landry et al. (2005)). However, in the survey we asked for perceptions about the outcomes in a separate question, although broadening the scope beyond patents and their commercial licensing. Later on we discuss how the answers to these questions are pooled as the dependent variables in the multivariate analysis. In table 4 we present them non-pooled as the percentage share of respondents giving a high score for these items, i.e. `quite often´ or `very often´ on an ordinal scale from 1 to 4, along with the mean scores across the affiliations of researchers.

Table 4. Outcomes of technology transfer across the affiliations

	University			Company	
	% giving a hige score	Mean value		% giving a hige score	Mean value
Receiving research funding	39%	2.259	Identification of new product ideas	22%	1.965
Identification of new research questions	42%	2.260	Patenting of research results	19%	1.765
Identification of commercial opportunities	28%	1.959	Licensing of research results	12%	1.400
Patenting of research results	17%	1.652	Recruitment of new personell	37%	2.318
Licensing of research results	5%	1.276	Development of existing products/processes	40%	2.279
			Development of new products/processes	35%	2.128

Since these results are non-pooled at this point it makes sense to discuss the distribution of outcomes separately for university and company researchers. From the university viewpoint idea generation, in terms of the identification of new research questions and commercial opportunities, appears to be more frequent outcomes when compared with patenting of research results and the commercial licensing of these research results. Further, receiving research funding is obviously also considered as an important outcome when interacting with companies.

The importance of idea generation that we find here is broadly in line with Landry et al. (2005). Based on comparable Canadian data Landry et al. (2005) show that issues such as communication of research results, provision of consulting services to companies and other organisations, and the contribution to the development of new or improved products or services, are considered more frequent outcomes when compared with the commercialization of research e.g. through patents and licensing (compare also with the discussion in Schartinger (2001); Agrawal and Henderson (2002), and D'Este and Patel (2005)).

The broad scope of outcomes is also visible when considering the viewpoint of researchers from companies. From this viewpoint idea generation might be considered as equivalent to the identification of new product ideas, the development of existing or new products or processes. Again these types of outcomes appear as more important than patenting and commercial licensing of research results. In this context the answer options were broadened also to the `recruitment of new personnel´. When looking at the mean values, this outcome is perceived as the single most important one and it echoes the emphasis given on human mobility in the technology transfer literature (see e.g. Zucker et al. (2002)). This important outcome had to be excluded from the university viewpoint since the branching structure of the survey forced researchers who had gained recruitment at companies to stick to this affiliation when answering.

3.4. Multivariate analysis: determinants of outcomes

3.4.1. Definition of the dependent and independent variables

The ensuing multivariate analysis is intended as a validation exercise of the results discussed above, while also assessing how various modes and challenges affect outcomes of technology transfer in the field of nanotechnology. Thus, in the multivariate analysis the dependent variables are formed based on the perceptions that university and company researchers have about the frequency of various outcomes of technology transfer.

In terms of the dependent variable an analysis across university and company researchers is tricky since different types of viewpoints of necessity were covered and have to be pooled. Factor and correlation analysis suggest that university researchers perceive the identification of new research questions and the identification of commercial opportunities as similar and distinct dimensions, when compared with patenting and licensing of research results. As suggested above the former dimension can be considered as idea generation, while the latter covers the direct commercial utilization of research results often highlighted in the literature. When factor and correlation analysis is applied in an explorative way for perceptions of outcomes amongst company researchers somewhat similar dimensions emerge. New product ideas and the development of existing or new products and processes appear as distinct dimensions when compared with patenting and licensing of research results (see Appendix 1 for the explorative factor analysis).

When forming the pooled dependent variables the assumption is that the identification of new research questions and commercial opportunities amongst university researchers corresponds to the identification of new product ideas and the development of existing or new products or processes from the viewpoint of company researchers. Thus the first pooled dependent variable, O_IDEA, is considered to broadly capture idea generation as an outcome.

The second pooled dependent variable, O_PATLIC, captures patenting and licensing of research results as a narrower and more traditionally considered outcome of technology transfer. It is easier to form and motivate as it has a one-to-one match across the two types of affiliations covered by the survey. These two dependent variables are pooled as the maximum value that the relevant variables get across the university and company researchers. Receiving funding and the recruitment of new personnel are outcomes for which pooling does not appear reasonable and hence these dimensions, albeit also important, have to be dropped. Table 5 provides descriptive statistics of the dependent and independent variables of primary interest.

Table 5. Explanation and descriptive statistics of dependent and independent variables

Variable name	Variable decsription	Obs	Mean	Std. Dev.	Min	Max
Dependent variables						
O_IDEA	Idea generation	465	2.262	0.974	1	4
O_PATLIC	Patenting/licenisng	465	1.624	0.814	1	4
Independent variables						
Challenges of technology transfer						
C_PASS	Passiveness of university researchers	421	1.527	0.785	1	4
C_BASIC	Basic research orientation of the field	442	2.563	1.074	1	4
C_COMOPP	Identification of commercial opportunities	420	2.355	0.970	1	4
C_COMM	Communication problems	426	1.793	0.829	1	4
C_IPR	IPR issues	423	1.846	0.902	1	4
C_NOMARK	University researchers lack of business or market skills	410	2.227	0.951	1	4
C_NOPROD	Underdeveloped production technologies	395	2.066	0.932	1	4
Interaction variables						
BASIC*COMP	Basic research orientation of field x company dummy	442	0.432	0.988	0	4
COMOPP*COMP	Identification of commercial opportunities x company dummy	420	0.505	1.128	0	4
IPR*COMP	IPR issues x company dummy	423	0.428	0.988	0	4
NOMARK*COMP	University researchers lack of business or market skills x company dummy	410	0.483	1.063	0	4
NOPROD*COMP	Underdeveloped production technologies x company dummy	395	0.481	1.043	0	4
Modes of interactions						
M_CONF	Conferences, seminars	463	2.505	0.951	1	4
M_RDIND	Supervision of thesis or joint publications	464	2.028	1.019	1	4
M_RDDIR	R&D consultation or bilateral R&D project	464	2.384	1.076	1	4
M_PUBPROG	Public R&D-programs	462	2.481	1.140	1	4
M_JOINEMP	Joint facilities or temporary employment	463	1.594	0.902	1	4

The *dependent outcome variables* O_IDEA and O_PATLIC are on an ordinal scale from 1 to 4. The independent variables are listed as blocks of variables where the first three blocks contain those of primary interest in this paper, namely the different challenges and modes of nanotechnology transfer.

The variables covering the *different challenges* have a one-to-one match across the two types of affiliations covered by the survey. They are on an ordinal scale from 1 to 4 to reflect the degree to which the respondents consider the challenges and inhibiting factors for technology transfer. C_PASS refers to the passiveness of university research groups, C_BASIC to the basic research orientation of the field in questions, C_COMOPP to challenges in identifying commercial applications, C_COMM to communication problems, C_IPR to ownership issues relating to research results, C_ to university researchers insufficient knowledge of business or markets, and C_NOPROD to lack or underdevelopment of production technologies. The variables are motivated by the analytical framework and specificities of nanotechnology as the broader setting for technology transfer.

The variables covering the *different modes of interaction* likewise have a one-to-one match across the affiliations on the ordinal scale from 1 to 4 to reflect their frequency of occurrence. M_CONF refers to conferences and seminars, M_RDIND to supervision of thesis of employees of companies or joint publications involving company researchers, M_RDDIR to consultation related to R&D at companies or bilateral R&D projects funded by companies, M_PUBPROG to public science and technology programs, and M_JOINEMP to joint R&D facilities or temporary employment at companies. M_RDINDIR, M_RDDIR and M_JOINEMP are pooled as the maximum value of the relevant underlying variables across the university and company researchers. These variables covering the modes are primarily motivated by the analytical framework while they might not be typical for nanotechnology.

We also include *interaction variables* for the challenges and affiliation to elaborate whether a different perception of company researchers regarding a specific type of challenge has an idiosyncratic effect on the outcomes. There are two motivations for this. First, both the analytical framework and univariate analysis suggests that universities and companies have significantly different perceptions of challenges. Second, it was also argued that these differences might be accentuated in the case of nanotechnology as a field in a science-based and pre-paradigmatic phase of development with numerous research approaches, application and commercialization paths. The interaction variables are defined only for the challenges that received the highest scores in the survey, and for which the perceptions of university and company researchers differ significantly.

BASIC*COMP refers to the interaction between company researchers and the basic research orientation of the field, COMOPP*COMP to the interaction between company researchers and challenges in identifying commercial applications, IPR*COMP to the interaction between company researchers and ownership over research results, NOMARK*COMP to the interaction between company researchers and lack of business or market skills of university researchers, and NOPROD*COMP to the interaction between company researchers and the lack or underdevelopment of production technology at companies. The variable COMP refers to the present primary affiliation of researchers, where 0 refers to universities and 1 to companies.

In addition to these primary variables we also include *controls* to capture the *nature and nanotechnology intensity of R&D, the years elapsed since the time of the highest degree, the educational background of the respondents*, as well as *the potential application industries*. As control variables these will not be interpreted analytically in the ensuing multivariate analysis.

APPLI is a binary dummy variable, taking the value 0 if R&D covers the characterization, modelling and manipulation of new materials, structures or appliances as more basic research oriented activities, and the value 1 for the actual use or application of such technologies. NNI is a categorical variable on the ordinal scale from 1 to 4 to reflect their degree to which the common definition of nanotechnology fits the content of R&D of the respondents. AGE_DEG is a continuous variable of the number of years elapsed since the time of the highest degree (typically a PhD degree).

The variables E_MULTI, E_PHYSIC, E_CHEM, E_BIO, and E_ENG are binary dummy variables taking the value 1 for the self-explicative educational background and the value 0 otherwise, the benchmark being an educational background in all other disciplines E_OTH. Finally, the application industries are captured through the self explicative binary variables ELECTRONICS, ENGINEERING, FOODSTUFFS, PULP&PAPER, PHARMA, and CHEMICALS.

3.4.2. Logistic regression

Before the multivariate analysis an unconditional pair-wise correlation was performed across the dependent variables as well as those independent variables that are the primary interest in this paper (see Appendix 2). While this analysis already provides some insights about the way in which various challenges and modes of nanotechnology transfer relate to the outcomes, the relatively low value of the correlation coefficients also suggest that multicollinarity (cross-correlation between the independent variables that complicates interpretations) will not be a major problem in the estimations.

The dependent variables O_IDEA and O_PATLIC in the multivariate analysis are modelled with the same blocks of independent variables. The blocks of independent variables were introduced above, and each block is added stepwise to check their total effect on the outcomes using Wald-test statistics. Thus, the first block introduces the challenges, the second introduces the interaction variables and the company dummy, the third introduces the modes of interactions, the fourth introduces the nature of the research field and the nanotechnology intensity of researchers, the fifth introduces their educational background and years elapsed since the highest degree, while the final fifth block introduces the envisioned application industries. The results for O_IDEA are presented in Appendix 3 and for O_PATLIC in Appendix 4, while the reduced models based on these full ones are presented below for added clarity.

For O_IDEA in the first block considering the challenges C_PASS and C_BASIC are negative and significant ($p<0.01$), while C_COMOPP, C_IPR and C_NOPROD are positive and significant ($p<0.05$). The coefficient for the interaction variables and the company dummy of the second block are non-significant across the board, while M_CONF, M_RDDIR, and M_PUBPROG of the third block are positive and significant ($p<0.01$). Further, the introduction of these two latter blocks also overrides the significance of all challenges except for C_BASIC and C_IPR; they also seem to contributed significantly to the overall performance of the model by the Wald-tests and associated Chi2 statistics ($p<0.10$ respectively $p<0.01$).

Thus, idea generation as an outcome of nanotechnology transfer appears to primarily be inhibited by the basic research orientation of the field. It is facilitated by the challenges related to IPR ownership of research results, the frequency of interactions during conferences, R&D consultancy and bilateral R&D projects, as well as by interactions throughout public programs. Regarding the positive effect of IPR ownership issues as a challenge, one interpretation could be that the researchers more deeply involved in idea generation also more frequently face these challenges and have to solve them proactively. Overall, the different perceptions of company researchers on challenges do not seem to matter in this model.

What happens to these results and interpretations when the blocks of control variables are added to the estimations? Overall only the coefficients for ELECTRONICS and ENGINEERING, as application industries, are positive and weakly significant ($p<0.10$). The application orientation of research fields (APPLI), as well as the nanotechnology intensity of researchers (NNI) does apparently not affect idea generation as an outcome. Moreover the results and interpretations related to the primary variables are not significantly altered with the exception that C_COMOPP overrides C_BASIC in significance and with a positive coefficient. The interpretation might be similar as for C_IPR; those more deeply involved in idea generation might be more proactive in addressing challenges related to the identification of commercial applications.

The results including only the most relevant variable coefficients are also summarized in the form of a reduced model in table 6 below along with the marginal effects estimated for each individual outcome value. This reduced model confirms the results and interpretations above with the exception that there appears to be an interaction between challenges in identifying commercial applications and ownership issues over research results, which appear to cancel out the joint effect of these two variables on idea generation as the outcome. This interaction will require further attention in the next version of this paper. Otherwise the Chi2-statistics, based on the Wald-test, suggests that the model has a good overall fit ($p<0.01$).

The marginal effects are difficult to interpret strictly in a logistic regression. However, the sign changes across the four individual outcome values of the dependent variable give indication of the robustness of the estimations. Here we notice consistency of the estimates, going from positive (alternatively negative) coefficients from 1 to 2, while they become negative (respectively positive) from 2 to 3 and to 4.

Table 6. Estimation results of the reduced model for O_IDEA

Dependent variable O_IDEA				
	Coef.			
C_BASIC	-0.254**			
C_COMOPP	0.115			
C_IPR	0.146			
M_CONF	0.649***			
M_RDDIR	0.998***			
M_PUBPROG	0.535***			
N	392			
Chi2	162.364***			
Pseudo R2	0.264			
Log pseudolikelihood	-378.335			
Marginal effects				
	Outcome 1	Outcome 2	Outcome 3	Outcome 4
	dy/dx	dy/dx	dy/dx	dy/dx
C_BASIC	0.026**	0.037**	-0.053**	-0.010**
C_COMOPP	-0.012	-0.017	0.024	0.004
C_IPR	-0.015	-0.021	0.030	0.006
M_CONF	-0.066***	-0.095***	0.136***	0.025***
M_RDDIR	-0.102***	-0.145***	0.209***	0.038***
M_PUBPROG	-0.055***	-0.078***	0.112***	0.021***

Statistical significance: * p<0.1, ** p<0.05, *** p<0.01.

Turning to O_PATLIC (see Appendix 4), somewhat similar results and interpretations emerge, but with the difference that the interaction variables and some of the control variables more clearly turn into explanatory variables. Again the coefficient for O_BASIC takes on a negative and significant value (p<0.01), while the coefficients for C_IPR as well as C_COMOPP are positive and significant (p<0.05). When the blocks covering the interaction variables and the different modes of interaction are included the above mentioned results remain, while COMOPP*COMP, NOMARK*COMP, M_RDINDIR, M_RDIR and M_PUBPROG all show up positively and significantly (p-values in the range of 0.01-0.10). Again especially the different modes appear to add significantly to the overall performance of the model by the Wald-test statistic (p<0.01).

It thereby seems that patenting and licensing of research results as outcomes by and large are inhibited and facilitated by the same types of challenges and modes of interactions as idea generation. However, in this setting the different perceptions of company researchers matter more, both generally speaking by the dummy variable COMP as well in relation to specific challenges by the interaction variables. If company researchers perceive the identification of commercial applications as a bigger challenge this also has an inhibiting effect on patenting and licensing of research results as an outcome. On the other hand, if this concerns the lack of business and market skills of university researchers the effect appears to be an opposite one; this result is tricky to interpret.

When adding the blocks of different types of control variables it appears that the effects of application orientation of the research field, APPLI, as well as the educational background of the respondents more clearly are picked up in the estimations. Specifically, a background education in all of these fields appears to be negatively related to the outcomes set against the benchmark, although a detailed interpretation of this result is outside the scope of this paper. However the results and interpretations of the primary variables again remain unaltered. The coefficient for APPLI is positive and significant ($p<0.05$), indicating that application oriented research fields facilitate patenting and licensing of research results as could be expected. Further, all coefficients for the dummy variables capturing the educational background are significant and affect O_PATLIC negatively, set against the benchmark of E_OTH.

For the sake of clarity we again summarize the most relevant variables in the form of a reduced model in table 7 below, along with the marginal effects estimations. This reduced model convincingly confirms the results and interpretations for O_PATLIC as all the coefficients remain significant and sign-wise the same. The Chi2-statistics, based on the Wald tests, again produces a highly significant p-value (<0.01) and points to an overall good fit for the model. Further, the marginal effect specification indicates robust estimations when considering the sign changes of the coefficients across the different outcome values of the dependent variable.

Table 7. Estimation results of the reduced model for O_PATLIC

Dependent variable O_PATLIC				
	Coef.			
C_BASIC	-0.382***			
C_COMOPP	0.325**			
COMOPP_COMP	-0.455*			
NOMARK_COMP	0.389*			
M_RDDIR	0.709***			
M_PUBPROG	0.460***			
APPLI	0.392***			
E_MULT	-1.356***			
E_PHYSIC	-1.946***			
E_CHEM	-1.282***			
E_BIO	-1.505***			
E_ENG	-2.373***			
N	386			
Chi2	137.147***			
Pseudo R2	0.205			
Log pseudolikelihood	-337.058			
Marginal effects				
	Outcome 1	Outcome 2	Outcome 3	Outcome 4
	dy/dx	dy/dx	dy/dx	dy/dx
C_BASIC	0.095***	-0.060***	-0.031***	-0.005**
C_COMOPP	-0.081**	0.051**	0.026**	0.004**
COMOPP*COMP	0.113*	-0.071*	-0.036*	-0.006
NOMARK*COMP	-0.097*	0.061	0.031*	0.005
M_RDDIR	-0.176***	0.111***	0.057***	0.009***
M_PUBPROG	-0.114***	0.072***	0.037***	0.006**
APPLI	-0.097***	0.061***	0.031***	0.005**
E_MULT	0.293***	-0.210***	-0.073***	-0.010***
E_PHYSIC	0.420***	-0.285***	-0.118***	-0.018***
E_CHEM	0.293***	-0.201***	-0.081***	-0.012***
E_BIO	0.326***	-0.231***	-0.083***	-0.012***
E_ENG	0.437***	-0.319***	-0.103***	-0.015***

Statistical significance: * p<0.1, ** p<0.05, *** p<0.01.

4. A CONCLUDING DISCUSSION

4.1. Nanotechnology as the context for technology transfer

This paper analyses the appropriability of research in the context of technology transfer as one key issue in the promotion of emerging science-based technologies. It uses new and unique individual level survey data to interrogate how the perceptions of university and company researchers in the Finnish nanotechnology community differ in terms of challenges, modes of interactions, and outcomes of technology transfer.

The focus on nanotechnology is motivated by the huge – and partly hyped – commercial expectations that characterize this emerging field. Nanotechnology is also actively promoted in Finland and developments are foremost reflected in a rapid growth of scientific publications, while commercialization activities still are in a very early phase. Nonetheless, nanotechnology might well evolve into a general purpose technology and engine of growth later on in the 21th century.

The empirical analysis takes inspiration from extant research on the different incentive structures of universities and companies during technology transfer. The literature identifies several different types of challenges and modes of interactions. It is also suggested that one should take a broad viewpoint on the outcomes of technology transfer beyond the commercial utilization of research through patents and licensing. A point of departure of this paper is that the immaturity and uncertainties surrounding nanotechnology might lead to further contrasting perceptions of university and company researchers on top of those that already characterize technology transfer across these organizational boundaries generally. The survey data can be analysed across university and company affiliations of researchers to facilitate comparisons.

4.2. Challenges and modes of nanotechnology transfer

The basic research orientation of the field, problems in the identification of commercial applications, and the lack of business and market skills amongst university researchers are challenges that inhibit the transfer of nanotechnology the most. These results are broadly in line with extant research covering other technology fields (see especially Schartinger et al. (2001). We also clearly observe statistically significant differences across the affiliations. University researchers appear to view nanotechnology as more basic research oriented compared with companies, while the latter highlight the passiveness of university researchers and problems in the identification of commercial applications as the biggest challenges. The interpretation might be that university researchers in this interdisciplinary and natural science oriented field are accustomed to doing basic research without immediate requirements for commercialisation. As new policy initiatives are set-up to also engage companies, these might have particular problems in identifying commercial applications, given the early and pre-paradigmatic phase of nanotechnology developments.

Beyond these differences, company researchers highlight IPR ownership issues, and the lack or underdevelopment of production technologies in industry as challenges. We suggest that the lack or underdevelopment of production technologies might be specific to nanotechnology due to the uncertain and immature phase of development, especially of `bottom-up' approach to nanoscale engineering. Among others Ratner and Ratner (2003) suggest that such more discontinuous nanotechnologies require that companies invest in absorptive capability, new instrumentation, R&D and production facilities. Generally speaking, such `bottom-up´ approaches still have a long way to go before they become viable on an industrial scale. This contrasts with `top-down´ approaches that can benefit from production technologies used in many industries already now (especially in the electronics industry).

Public technology programs, in which universities, research institutes and companies are drawn together to facilitate technology transfer, is a typical feature of Finnish innovation policies. In nanotechnology reference can be made to the FinNano-programs, and the survey data also points to the active stance that the researchers have taken towards these programs (see also Palmberg et al. (2007)). Conferences and seminars and public programs are the most common modes of interactions between universities and companies. Nonetheless, companies use a wider range of different types of modes, and thereby appear to be active on a broader front. One interpretation might be that companies also interact with researchers outside the nanotechnology community in Finland. Companies might also need a broad range of knowledge inputs from various disciplines for the commercialization of nanotechnology. Nanotechnology is an interdisciplinary field, mixing various sub-disciplines of physics, chemistry, and biology (including biotechnology) (see Grodal and Thoma (2006); Hall, 2005).

4.3. The determinants of outcomes

Apart from comparing the challenges and modes of nanotechnology transfer across university and company researchers, this paper also capitalizes on the specificities of the survey data to assess how challenges and modes determine the outcomes of this transfer through multivariate analysis. A distinction is proposed between idea generation and the commercial utilization of research results through patenting or licensing as the outcomes. Idea generation covers the identification of new research questions or commercial opportunities, the identification of new product ideas, the development of existing or new products or processes. It represents a broader viewpoint on the outcomes of technology transfer, often called for in extant research (see especially Landry et al. (2005)). Patents and licensing represent the more traditional types of outcomes.

By and large we see the dominance of idea generation over patents and the commercial licensing of research results both from the viewpoint of university and company researchers. This result communicates well with much of the recent research on the outcomes of technology transfer (see the discussion in Schartinger (2001); Agrawal and Henderson (2002); D'Este and Patel (2005)). However, in the multivariate analysis we elaborated and validated further these descriptive insights by considering how these two different types of outcomes are affected by challenges and modes of interactions when taking into account the nanotechnology intensity of researchers, the content of R&D, the educational background of the respondents, as well as the potential application industries. Further, the data also made it possible to incorporate the different perceptions of challenges of university and company researchers.

Across the board the results appear similar for both idea generation, and patenting and licensing as the outcomes of nanotechnology transfer. The basic research orientation of the field is an inhibiting factor for idea generation, challenges in the identification of commercial opportunities and IPR issues have a positive effect of the outcomes, also when various control variables are included.

The basic research orientation as a challenge is compatible with observations about the present early and science-based phase of the development of nanotechnology. However, those researchers that have passed the `first hurdle´ during commercialization, might be proactively engaged in the identification of commercial opportunities and settling IPR issues and thus also consider these challenges as positive ones in terms of the outcomes. Researchers achieving the outcomes also appear to be more actively engaged with companies through conferences, R&D consulting and bilateral projects with companies, as well as through public technology programs. This interpretation does not appear to depend on the years elapsed since the researchers received their highest degree in the field (usually a PhD). However, an important follow-up analysis would be to consider to what degree different entry times to the field matter.

The multivariate analysis suggests that the intensity with which the researchers are engaged in nanotechnology does not seems to affect achieved outcomes. Thus, nanotechnology does apparently not provide specific new challenges on top of those that characterise the transfer and outcomes of science-based technologies from universities to companies generally, at least when viewed from the vantage point of this survey (compare also to the conclusion reached in Palmberg et al. (2007)). We also note that the markedly different perceptions of company researchers on the challenges of technology transfer that we find only seem to affect outcomes in terms of patenting and licensing activities, while no effect is detected in terms of idea generation. In part this result is intuitive. The different perceptions of university and company researchers become imperative once activities move from basic research towards applications where commercial issues start to surface for closer considerations. Future research would benefit from including such intemporal issues into considerations

Finally, we note that the educational background also appears to matter, while this does not appear to be the case when considering the envisioned application industries. More research is needed on emerging application and commercialization paths of nanotechnology. However this result might simply point to certain aspects of the general purpose nature of nanotechnology in its present development phase where many application industries appear as relevant although few are still actively using nanotechnology on a larger scale.

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APPENDIX 1: FACTOR ANALYSIS

Outcomes of technology transfer: university researchers

Factor analysis, orthogonal varimax rotation

Obs.=306

Factor	Variance	Difference	Proportion	Cumulative
Factor 1	1.14535	0.31447	0.7139	0.7139
Factor 2	0.83089	.	0.5179	1.2319

LR test: Chi2(6)=363.80, p=0.000

Variable	Factor 1	Factor 2	Uniqueness
Identification of new research quetsions	**0.6424**	0.1818	0.5543
Identification of commercial opportunities	**0.6949**	0.3968	0.3596
Patenting of research results	0.4339	**0.5942**	0.4587
Licensing of research results	0.248	**0.5361**	0.6512

Outcomes of technology transfer: company researchers

Factor analysis, orthogonal varimax rotation

Obs.=84

Factor	Variance	Difference	Proportion	Cumulative
Factor 1	1.18885	0.06003	0.6369	0.6369
Factor 2	1.12882	.	0.6047	1.2416

LR test: Chi2(10)=114.19, p=0.000

Variable	Factor 1	Factor 2	Uniqueness
Identification of new product ideas	**0.5604**	0.4074	0.52
Patenting of research results	0.3262	**0.6647**	0.4518
Licensing of research results	0.197	**0.6385**	0.5535
Development of existing products/processes	**0.5174**	0.1742	0.7019
Development of new products/processes	**0.6796**	0.2882	0.4551

Appendix 2: correlation matrix

Pairwise correlations

	O_IDEA	O_PATLIC	C_PASS	C_BASIC	C_COMOPP	C_COMM	C_IPR	C_NOMARK	C_NOPROD	BASIC_COMP	COMOPP_COMP	IPR_COMP	NOMARK_COMP	NOPROD_COMP	M_CONF	M_RDINDIR	M_RDDIR	M_PUBPROG	M_JOINEMP
O_IDEA	1.000																		
O_PATLIC	0.533	1.000																	
	465																		
C_PASS	-0.122	-0.061	1.000																
	421	421																	
C_BASIC	-0.337	-0.292	0.222	1.000															
	442	442	419																
C_COMOPP	0.047	0.065	0.366	0.243	1.000														
	420	420	399	414															
C_COMM	0.048	0.055	0.337	0.175	0.350	1.000													
	426	426	407	419	407														
C_IPR	0.208	0.180	0.176	0.006	0.218	0.286	1.000												
	423	423	401	415	401	410													
C_NOMARK	-0.020	0.014	0.324	0.253	0.546	0.381	0.327	1.000											
	410	410	388	402	400	398	394												
C_NOPROD	0.126	0.055	0.309	0.132	0.459	0.399	0.278	0.538	1.000										
	395	395	372	388	379	384	384	377											
BASIC_COMP	0.137	0.100	0.325	0.050	0.180	0.120	0.243	0.157	0.203	1.000									
	442	442	419	442	414	419	415	402	388										
COMOPP_COMP	0.155	0.123	0.374	-0.029	0.307	0.153	0.262	0.210	0.246	0.895	1.000								
	420	420	399	414	420	407	401	400	379	414									
IPR_COMP	0.129	0.098	0.361	-0.028	0.209	0.141	0.412	0.189	0.217	0.871	0.881	1.000							
	423	423	401	415	401	410	423	394	384	415	401								
NOMARK_COMP	0.124	0.118	0.388	-0.017	0.254	0.167	0.240	0.283	0.272	0.894	0.938	0.871	1.000						
	410	410	388	402	400	398	394	410	377	402	400	394							
NOPROD_COMP	0.140	0.102	0.378	-0.045	0.217	0.171	0.218	0.214	0.333	0.887	0.916	0.860	0.927	1.000					
	395	395	372	388	379	384	384	377	395	388	379	384	377						
M_CONF	0.502	0.311	-0.028	-0.202	0.045	0.059	0.100	-0.026	0.097	0.151	0.172	0.166	0.159	0.175	1.000				
	463	463	420	440	418	424	422	408	393	440	418	422	408	393					
M_RDINDIR	0.489	0.375	-0.053	-0.280	0.021	0.007	0.065	-0.090	0.078	0.211	0.239	0.177	0.167	0.188	0.503	1.000			
	464	464	420	441	419	425	422	409	394	441	419	422	409	394	463				
M_RDDIR	0.629	0.453	-0.071	-0.366	0.013	-0.048	0.205	-0.051	0.073	0.359	0.363	0.342	0.322	0.347	0.442	0.514	1.000		
	464	464	420	441	419	425	422	409	394	441	419	422	409	394	463	464			
M_PUBPROG	0.543	0.392	-0.147	-0.283	0.077	0.068	0.185	0.027	0.122	0.070	0.083	0.048	0.070	0.069	0.493	0.460	0.466	1.000	
	462	462	418	439	417	423	420	407	392	439	417	420	407	392	461	462	462		
M_JOINEMP	0.263	0.248	0.137	-0.215	0.050	-0.023	0.117	0.020	0.123	0.342	0.340	0.292	0.332	0.319	0.357	0.414	0.422	0.300	1.000
	463	463	419	440	418	424	421	408	394	440	418	421	408	394	462	463	463	461	

APPENDIX 3: FULL LOGISTIC REGRESSIONS FOR O_IDEA

Dependent variable O_IDEA						
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
C_PASS	-0.424**	-0.554***	-0.253	-0.239	-0.256	-0.336
C_BASIC	-0.599***	-0.558***	-0.195	-0.201*	-0.223*	-0.206
C_COMOPP	0.314**	0.280*	0.251	0.254	0.314*	0.335*
C_COMM	0.074	0.109	-0.053	-0.040	-0.030	-0.005
C_IPR	0.308**	0.377**	0.363**	0.368**	0.391**	0.428**
C_NOMARK	-0.108	-0.086	-0.018	-0.045	-0.061	-0.106
C_NOPROD	0.313**	0.273*	0.171	0.158	0.153	0.117
BASIC*COMP		-0.078	-0.409	-0.430	-0.341	-0.351
COMOPP*COMP		0.328	-0.048	-0.059	-0.212	-0.174
IPR*COMP		-0.460	-0.544	-0.518	-0.510	-0.564
NOMARK*COMP		-0.232	-0.143	-0.157	-0.137	-0.140
NOPROD*COMP		0.022	-0.012	-0.060	0.031	0.116
COMP		1.628	2.596*	2.733*	2.544*	2.583
M_CONF			0.680***	0.660***	0.630***	0.626***
M_RDINDIR			0.207	0.206	0.198	0.171
M_RDDIR			0.994***	0.974***	0.960***	0.960***
M_PUBPROG			0.386***	0.347**	0.374***	0.354**
M_JOINEMP			-0.277	-0.255	-0.219	-0.242
APPLI				0.162	0.155	0.114
NNI				0.034	0.010	-0.052
E_MULT					0.678	0.347
E_PHYSIC					-0.007	-0.513
E_CHEM					0.117	-0.154
E_BIO					-0.212	-0.229
E_ENG					-0.296	-0.897*
AGE_DEG					0.001	-0.001
ELECTRONICS						0.621*
ENGINEERING						0.613*
FOODSTUFFS						0.128
PULP&PAPER						0.499
PHARMA						0.140
CHEMICALS						-0.042
N	331	331	331	331	331	331
Chi2	57.547***	61.024***	141.534***	144.378***	149.174***	167.224***
Pseudo R2	0.073	0.087	0.261	0.264	0.270	0.281
Log pseudolikelihood	-399.548	-393.720	-318.546	-317.193	-314.964	-310.127
Block Wald tests (Chi2 stat.)		10.907*	93.328***	2.759	4.027	9.852

Statistical significance: * p<0.1, ** p<0.05, *** p<0.01.

APPENDIX 4: FULL LOGISTIC REGRESSION FOR O_PATLIC

Dependent variable O_PATLIC						
	(1)	(2)	(3)	(4)	(5)	(6)
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
C_PASS	-0.238	-0.386**	-0.152	-0.154	-0.202	-0.175
C_BASIC	-0.577***	-0.567***	-0.265**	-0.269**	-0.225	-0.262*
C_COMOPP	0.317**	0.413**	0.442**	0.469***	0.614***	0.625***
C_COMM	0.152	0.202	0.148	0.155	0.091	0.101
C_IPR	0.299**	0.380**	0.342**	0.328**	0.242	0.261
C_NOMARK	0.002	-0.136	-0.069	-0.097	-0.240	-0.217
C_NOPROD	0.066	-0.016	-0.214	-0.226	-0.122	-0.126
BASIC_COMP		0.092	-0.146	-0.150	-0.162	-0.113
COMOPP_COMP		-0.277	-0.690*	-0.708*	-0.884**	-1.013***
IPR_COMP		-0.423	-0.389	-0.350	-0.313	-0.279
NOMARK_COMP		0.532	0.658*	0.632*	0.722*	0.709*
NOPROD_COMP		0.294	0.456	0.430	0.297	0.390
COMP		-0.060	0.052	0.127	0.680	0.586
M_CONF			0.119	0.095	0.031	0.024
M_RDINDIR			0.265*	0.268*	0.205	0.219
M_RDDIR			0.634***	0.616***	0.657***	0.705***
M_PUBPROG			0.319**	0.281*	0.415***	0.424***
M_JOINEMP			0.008	0.031	0.079	0.075
APPLI				0.188	0.375**	0.344**
NNI				0.011	0.078	0.077
E_MULT					-1.061*	-1.080*
E_PHYSIC					-2.070***	-2.096***
E_CHEM					-1.391***	-1.484***
E_BIO					-1.705***	-1.705***
E_ENG					-2.506***	-2.444***
AGE_DEG					0.012	0.016
ELECTRONICS						0.315
ENGINEERING						-0.410
FOODSTUFFS						-0.090
PULP&PAPER						-0.082
PHARMA						0.026
CHEMICALS						0.237
N	331	331	331	331	331	331
Chi2	48.182***	54.212***	116.594***	119.938***	145.619***	148.896***
Pseudo R2	0.063	0.075	0.163	0.166	0.221	0.225
Log pseudolikelihood	-343.610	-339.323	-307.016	-305.766	-285.781	-284.245
Block Wald tests (Chi2 stat.)		10.277	62.221***	1.914	40.110***	3.754

Statistical significance: * p<0.1, ** p<0.05, *** p<0.01.

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