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Letter from the Editor

Tiny things being huge

For some time now the 'nano-topic' has been a big issue in academia and industry alike. We now have the ability to measure phenomena at the 'nano-scale' and to synthesize 'nano-materials' with completely different characteristics. This leads not only to new scientific achievements, but also to creating more value for companies active in the 'nano-field'. Those who expected the 'nano-hype' to be short-lived obviously erred. As an interdisciplinary trigger for biology, chemistry, engineering and physics, nanotechnology has been installed as a scientific discipline in its own right. It is sparking new solutions in many technological developments. Furthermore, researchers around the globe are working in promising nanotechnology collaboration projects to solve the challenges of our time in a sustainable way. Although our Special Issue can only cover a small part of this vast discipline, it is aiming at transmitting some of this spark to our readers as well.

In the first article of this Special Issue, Nina Preschitschek and Dominic Bresser compare the patent situation in China and Germany. In their article "Nanotechnology patenting in China and Germany – a comparison of patent landscapes by bibliographic analyses", they identify historical trends in nanotechnology patenting. Additionally, the authors present an overview of the most active patenting institutions and the emerging fields in both countries. Finally, they derive some implications for German-Chinese collaboration projects in nanotechnology.

In a second research article, Lu Huang, Zhengchun Peng, Ying Guo and Alan L. Porter also use bibliographic studies to identify emerging research paths. Their contribution "Identifying the emerging roles of nanoparticles in biosensors" provides additional insights in the existing research networks, identifying single researchers as well as research schools. The authors use nanoparticles in biosensors as an illustrative example for their study.

Steffen Kanzler builds on this background of network research in his article "Knowledge sharing in heterogeneous collaborations – a longitudinal investigation of a cross-cultural research collaboration in nanoscience". Especially crucial in collaboration projects, Steffen Kanzler examines knowledge sharing behavior with the example of the research collaboration SFB TRR 61. This first Chinese- German SFB is funded by the German Research Foundation and the National Natural Science Foundation of China. In his study, he sheds new light on cultural and personal influence factors of Chinese-German collaboration.

The last article of this Special Issue "Technological trajectories and multidimensional impacts: further remarks on the nanotechnology industry" by Paulo Antônio Zawislak, Luis FernandoMarques, Priscila Esteves and Fernanda Rublescki deals with effects of nanotechnology on different stakeholders. In their interview study, they present and evaluate opportunities and risks of this technology. They conclude that a regulatory framework is necessary to allow an exploitation of the full potential of nanotechnology.

Now, please enjoy reading the first issue of the seventh volume of the JoBC. We would like to thank all authors and reviewers who have contributed to this new issue. If you have any comments or suggestions, please do not hesitate to send us an email at contact@businesschemistry.org.

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Research Section

Nanotechnology patenting in China and Germany – a comparison of patent landscapes by bibliographic analyses

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This article gives a general overview on the patent landscapes of China and Germany within the emerging field of nanotechnology. A keyword based search, using the search term "nano", on SciFinder Scholar™ for the time period of 1985 to 2007 leads to 51,490 patent references overall and 12,979 Chinese and 2,901 German ones respectively. Bibliographic analyses focus on the historical trends in nanotechnology patenting as well as on major patent applicants, technological fields and international patenting strategies in China and Germany. They illustrate an above-average growth rate in nanotechnology patents for China, but a rather below-average one for Germany. Major differences in regard to the role of universities and research institutes in applied research and therefore as patent applicants are similarly emphasized as diverging international patenting strategies. Implications for future Chinese-German collaborations in applied nanotechnology research and potential improvements for future analyses are discussed.

1 Introduction

The definition of nanotechnology used by the European Patent Office (EPO) reflects its character of being a bridging technology:

The term nanotechnology covers entities with a geometrical size of at least one functional component below 100 nanometers in one or more dimensions susceptible of making physical, chemical or biological effects available which are intrinsic to that size. It covers equipment and methods for controlled analysis, manipulation, processing, fabrication or measurement with precision below 100 nanometers.

Beneath the definition of the EPO, there are several other ones available, e.g. from the US National Nanotechnology Initiative (NNI) or a working definition of the International Standard Organization (ISO). While all these definitions differ in the precise wording, they all underline three characteristics of nanotechnology. Firstly, nanotechnology focuses on materials or processes for which minimum one component of nanometer-scale is involved. Secondly, the control, handling and manipulating at this very small scale is emphasized. This excludes all "accidental" nanotechnology which can be also described as "natural" nanotechnology and occurs without any engineering or functionalizing process step. Thirdly, the commercialization aspect is highlighted in all definitions. Nanotechnology enables new industrial applications as well as technological innovations. In addition, the convergent character of nanotechnology is pointed out. Some nanotechnological innovations are used among various scientific disciplines and industry application fields. This can consequently lead to the fusion of nanotechnology and adjacent scientific disciplines, like modern biotechnology and information technology (OECD, 2009).

Since the 1980s, nanotechnology has developed from a research field, only known among

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experts, to one of the most promising research fields with especially high impact on research in physics, chemistry and biology. The global market of nanotechnology is forecasted to reaching up to USD 150-3,100 billion during the next years, possibly leading up to 2 million jobs globally. The high capacity of nanotechnology is derived from its various implications and applications on very different industries, ranging from manufacturing over life sciences to traditional industries like electronics or textiles (OECD, 2009).

In regard to the forecasted outstanding market volume and broad spectrum of scientific and application fields nanotechnology is affecting, there is consensus among experts that it is a key-technology of the 21st century. As a result, the competence of countries achieved in nanotechnology is used as a benchmark for a country's technological competence. Considering national R&D expenditures as well as the number of scientific publications and patents, the United States, Japan and main European countries like Germany, UK and France, can be identified as main players in nanotechnology (Liu et al., 2009; OECD, 2009). However, Asian countries, especially China and Korea, have increased their investments in the nanotechnology sector, both from public authorities as well as from private enterprises (BMBF, 2009). This results in high growth-rates of scientific publications and patent applications. Regarding the number of scientific publications between 1991 and 2007, China has already outperformed Germany and Japan, now being at 2nd position, right behind the USA (OECD, 2009). Though the quality of Chinese publications seems to be still at a low level, this development indicates that China will play a key role in nanotechnology-related R&D during the next years (Michelson, 2008). Therefore, China will become a highly important collaborative and strategic partner for other, also already established countries within the field of nanotechnology in the future (Shapira and Wang, 2009).

The first academic Chinese-German research collaboration on Nanoscience, the "Transregional Collaborative Research Centre" (TRR 61)[1], established in 2008, already affords researchers from both, China and Germany, the opportunity to conduct fundamental research within the field of nanotechnology in close collaboration. But in regard to the transfer of research results from this collaborative fundamental research to applied research within the two different systems in China and Germany, there are still best practices missing. Especially in China, some lags in the commercialization of results from nanotechnology research exist (Appelbaum and Parker, 2008). Moreover, the research systems of the respective countries significantly differ, e.g. in the influence of the government on research orientation or in research funding. In this context, we consider that it is of high importance to get an overview on the patent landscapes in nanotechnology in China and Germany. On the one hand, such an analysis will deliver insight into the degree of innovativeness and application orientation of the respective countries. On the other hand, the results may be used to develop a best-practice model, so that collaborations between Chinese and German researchers will also be successfully conducted at the level of applied research in future. Therefore, we aim to give an overview on patenting behavior in China and Germany, particularly focusing on historical trends in nanotechnology, the importance of private enterprises, universities and research institutes as patent applicants in the respective country as well as major fields of patenting within the broad field of nanotechnology and general patenting strategies.

The remainder of this article is structured as follows. In the next section, we will describe the research landscape in China with special focus on the role of the Chinese government in funding research. Afterwards, we will briefly introduce the Chinese as well as the German patent law. These information will account for the analysis of the differences revealed in nanopatenting in China and Germany. Then, we will demonstrate the use of patent data to generally describe the current status of technology systems. Based on this, the research design will be explained in detail and major results will be presented and discussed. Finally, we will draw conclusions, including a critical review of our research design as well as the impact of the derived results for further research within this or similar fields.

2 Research and development in China

Up to 1977, just like in other socialist countries, Chinese research, development and engineering activities were centralized and administratively coordinated by the government. Thus, research and development (R&D) was concentrated at universities and research institutions. The results of R&D were again disseminated by the govern-

1) Participants in the TRR 61 are the University of Münster (Germany), the Centre for Nanotechnology (CeNTech), the Centre for Nonlinear Science (CeNoS), the Tsinghua University (Beijing, China), the Chinese Academy of Sciences (CAS), the Interdisciplinary Research Centre for Cooperative Functional Systems (FOKUS) and the Chinese National Centre for NanoScience & Technology (NCNST, Beijing/China).

ment to business enterprises in order to commercialize the inventions. Furthermore, the government controlled every operational decision, like pricing, investment or distribution, made by corporations, and supervised the R&D activities undertaken by universities and research institutions.

However, at the end of the 1970s the government realized that the system had failed and – also due to Deng Xiaoping's Open Door Policy – great efforts were undertaken to decentralize R&D and engineering. One major goal was that universities and research institutions should become more autonomic in order to achieve international competitive research results by collaboration with domestic and foreign business enterprises as well as other universities and research institutes. Additionally, the absorption capacity of corporations for the universities R&D output should be enhanced. To achieve this goal, a set of economic and administrative reforms were adopted leading to a decrease of the government's direct control over corporations, universities and research institutions. Moreover, those reforms included the implementation of market-based resource allocation mechanisms, the introduction of a patent system as well as the creation of a regulatory framework for private-owned corporations and spin-offs from universities (Guan et al., 2005; Liefner and Kroll, 2007; Liu and White, 2001).

But still today, R&D sponsorship, e.g. the 863 program, is mainly funded by the Chinese government. By these investments, the political leadership of China tries to focus R&D on high-technology sectors like biotechnology or nanotechnology, offering great market potential and getting high strategic importance, in order to achieve a leading position within these emerging technological fields (Appelbaum and Parker, 2008). In comparison to other industrialized countries, the Chinese government still substantially affects its domestic innovation system. This is also reflected in the large proportion of R&D output, like publications and especially patents, generated by universities and research institutions (Guan et al., 2005; Liu and White, 2001).

3 Chinese patent system

Since the foundation of the People's Republic of China in 1949, the Chinese legal system, including regulations for intellectual property, has leant on that of other socialist systems. Inventions and innovations were owned by the state, whereas the actual inventors were awarded by getting certificates. Hence, all inventions as well as all related technologies were available for all corporations, free for personal as well as commercial use (Frietsch and Wang, 2007; Steinmann, 1992).

However, at the end of the 1970s, China lagged far behind industrial nations in economic and technological development. In order to modernize China's industry and technology sector, the Chinese government and especially Deng Xiaoping pursued, as already mentioned above, an Open Door Policy, having realized the necessity of foreign investments and technological knowledge (Liu and White, 2001; Steinmann, 1992). Being aware of the fact that foreign companies would not transfer their technological knowledge to China without offering legal protection for their intellectual property great efforts were undertaken to rapidly introduce a patent system guided by international standards (Steinmann, 1992). Thus, in 1980 the Chinese Patent Administration was founded and in 1982 the first Chinese Trademark Act was approved. In 1985, China acceded to the World Intellectual Property Organization (WIPO) and the Chinese Patent Law came in force, developed in close collaboration with the German Patent Office. For this reason, the Chinese patent system is very similar to the German one. Even nowadays, Chinese courts gear to rulings of German courts in issues of patent law (Frietsch and Wang, 2007; Liu and White, 2001; Steinmann, 1992).

After two revisions of the Chinese patent law in 1992 and 2000, state-owned corporations are no longer privileged and pharmaceutical, chemical or alimentary inventions – in former times excluded from patent protection - can be filed for patent application. In 1998, the former Chinese Patent Administration was renamed to the State Intellectual Property Office (SIPO). In 2002, China took another big step forward on its way to internationalize its economic and patent system by becoming a member of the World Trade Organization (WTO) and acceding to the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) (Chen et al., 2007; Frietsch and Wang, 2007; Steinmann, 1992).

4 German patent system

The first German patent law was approved in 1877. Up to this time, inventors had only received privileges by the governing sovereign, a legal entitlement to protection of inventions and innovations did not exist. In 1891 and again in 1936, German patent law underwent major revisions. Patent protection for processes was changed and utility models were introduced in order to grant

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protection even for more trivial and economically less important inventions. In 1949, the German Patent and Trade Mark Office (DPMA) was founded in Munich and the former Patent Office in Berlin lost its status as head. In the course of the harmonization of the European patent systems and the European Patent Convention (EPC) of 1973, the German patent law was ultimately reformed in 1981, creating the present legal version (Kraßer, 2009).

In Germany, just as well as in China, inventions for which patent protection is applied have to comply with three requirements: novelty, inventiveness and practical applicability. Novelty implies that the invention must not have been published or used anywhere else in the world. Inventiveness means that the invention is neither already state of the art nor an obvious result of its application. Practical applicability stands for at least the possibility of commercial production and use of the object of invention. Patent applications are examined according to these formal requirements and published 18 months after initial filing. In some cases, the substantial examination, which is required for the final granting of patent protection, can even take several years. A granted patent then protects an invention for a maximum of 20 years (Kraßer, 2009).

5 Patents as indicators for technological analyses

The analysis of bibliometric indicators, derived from publication and patent references, represents an efficient method to illustrate, compare and evaluate research activities both in a specific established thematic area and in an emerging sector, like nanotechnology (Allencar et al., 2007). Whereas the analysis of scientific publications offers an evaluation of the quality of a country's research capability within a certain field, the analysis of patent data is regarded to be one of the best methods of quantifying the output of a technology system (Debackere et al., 2002). The number of patents an institution or a country owns can be taken as a measure for its technological knowledge and vigor within the respective field (Allencar et al., 2007). Since the number of patents coheres with the output of industrial R&D and other innovative activities, currently a better indicator for this measurement intention does not exist.

In detail, the advantages that patent indicators offer as measures of technological activity are their world-wide geographical coverage as well as their coverage of nearly every field of technology. Moreover, patent documents contain various bibliographic data, e.g. date of publication, names of inventors and applicants or technical classifications, which are all largely free of errors due to the status of patents being legal documents. Not least, their easy and large-scale availability through patent databases leads to the fact that patents are more widely used than any other innovation indicator to assess technological progress. Nevertheless, taking patents as indicators of technological progress also brings some biases about. Not every patent is of high technological or economical value. Furthermore, there are differences among the various national patent systems, regarding legal as well as economic and cultural factors, e.g. the 'home advantage' effect or the different definition of the term 'inventor' (Debackere et al., 2002).

Within the field of nanotechnology, several studies aim to measure technological progress using bibliometric indicators (Alencar et al., 2007; Liu et al., 2009). Since nanotechnology is still an emerging technology, just being right at the very beginning of its life-cycle, the number of scientific publications exceeds the number of patents considerably. So, a high number of studies focus on analyzing scientific publications. But due to a substantial increase in patent applications since the mid of the 1990s, patent analyses offer some important insights for the understanding of current and future developments within the field of nanotechnology, e.g. the identification of major players or the evaluation of different patenting strategies.

6 Research methodology

There are several studies available analyzing patent landscapes of different countries within the field of nanotechnology (Alencar et al., 2007; Huang et al., 2006; Li et al., 2007; OECD, 2007). Previous to the analysis of patent landscapes, on the one hand it is of high importance to select suitable databases and on the other hand to define keywords covering all facets of the respective research field to preferably conduct entire searches.

Whereas numerous studies conduct searches accessing only one single patent database, e.g. the database of the United States Patent and Trademark Office (USPTO) or the one of the European Patent Office (EPO), fewer ones make use of databases containing data from several national and international patent offices, like the Chemical Abstracts (CA) database (Huang et al., 2006; Liu et al., 2009; OECD, 2007). Since first preexaminations suggest that a high share of Chinese nanotechnology patents was only applied at the Chi-

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nese patent office, but international applications were nearly completely missed, we decide to employ a patent database containing data from several patent offices. Accordingly, we choose SciFinder Scholar™ for our analysis. SciFinder Scholar™ is a research discovery tool, offering access to approximately 50 million documents from more than 10,000 relevant scientific journals as well as 59 patent authorities, focusing on diverse chemical-related scientific fields. Having direct access to nanotechnology-related references from all major patent authorities via this database, we conducted a keyword-based search to generate a dataset of nanotechnology patents.

In regard to the selection of keywords covering all facets of nanotechnology, there are a couple of scientific articles refining search terms for nanotechnology (Alencar et al., 2007; Kostoff et al., 2005; Porter et al., 2008). In most cases, the root search term is "nano", augmented with additional search terms, e.g. quantum or self-assembly. The authors argue that such an enlarged search algorithm is necessary to conduct entire searches and simultaneously to avoid the inclusion of non-relevant references. For instance, there are certain terms co-occurring with "nano" which are of high relevance, like "atomic force microscopy", but also some with less relevance like the very general "silicon". Of course, these search algorithms afford the creation of datasets characterized by high precision and recall (Porter et al., 2008). But then, those searches are very time consuming and not easily to conduct. As we aim to give a general overview on the nanotechnology patent landscapes in China and Germany with special focus on differences in patenting behavior of these two countries, we decide to concentrate on employing "nano" as single search term for the creation of our dataset, having in mind that this does not lead to an all-embracing characterization of the respective patent landscapes.

For this reason, we focus on general trends instead of absolute numbers for the following analyses. Nevertheless, a keyword-based search, conducted by Huang et al., shows that the majority of references is obtained by solely using "nano" as search term, since 91% of all patent references were identified. Due to this and in consideration of our research aim, we opt for this research design, which is characterized on the one hand by accessing data from a high number of various patent offices, but on the other hand by focusing on one single search term.

Since nanotechnology represents a research field, just emerging at the beginning of the 1980s and additionally the Chinese patent system in its contemporary constitution was not established until 1985, we limited our search to patent documents published between 1985 and 2007. We scan the patent full-texts, which led to 51,490 relevant patent references worldwide. In a second step, we extracted those patent references applied by minimum one German or Chinese private person, institution or enterprise. Hence, 2,901 German and 12,979 Chinese patent references remained, building two separate data sets. By using these two datasets, we were able to analyze and compare the patent landscapes as well as the patenting behaviors in Germany and China within the field of nanotechnology. In addition, we generate two more separate datasets, containing patents from Japan and the United States respectively, since these two countries are so far considered as technological leaders in the field of nanotechnology (Huang et al. 2004).

7 Results and discussion

First of all, we will present a historical trend by patent publication dates for nanopatenting over the period of 1985 to 2007. Following this general overview, we will present major results regarding the patent landscapes of China and Germany in nanotechnology. Analyzing major applicants in each country emphasizes the main differences in nanotechnology patenting between the respective countries. Moreover, we point out the core areas of each country within the broad field of nanotechnology. Finally, we briefly comment on patent strategies regarding national versus international patenting.

7.1 Historical trend

Though it is recommended to use the priority year for the analysis of historical trends in patenting, since this leads to a more accurate picture of time when research actually took place, we employ the publication date of the respective patent for our analysis (Wilson, 1987). The reason for this approach originates from the fact that only the publication year of the respective patent is available via SciFinder Scholar™. In figure 1, the historical trend in nanopatenting is depicted, whereas we analyzed this trend for all patents (worldwide) as well as for selected countries. A strong increase in the number of patents can be identified at the beginning of the 2000s, rising from about 1,100 patents in 2000 to more than 11,000 in 2007. The average annual growth rate for this period amounts to 34%. Considering the historical trends in nanopatenting of the United States, Japan, China and Germany, the rapid growth rate of Chinese patents is especially remar-

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Figure 1 Historical trend of patents in nanotechnology (1985-2007). Number of patents: 50,549[2]. Source: SciFinder Scholar™, November 2009.

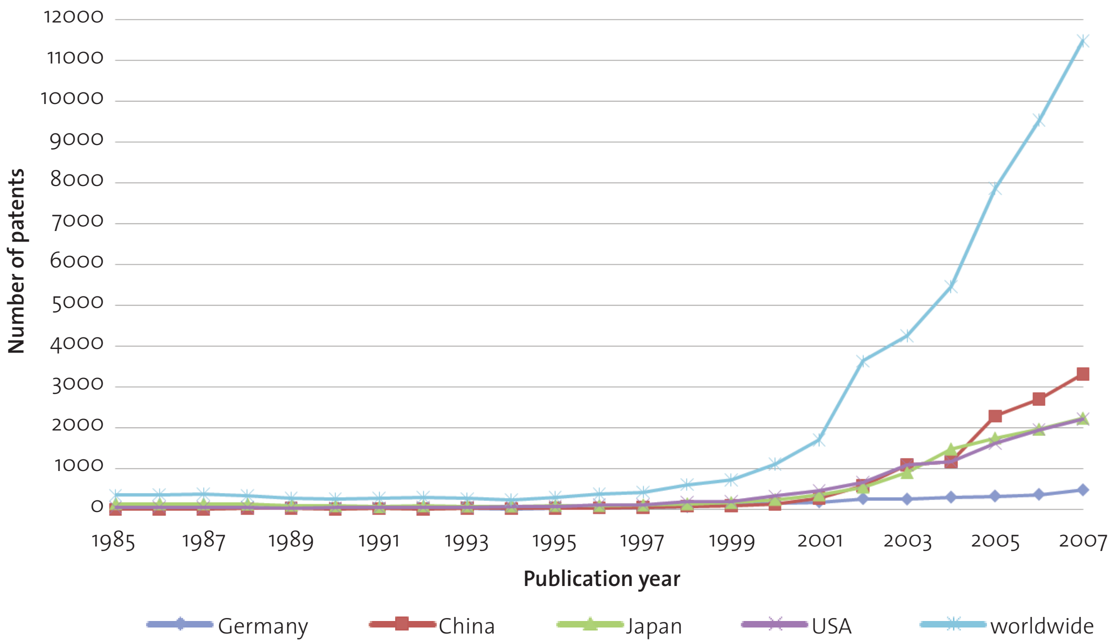
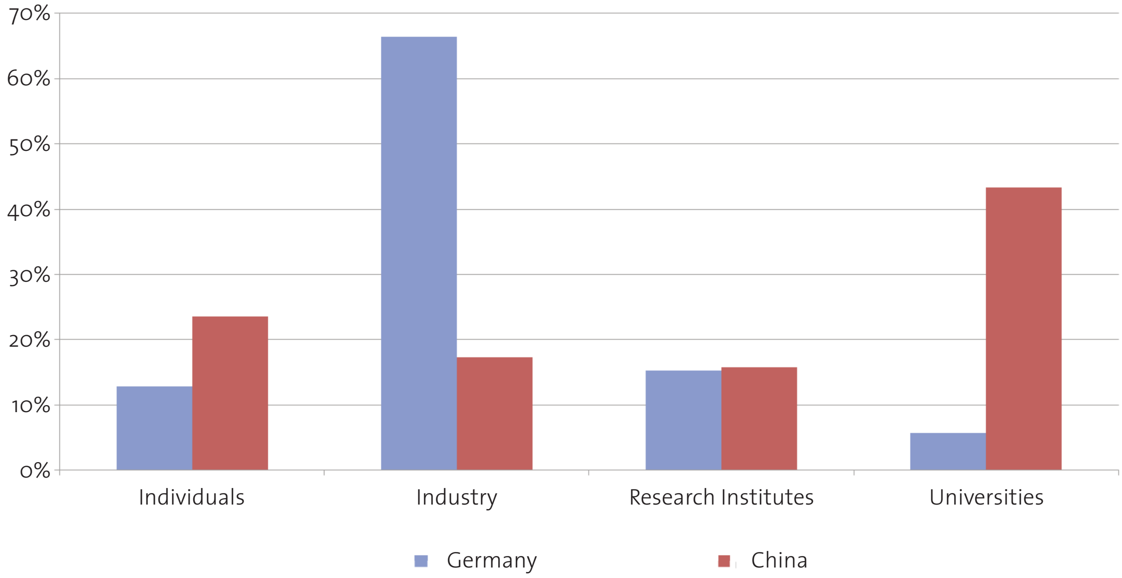


Figure 2 Comparison of patent applicants clusters. Number of patents: 50,549. Source: SciFinder Scholar™, November 2009.



kable. For the period of 2000 to 2007, it accounts for 49%. Since 2005, China exceeds Japan and the United States, formerly representing the technological leaders in nanotechnology, regarding the absolute number of patents. The number of German patents remains relatively low for the whole considered time period. The annual growth rate averages out at 15%. In regard to our research objective, we can assert that China holds a considerable higher amount of patents within the

2) For 2002 the dataset was adjusted: 941 patents were applied by one Chinese private person to protect a variety of different medicinal herbs. Since such a singular incident distort the analysis regarding the general trend of nanotechnology patenting in China, we decide to exclude these references.

Table 1 Top 10 of patent applicants in China (1985-2007). Source: SciFinder Scholar™, November 2009.

Rank	Applicant	Number of patents	Percentage of all patents
1	Chinese Academy of Sciences	1,368	10.5%
2	Tsinghua University	340	2.6%
3	Zhejiang University	311	2.4%
4	Shanghai Jiao Tong University	288	2.2%
5	Fudan University	208	1.6%
6	Zhongyuan University of Technology	167	1.3%
7	Shanghai University	136	1.0%
8	Hon Hai Precision Industry Co Ltd	131	1.0%
9	Nanjing University	128	1.0%
10	Tongji University	122	0.9%

Table 2 Top 10 of patent applicants in Germany (1985-2007). Source: SciFinder Scholar™, November 2009.

Rank	Applicant	Number of patents	Percentage of all patents
1	BASF SE	146	5.0%
2	Bayer AG	141	4.9%
3	Infineon Technologies AG	118	4.1%
4	Henkel KGaA	73	2.5%
5	Siemens AG	70	2.4%
6	Degussa AG, Germany	62	2.1%
7	Robert Bosch GmbH, Germany	42	1.4%
8	VEB, DDR	36	1.2%
9	Hoechst AG, Germany	35	1.2%
10	Merck KGaA	29	1.0%

field of nanotechnology compared to Germany. Especially the high growth rate indicates that China will play a key role within this sector during the next years.

7.2 Patent applicants

SciFinder Scholar™ also provides the opportunity to analyze the patent applicants within the patent datasets. In a first step, we cluster the patent applicants into 4 groups (universities, research institutes, industry and individuals) to demonstrate a key difference in nanopatenting between China and Germany, which is originated in the respective role of universities and industry in nanopatenting (see figure 2).

Whereas universities are the dominant patent applicants in China, owning 43% of all patents, in Germany 66% of all patents are owned by industry. Patenting of research institutes is nearly on the same level in both countries. However, in China the main part of these patents is possessed by the Chinese Academy of Sciences (66% of overall 2,078 patents). With regard to the share of patents assigned by individuals, there can be identified a significantly higher amount for China than for Germany. The dominant role of universities in nanopatenting in China is also reflected in the analysis of the Top 10 of patent applicants in nanotechnology (see table 1). Whereas the Chinese Academy of Sciences, including all associated institutes, holds overall 1,368 patents within nanotechnology and consequently represents the most active nanopatenting institution in China, eight universities, but only one private enterprise are to be found in this Top 10 listing. Overall, these TOP 10 patent applicants account for about 25% of all patents determined for China in nano-

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Table 3 Top 10 patent technology fields in China (analysis using CA section titles). Source: SciFinder Scholar™, November 2009.

Rank	CA section title	Number of patents	Percentage of all patents
1	Pharmaceuticals	1,868	14.4%
2	Industrial Inorganic Chemicals	1,555	12.0%
3	Plastics Manufacture and Processing	819	6.3%
4	Electric Phenomena	768	5.9%
5	Coatings, Inks & Related Products	706	5.4%
6	Ceramics	702	5.4%
7	Nonferrous Metals & Alloys	574	4.4%
8	Plastics Fabrication & Uses	476	3.7%
9	Radiation Chemistry, Photochemistry, Photo-graphic & Other Reprographic Processes	417	3.2%
10	Electrochemical, Radiational, & Thermal Energy Technology	409	3.2%

Table 4 Top 10 patent technology fields in Germany (analysis using CA section titles). Source: SciFinder Scholar™, November 2009.

Rank	CA section title	Number of patents	Percentage of all patents
1	Electric Phenomena	324	11.2%
2	Pharmaceuticals	231	8.0%
3	Coatings, Inks, & Related Products	220	7.6%
4	Ceramics	164	5.7%
5	Plastics Fabrication & Uses	164	5.7%
6	Plastics Manufacture & Processing	158	5.5%
7	Biochemical Methods	123	4.2%
8	Industrial Inorganic Chemicals	94	3.2%
9	Essential Oils & Cosmetics	88	3.0%
10	Optical, Electron, Mass Spectroscopy & Other Related Properties	86	3.0%

technology.

With regard to the Top 10 of patent applicants in Germany, a completely different situation arises (see table 2). Here, all Top 10 patent applicants are private enterprises. Universities or research institutes play a secondary role. Though, the share of patents, related to the Top 10 patent applicants, is comparable, it also adds up to about 25%. In summary, there can be identified a significant difference between China and Germany regarding the key players in nanotechnology. Nanopatenting in China is dominated by research institutes and universities, indicating that applied research, similar to fundamental research, within the field of nanotechnology is conducted by these institutions. On the contrary, patenting and consequently applied research within nanotechnology in Germany is pursued by industry.

7.3 Technology fields

Despite major differences in the role of the various patent applicants, nanopatenting in China and Germany focuses on similar technology fields (see table 3 and 4). For this analysis, we make use of the CA section titles provided within SciFinder Scholar™. Each reference within SciFinder Scholar™ is assigned content based to one subject area by the CAS (the responsible division of the American Chemical Society for SciFinder Scholar™). In China, most patents refer to inventions within the field of pharmaceuticals or industrial inorganic chemicals. Electric phenomena are ranked at fourth place for China (5,9% of all patents are related to this field). Meanwhile this particular technological field covers the highest number of patents in Germany. Such as in China, a high amount of nanopatents comprises inventions in the range of pharmaceuticals and also plastics. Comparing the Top 10 patent technology fields, interference for 7 of the Top 10 technology fields can be determined. On the whole, we can only identify slight differences. However, the analysis of the section titles reveals the bridging and interdisciplinary character of nanotechnology, already mentioned in the introduction of this article, since nanopatents refer to inventions from diverse technological fields, both in China and in Germany.

7.4 Internationality

Finally, we also analyze to what extent internationality matters in the respective patenting strategies of China and Germany. Whereas in Germany only about the half of all patents within nanotechnology are solely applied for at the DPMA, an international patenting strategy is pursued for the other half, including EPO and PCT (Patent Cooperation Treaty) applications. In China, more than 98% of all patents are solely applied for at the SIPO. An increasing trend towards international patenting in future cannot be identified so far, as the average number of patents applied for at the WIPO, USPTO or other patent offices still remains very low. Reasons for this lack of internationality in Chinese nanopatenting may originate from the dominant role of universities and research institutes in nanopatenting. Both may be less interested in international patent protection of their inventions, since they possibly do not generally focus on a worldwide commercialization of their research results. Another argument could be that international patent applications are too cost-intensive, due to high costs for translation as well as for international patent attorneys.

8 Conclusions

In this article, we conduct a keyword search, based on the search term “nano”, to give an overview on the patent landscapes of China and Germany within the emerging field of nanotechnology. For this purpose, we apply patent analyses to assess historical trends in nanopatenting as well as major patent applicants, research topics and patenting strategies for China and Germany respectively. This enables us to describe the current status of patenting activities in nanotechnology as well as major differences in regard to the patenting strategies of both countries.

Our findings confirm the increasing importance of China, becoming a major player within the field of nanotechnology. Both, the above-average growth rate and the highest absolute number of nanopatents per year since 2005 indicate that China will play a significant role in nanotechnology applied research in the future. For this reason, China is an important strategic and collaborative partner for established countries like Germany, not only in fundamental research, as the high number of scientific publications in nanotechnology indicates, but also in applied nanotechnology research.

Furthermore, our analyses show that significant differences exist in regard to key players in nanopatenting between China and Germany. On the one hand, the high importance of universities and research institutes in nanopatenting in China is a residue from the period of state-controlled research planning, when research and industrial production were separated from each other. As already mentioned earlier within this article, research was solely undertaken by universities and research institutes until the beginning of the 1990s. Thus, Chinese enterprises then lacked competence in undertaking research and innovation management and this fact continues to affect China’s current research activities. Nowadays, private enterprises in China benefit from their advantage in labor-intensive production compared to other industrial countries. Therefore, they are still less interested in gaining competences in research and development (Liefner and Kroll, 2007). On the other hand, Chinese universities and research institutes gain enlarged freedom in research in the course of the reform of the national research system and therefore intensify their engagement in applied research. Due to the decreasing governmental sponsorship, universities simultaneously set up science-parks and spin-offs to commercialize their research and consequently to secure their research funding (Shapira and Wang, 2009). Both developments account for the dominating role of universities and research institutes in applied research in China.

In contrast to Chinese universities, German universities mostly concentrate on fundamental and little on applied research. As fundamental research is generally excluded from any patent

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protection, German universities do not appear as key players in patenting. In addition, they stand for an open-science mentality and therefore focus on publishing their research results within scientific literature instead on their commercialization resulting in increased patenting activities (Baldini, 2009) Besides this, research in Germany is considerably funded by government, so that private funding is of less importance, at least in fundamental research so far (Beise and Stahl, 1999; Vincent-Lancrin, 2006). For this reason, German universities are not forced to search for alternative sources of income, as universities in China have to.

Moreover, patenting strategies vary in the degree of the broadness of patent protection. Chinese patent applicants only pursue national patenting, whereas German applicants focus to a considerable degree on international protection for their inventions. It is of high importance for all involved parties to be aware of and to consider these differences before searching for and establishing collaborations between both countries, since they may complicate successful collaborations.

In this regard, more detailed and revised analyses of the respective patent landscapes should be considered. In particular, other databases, e.g. special patent databases like Derwent World Patents Index, should be scanned to verify if the present datasets are substantially representative for the patent landscapes of the respective research field and countries. Moreover, the employment of a detailed search algorithm will lead to more entire datasets and therefore more specific bibliometric analyses will be realizable, e.g. in regard to technological fields or citations and co-authorships which can be used as indicators for already existing collaborations.

References

Alencar, M.S.M., Porter, A.L., & Antunes, A.M.S. (2007): Nanopatenting patterns in relation to product life cycle, *Technological Forecasting and Social Change*, **74** (9), pp. 1661-1680.

Appelbaum, R.P., & Parker, R.A. (2008): China's bid to become a global nanotech leader: Advancing nanotechnology through state-led programs and international collaborations, *Science and Public Policy*, **35** (5), pp. 319-334.

Baldini, N. (2009): Implementing Bayh-Dole-like laws: Faculty problems and their impact on university patenting activity, *Research Policy*, **38** (8), pp. 1217-1224.

Beise, M., & Stahl, H. (1999): Public research and industrial innovations in Germany, *Research Policy*, **28** (4), pp. 397-422.

BMBF (2009): *nano.DE-Report 2009 – Status Quo of nanotechnology in Germany*, Bonn.

Chen, Z.L., Gao, W., & Xu, J. (2007): IP rights in China: Spurring invention and driving innovation in health and agriculture, in: Krattiger, A., Mahoney, R. T., Nelsen, L. et al. (eds.), *Intellectual property management in health and agriculture innovation: A handbook of best practices*, MIHR, Oxford; PIPRA, Davis, pp. 1585-1592.

Debackere, K., Verbeek A., Luwel, M., & Zimmermann, E. (2002): Measuring progress and evolution in science and technology – II: The multiple uses of technometric indicators, *International Journal of Management Review*, **4** (3), pp. 213-231.

Frietsch, R., & Wang, J. (2007): *Intellectual property rights and innovation activities in China: Evidence from patents and publications*, Fraunhofer Institute for Systems and Innovation Research, Karlsruhe.

Guan, J.C., Yam, R.C., & Mok, C.K. (2005): Collaboration between industry and research institutes/universities on industrial innovation in Beijing, China, *Technology Analysis & Strategic Management*, **17** (3), pp. 339-353.

Huang, Z., Chen, H., Chen, Z., & Roco, M.C. (2004): International nanotechnology development in 2003: country, institution, and technology field analysis based on USPTO patent database, *Journal of Nanoparticle Research*, **6** (4), pp. 325-354.

Huang, Z., Chen, H., Li, X., & Roco, M.C. (2006): Connecting NSF funding to patent innovation in nanotechnology (2001-2004), *Journal of Nanoparticle Research*, **8** (6), pp. 859-879.

Kostoff, R.N., Murday, J.S., Lau, C.G.Y., & Tolles, W.M. (2007): The seminal literature of nanotechnology research, *Journal of Nanoparticle Research*, **8** (2), pp. 193-213.

Kraßer, R. (2009): *Patentrecht*, 6. Auflage, C.H. Beck, München.

Liefner, I., & Kroll, H. (2007): *Universitäre Spin-off-Unternehmen und universitär-industrieller Technologietransfer in China*, in: Hof, H., Wengenroth, U. (eds.), Innovationsforschung, LIT Verlag Dr. W. Hopf, Hamburg, pp. 227-241.

Li, X., Lin, Y., Chen, H., & Roco, M.C. (2007): Worldwide nanotechnology development: a comparative study of USPTO, EPO, and JPO patents (1976-2004), *Journal of Nanoparticle Research*, **9** (6), pp. 977-1002.

Liu, X. & White, S. (2001): An exploration into regional variation in innovation activity in PR China, *International Journal of Technology Management*, **21** (1/2), pp. 114-129.

Liu, X., Zhang, P., Li, X., Chen, H., Dang, Y., Larson, C., Roco, M.C., & Wang, X. (2009): Trends for nanotechnology development in China, Russia, and India, *Journal of Nanoparticle Research*, **11** (8), pp. 1854-1866.

Michelson, E.S. (2008): Globalization at the nano frontier: The future of nanotechnology policy in the United States, China, and India, *Technology in Society*, **30** (3-4), pp. 405-410.

OECD (2007): *Capturing nanotechnology's current state of*

development via analysis of patents, STI working Paper.
OECD (2009): *Nanotechnology: An overview based on indicators and statistics*, STI Working Paper.
Porter, A.L., Youtie, J., Shapira, P., & Schoeneck, D.J. (2008): Refining search terms for nanotechnology, *Journal of Nanoparticle Research*, **10** (5), pp. 715-728.
Shapira, P., & Wang, J. (2009): From lab to market? Strategies and issues in the commercialization of nanotechnology in China, *Asian Business & Management*, **8** (4), pp. 461-489.
Steinmann, M. (1992): *Grundzüge des chinesischen Patentrechts*, Carl Heymanns Verlag, Cologne.
Vincent-Lancrin, S. (2006): What is changing in academic research? Trends and future scenarios. *European Journal of Education*, **41** (2), pp. 169-202.
Wilson, R.M. (1987): Patent analysis using online databases – I. Technological trend analysis, *World Patent Information*, **9** (1), pp. 18-26.

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Research Section

Identifying the emerging roles of nanoparticles in biosensors

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This paper profiles R&D on the application of nanoparticles in biosensors and explores potential application development pathways. The analysis uses a dataset of nanotechnology publication records for the time period 2001 through 2008 (part year) extracted from the Science Citation Index. It focuses on emergent research activities in the most recent years. Bibliometric analyses are employed to ascertain R&D trends and research networks for key biosensors. Growth models are fit to forecast the technological trend for nanoparticle-enhanced biosensor research activity. In addition, a combination of quantity (publication) and quality (citation) analysis for nanoparticle-enhanced biosensors helps position the leading countries in this research field. Science overlay mapping shows different emphases of nanoparticle-enhanced biosensor research between the US and China, the leading countries. Recent studies suggest that nano-enhanced biosensors show promise for gains in stability, sensitivity, selectivity, and accuracy - for both direct and indirect detection. This paper demonstrates how bibliometric analyses can help anticipate emerging technology development and application potential.

Introduction

Nanotechnology is playing an increasingly important role in the development of sensors. Biosensors represent an especially exciting opportunity for high-impact applications benefiting from "nano" attributes. A biosensor is a device that combines a biological recognition element with a physical or chemical transducer to detect a biological analyte. In general, a biosensor consists of three components: the biological recognition element, the transducer, and signal processing electronics. Nanomaterials can contribute in either the bio-recognition element or the transducer, or both, of a biosensor. The effective biorecognition area, i.e. the area actually interacting

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with the analyte, is one of the important parameters that determines the sensitivity of a biosensor. Nanomaterials, especially nanoparticles, provide a promising way to increase the bio-recognition area (Khanna, 2008), because the high surface to volume ratio of nanoparticles provides a large number of sites available for molecular interactions (Kim et al., 2004).

In recent years, a wide variety of nanoparticles with different properties have found broad application in biosensors. Because of their small physical size, nanoparticles present unique chemical, physical, and electronic properties that are different from those of bulk materials (Luo et al., 2006), and improved and new biosensors are designed benefiting from these novel attributes. Functional nanoparticles bound to biological molecules (e.g. peptides, proteins, nucleic acids) have been developed for use in biosensors to detect and amplify various (e.g. electronic, optical, and magnetic) signals (Chen, 2004). Most recent studies show that biosensors composed with nanoparticles do take on rapid, sensitive, accurate, and stable measurements, which offers exciting new opportunities for the development of biosensing capabilities. Nowadays, nanoparticle-enhanced biosensors show significant development. Researchers tend to integrate nanoparticles into the materials used for biosensor construction in order to improve the performance of the system in both existing and potential sensing applications.

Analyzing R&D development trends and relationships for nano-enhanced biosensors can help business decision-makers take best advantage of emerging opportunities (Porter et al., 1991). Although nanoparticle-enhanced biosensors have been researched and affirmed to provide remarkable functional improvements, few studies have tried to systematically characterize the roles of nanoparticles in enhancing biosensor functionality (Shipway, 2008). Our research questions about nano-enhanced biosensors R&D are:

- What are the R&D trends?
- Which countries lead the nano-enhanced biosensors R&D?
- Which fields are engaged in this research?
- What are the emerging roles of nanoparticles in biosensors?
- Which nanoparticles offer the greatest potential for commercial applications?

Approach and data

We employ bibliometric analyses to ascertain R&D trends and research networks for nanoparticle-enhanced biosensors. Bibliometric analysis is a set of tools for extracting information from large databases looking for patterns and explained reasons for apparently unstructured behavior (Daim, 2005). Bibliometric analysis can play important roles in pursuing chemical business opportunities from three aspects. The first is technology forecasting. After getting historical data from authoritative databases, we can adjust these bibliometric data using an S-curve as a way to fit the technological growth process (Daim, 2006), analyzing research trends and identifying emerging areas of technology. Secondly, bibliometric methods can help determine the technology life cycle position and gauge its maturity level. Martino (2003) presents bibliometric analysis dividing the data in five categories. As he described, when the technological development is at the basic research stage, the Science Citation Index (SCI) nicely represents that literature. When the technological development reaches the applied research stage, the technological literature is well represented by the Engineering Index (EI) literature (for certain technologies). When development reaches the experimental development phase, patent documentation is a good reflection. When the development reaches the application stage, Newspaper Abstracts depict activity patterns. At last, bibliometrics can investigate information through the use of different indicators such as publications, cited references, occurrences of words, phrases, citations, co-citations, authorship and related characteristics that may extract hidden patterns from structured data, presenting the whole picture of research networks and relationships (Watts et al., 2001).

The datasets used in these bibliometric studies come from global nanotechnology publications for the time period 2001 through 2008 (part year) extracted from different databases: SCI, Inspec, Compendex, and Factiva. This paper focuses on SCI data for intensive study to capture the emergent research activities, especially those prominent in the most recent 4 years. The SCI dataset of publications draws upon the definition of nanotechnology and the data-cleaning methods developed by a Georgia Tech group. Our basic nano search locates abstract records containing "nano*" or any of 7 modular term sets, as discussed by Porter et al. (2008). Within the resulting dataset (of some 500,000 publication abstracts), we then search for those specifically discussing "biosensors," and "nanoparticles". Besides these basic search terms, we add other terms like specific categories of biosensor (such as glucose, cholesterol, enzyme, DNA, genome, hydrogen-peroxide, alcohol, nitrate, amino acid, protein chip, DNA

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array, immunoassay, sandwich assay, competitive assay, etc.) and variants of nanoparticles (such as Ag, Au, Pt, Cds, Pbs, ZnO, SiO2, polystyrene, quantum dots, metal, semiconductor, polymer, etc.). Using this approach, 1,400 publication records were drawn from SCI to create a dataset for the 2001-2008 (mid-year) time period. At the same time, we also set up two other datasets drawn from the Inspec & Compendex databases with 1,715 records, and from Factiva with 489 records. However, the search method for these later datasets is much simpler than that used for the SCI dataset, just using basic search terms of "biosensor" and "nanoparticles".

Results

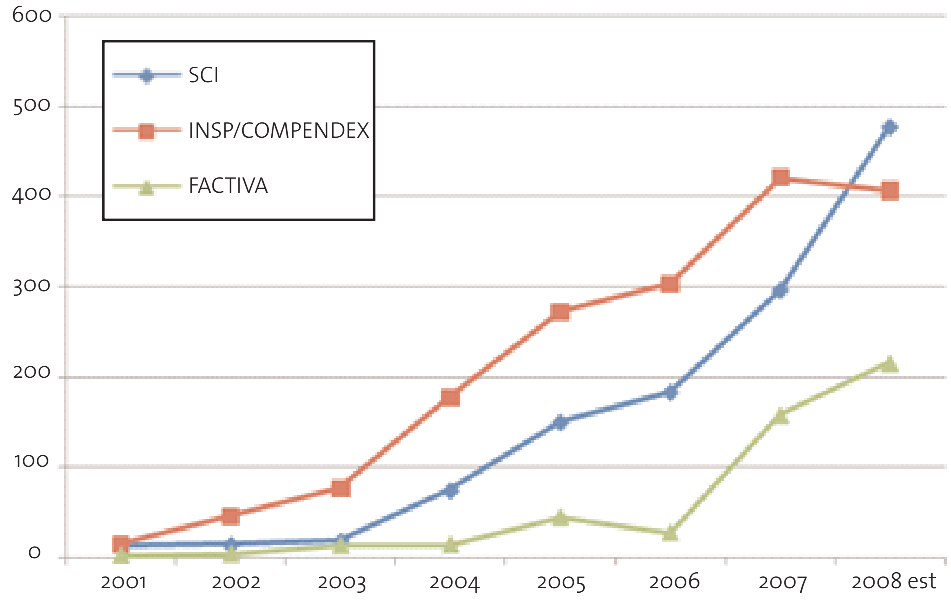
Trend analyses

We begin by showing a trend line based on the cumulative number of publications by each of the three datasets (Figure 1). We are trying to find out the development status of nanoparticle-enhanced biosensors. The sharp upward trend in articles relating nanoparticles to biosensors shows their increasingly important role. Examining these three growth curves, we find that 2004 is the key point for both the SCI and Inspec & Compendex data series. At about that time, the basic research and the more applied research on nanoparticle-enhanced biosensors accelerated into a steeper rate of growth. In comparison, the publication counts of Factiva, reflecting broader business and general public attention, started to increase more steeply in 2007. This suggests that the popular business application of nanoparticles in biosensors lags basic and applied research by about three years.

What is likely to happen in the near future? The last data point for the INSP/Compendex series is estimated because our data reflect only about half of the expected complete 2008 tally. That said, we still note that this point indicates a possible slight decline in applied research on the topic. On the other hand, the increasing rate of publications for SCI in the most recent two years suggests that a further expansion of applied R&D could be anticipated. So, those interested in tracking this emerging technology would want to monitor developments quite closely in the coming years to ascertain the development pattern.

In order to gain a richer perspective on the technology life cycle position and maturity level for nanoparticle-enhanced biosensors, we extra-

Figure 1 Cumulative publications of nanoparticles applications in biosensor by database[1]



1) Databases used: Science Citation Index, INSPEC&COMPENDEX, and Factiva, 2001-2008 (estimated). In order to get more accurate result for the comparison analysis for these three datasets, search terms for SCI in this chart are the same with the other two datasets with "nano*","biosensor" and "nanoparticle".

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polate the R&D trends.[2] Figure 2 gives one result of trend analyses of publications indexed by SCI through the year 2012. Bibliometric data can be modeled using an S-curve as a way to fit the technological growth process. Here, we choose a Gompertz Model to fit the data with a high R^2 coefficient of 0.99. It suggests that steep growth could continue over the next few years. Similarly, trend analyses for the INSPEC & Compendex datasets also follows an increasing trend over the next 4 years (not shown here). According to the results of our trend extrapolation, we estimate that there is still a long time, likely several years or longer, for basic and applied research on nanoparticle-enhanced biosensors to grow.

The evidence is strong that nanotechnology has recently become one of the most exciting forefront elements in biosensor R&D. In order to identify the position of nanoparticle-enhanced biosensors among all the nanomaterial-enhanced biosensors, this paper partitions the bibliometric data. We separate the publication counts of nanoparticle-enhanced biosensors from those of any nanomaterial-enhanced biosensors. We then establish a ratio between these. The publications of nanoparticle-enhanced biosensors are primarily from the results of searching the terms, “nanoparticle” and “biosensors”. The publications of nanomaterial-enhanced biosensors come from the results of searching the term “nano*” with “biosensors”. Based on these bibliometric data, we again seek to examine the trend and to forecast the technological growth process of nanoparticle-enhanced biosensors using suitable growth models. In Figure 3, a linear model is used to fit the ratio data from SCI for 2001 to 2008 and gives another trend trajectory extended to the year of 2012. Similarly, a linear model fits the data from INSPEC/COMPENDEX quite well (not shown here). According to the results, we estimate that nanoparticle-enhanced biosensors have more potential than other nanomaterial-enhanced biosensors in the next few years, because the value in the year 2012 is still smaller than the limit of “1.” However, to some extent we were concerned by the goodness of fit of the two trend analyses, because the coefficients of determination of these two models are not very high (0.78 and 0.79, respectively).

Those coefficients just affirm the visual appearance – the fit of the line is not so strong in the earlier years; however, it is quite close in more recent years.

National comparisons based on publication and citation activity

As an emerging field, there has been much interest in the leading countries in research on nanoparticle-enhanced biosensors. This paper not only compares the numbers of publications, but also focuses on the quality and influence of countries in this research field. Citations, as measured by the number of times a paper has been

Figure 1 Cumulative publications of nanoparticles applications in biosensor by database[3]

2) We show this only for the SCI data; in the text we mention the other R&D trends based on INSPEC/Compendex. The Factiva data don’t pertain to R&D, so we don’t analyze them in this way to model the technology maturation.
3) The limit of Gompertz Model here is equal to 1,200, and Coeff Det. is equal to 0.99, which is higher than other models, such as Fisher-Pry Model and Exponential Model.

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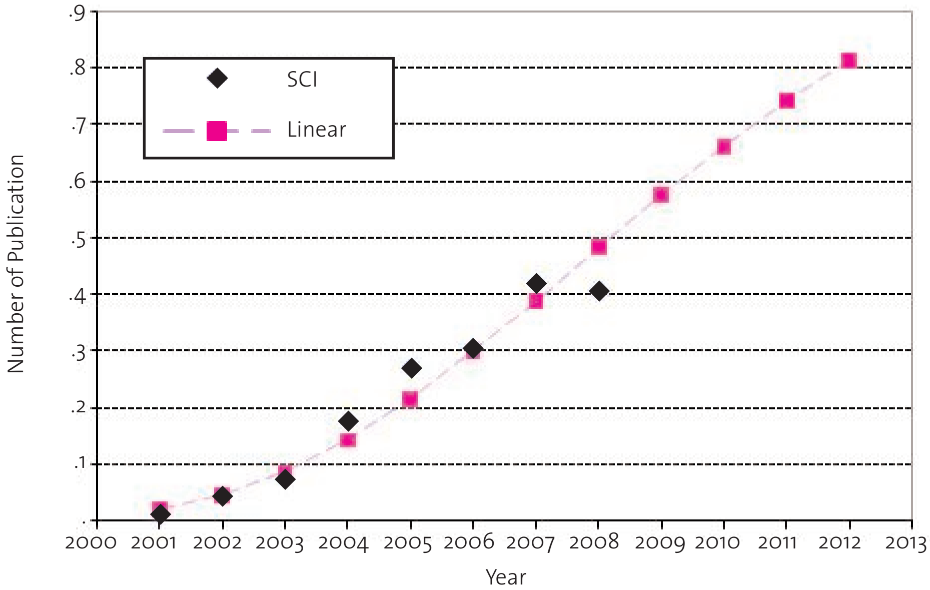
Figure 3 Linear model adjust to ratio of nanoparticle-enhanced biosensor SCI data[4]



cited, are used here to gauge the level of quality, or impact, of the publications of a country. [This is an imperfect measure, of course, but it is widely accepted as a reasonable indicator that other researchers find worthwhile research knowledge therein (Van, 1988).] The particular analytical method used in this paper focuses on the country location of the affiliation of the first author of the publication. The first author's country is used to assign citation numbers to that country. This focus on the first author is designed to preclude duplicating citation counts.

Another method to be pointed out is that we employ a simple aging practice based on dividing the citations in a given year by the number of years of opportunity to be cited. This is because citations are difficult to evaluate over time. Earlier papers have more occasions to receive citations than do more recent papers (Youtie et al., 2008). As for our dataset of SCI, the most recent year is the mid-year of 2008; thus in 2001, papers have 6.5 years of opportunity to attract citations relative to the end-point of our dataset. So the number of citations to papers published in that year is divided by 6.5. Similarly, in 2002, the number of citations should be divided by 5.5; the number 2006 citations is divided by 1.5; and so forth. So, "aged citations" gives us a metric to help gauge change in nations' research publications impact over time. Again, this is not a precision measure, but it provides for viable comparison.

In order to make results more robust, we combine the tallies for two-year periods. To reflect the earlier time period, we add 2001 and 2002 together, and compare with the corresponding number for 2005 and 2006 combined. We use 2005-06 to allow a few years for papers to accrue citations. Figure 4 shows the results. A trend line connects the results for (2001 + 2002) to those for (2005 + 2006). We first consider location along the X axis, which reflects publication counts, and find that, in the early time period, the USA is the leader, although the publication counts are modest with 14. However, by the later period, China has taken over the lead in publishing on nanoparticles in biosensors with 158. The Y axis of Figure 4 shows the citations received by those papers, adjusted by the years available since publication in which to be cited. Looking at the starting and the ending points of the lines, we find the US was highest in 2001-02 citation intensity and it remains the leader in the 2005-06 period.

The steeper the slope of the line connecting these two points, the greater the quality orientation of the country has been increasing. From Figure 4, we can find that the US has the steepest slope, suggesting that its nanoparticle-enhanced research receives the greatest attention by

4) The value of the points in the chart represents the ratio of publication counts of nanoparticle-enhanced biosensors divided by publications counts of any nanomaterial-enhanced biosensors. The search terms of nanoparticle-enhanced biosensors are "biosensors" and "nanoparticle'; While search terms of nanomaterial-enhanced biosensors are "biosensors" and "nano*".

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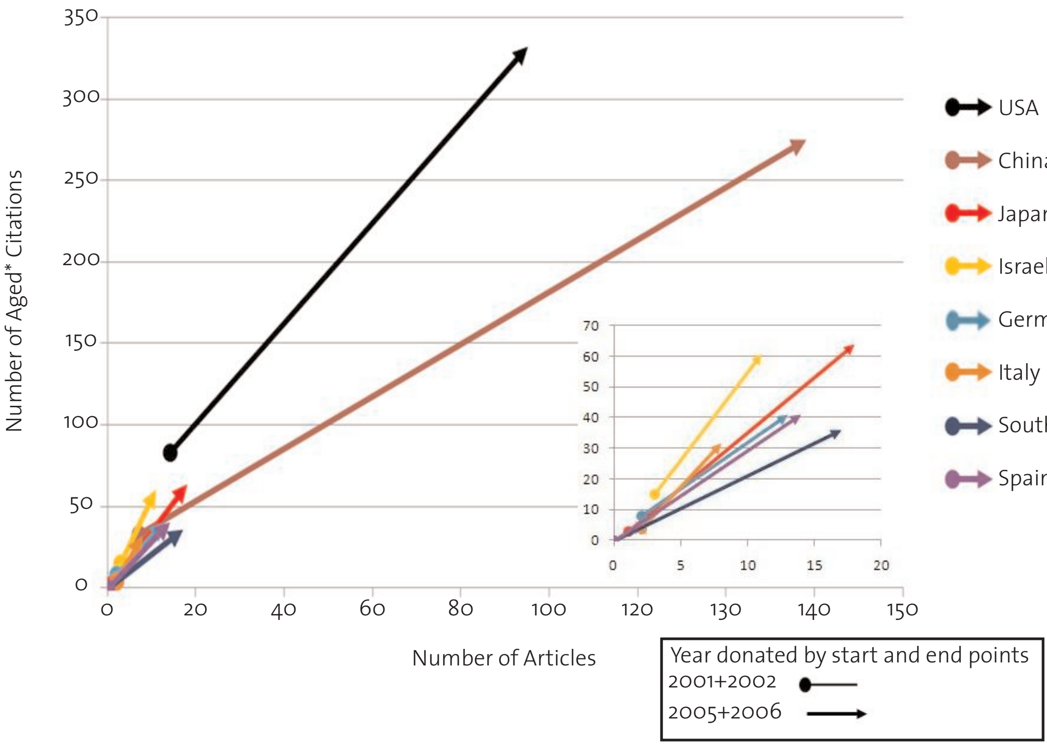
Figure 4 Number of aged citations of nanoparticles applications in biosensor in 2001 plus 2002 and 2005 plus 2006 relativ to number of articles of nanoparticles applications in biosensor by first author.[5]



researchers. As noted, China is also a leading country in research publication; here we see that Chinese publications also receive increasing citations. Israel, Italy, and Japan have far fewer publications and citations than does China (see the insert of Figure 4). However, the steep slope of their lines relative to China suggests that their papers have relatively higher impact. Germany, Spain, and South Korea are also important players in the research on nanoparticle-enhanced biosensors. So any competitive technical intelligence ("CTI") endeavors would also want to monitor their research initiatives.

Exploring multidisciplinary aspects of nanoparticle-enhanced biosensor research

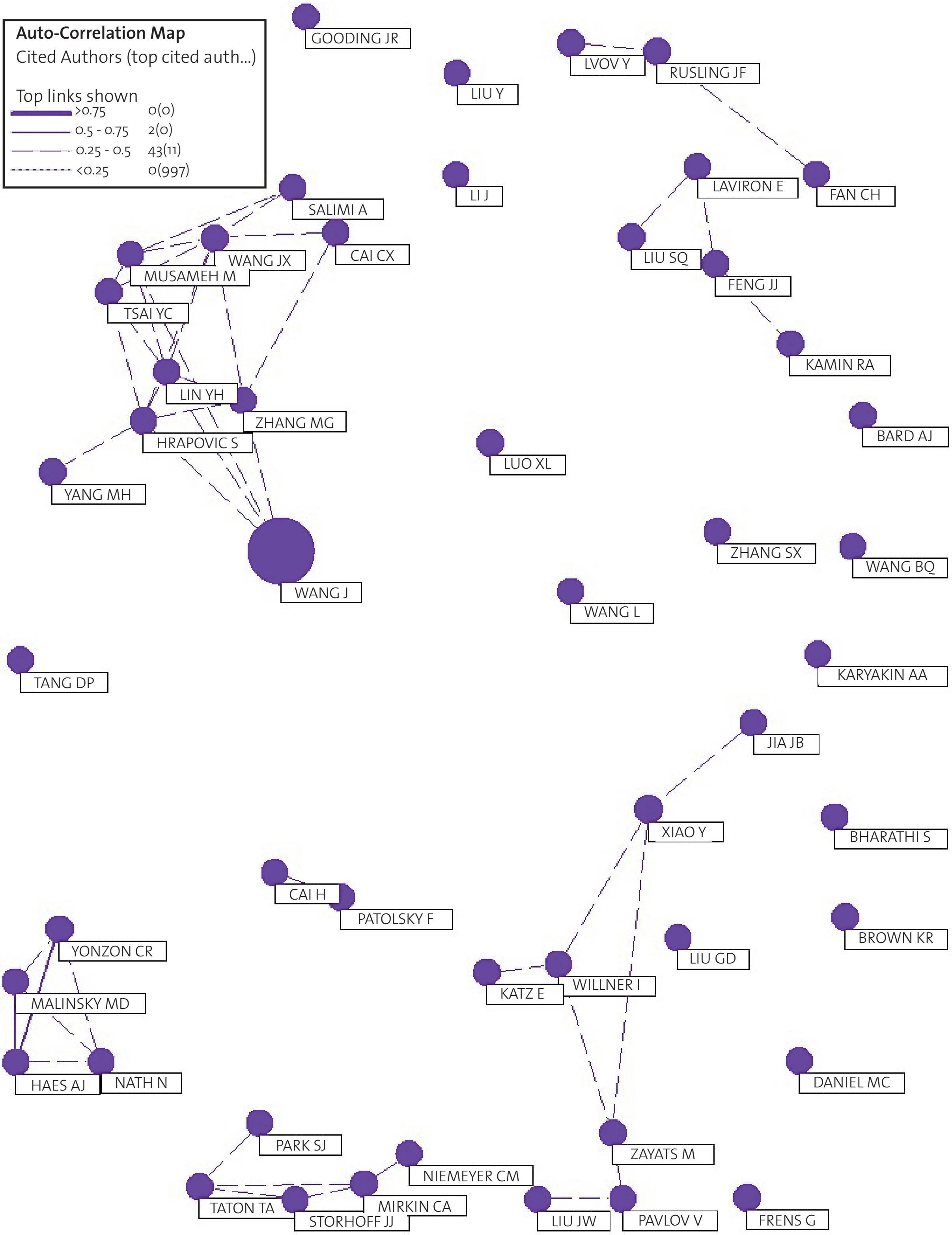
"Nano" research is highly multidisciplinary (National Science and Technology Council, 1999; Eto, 2003; Loveridge et al., 2008; Roco, 2008; Porter and Youtie, under submission). That said, there is considerable discourse as to which fields are importantly involved and the extent to which research knowledge is actively shared among them (Roco and Bainbridge, 2003; Meyer, 2006). We have found that visualizations of the research fields involved help one gain perspective on the activity.

We also examine the citations from a different point of view. Most highly cited authors (top 50) in our SCI dataset from 2001 through 2008 are mapped via the help of VantagePoint software [see www.theVantagePoint.com] in Figure 5. The size of the node reflects the number of citations, and the strength of the links shown represents the degree of association based on co-citation (the extent to which papers reference both of a pair of authors). It should be noticed that no link between two nodes doesn't mean zero co-citations, just fewer co-citations[6]. Proximity in these Multi-Dimensional Scaling (MDS) maps also suggests relationship, but not as definitely

5) *Aged citations(AC) for country$_i$ calculated as $AC_i=Ct_i/(Y_n-Y_t)$ where Ct_i=total number of citations for articles in target year for country$_i$; Y_n=most recent year in dataset (2008, mid-year); and Y_t=target year. For 2001, Y_n-Y_t=6.5; for 2002, Y_n-Y_t=5.5; for 2005, Y_n-Y_t=2.5; for 2006, Y_n-Y_t=1.5. Country designated by article first author. Database used: Science Citation Index.

6)The threshold of the MDS is set to 0.25 here. So, absence of a connecting link means that few (not necessarily zero) papers cite both researchers. The nature of this "co-citation" sampling means that not all prominent researchers will likely be located.

Figure 5 Co-citation map of top 50 cited authors



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as do the path-erasing based links (lines). Location along the axes has no inherent meaning.

The clustering seen in Figure 5 suggests possible concentrations in the cited literature. We examined in which journals the different highly co-cited authors published most heavily. We then associate those journals with their SCI subject categories, noting four particularly prominent ones:

- **Chemistry, Analytical:** with Wang J (Arizona State Univ) as the centrally-cited author
- **Materials Science, Multidisciplinary:** a group at Northwestern University, including Mirkin CA, Yonzon CR, Malinsky MD , and Haes AJ
- **Electrochemistry:** Bard AJ (University of Texas, Austin); Liu SQ (Nanjing University); Rusling JF (University of Connecticut); Lvov Y (Louisiana Tech Univ)
- **Biotechnology:** Willner I and Xiao Y (The Hebrew Univ of Jerusalem); Liu GD (Pacific Northwest National Lab); Mirkin CA (Northwestern University); Nie SM and Bao G (Georgia Institute of Technology).

Science mapping is emerging as a specialty in its own right (Chen, 2003; Boyack et al., 2005). We have been developing a "science overlay mapping" approach to locate particular research sets on a base science map (Leydesdorff and Rafols, forthcoming; Rafols and Meyer, forthcoming). This approach uses the Subject Categories that Web of Science assigns to journals. For a set of publications indexed by Web of Science (in this case, by SCI, which is part of Web of Science), we locate that research by the journals in which it appears. Figures 6 and 7 do that for subsets of the "nanoparticles and biosensors" research papers, which are based on SCI dataset for 2005 through part-year 2008 in order to focus on the emergent characters of recent 4 years. The base map reflects the 175 Subject Categories shown by the background intersecting arcs among them. The Subject Categories are then grouped into "macro-disciplines" using a form of factor analysis (Principal Components Analysis) based on the degree of co-citation of the Subject Categories in a large sample of articles indexed by Web of Science (Porter and Rafols, forthcoming). Those macro-disciplines become the labels in the figure. The "nanoparticles in biosensors" research concentrations appear as nodes on this map.

These science overlay maps particularly help us answer two questions: which research fields are engaged? And how similar is the approach of different players? In this case, we choose to focus on national comparisons. We only show two of the leading countries active in this research arena – the US and China. Some observations include:

- Nanoparticles in Biosensors research involves a very extensive range of research fields
- That research is centered in Materials Sciences and Chemistry
- The research also involves a number of Biomedical Sciences

The Chinese and American research patterns are largely similar – both engage the same broad swath of research fields. But Chinese and American research emphases are not identical (Table 1 shows significant variations, particularly in chemical specialties).

Table 1 tabulates the leading Subject Categories represented by Chinese and American publications in this area for 2005-08. On the left, one sees the number of publications associated with each Subject Category. At the top is the number of publications by China and by the USA. The percentages are taken of the national totals. So, for example, 57% of China's articles indexed by SCI for this search set (nanoparticles and biosensors) are associated with Analytical Chemistry journals and another 40% are linked to Electrochemistry [We note that the column percentages total over 100%; that is because Web of Science associates some journals (~39%) with more than one Subject Category.]. So, the Chinese research, in comparison to the American, emphasizes Chemistry more heavily. Conversely, notice that American articles are considerably more apt to entail Physics sub-areas than are the Chinese. Discerning such differences (and pursuing their implications) can be vital to proactive business management.

Comparing different types of nanoparticles involved in biosensor enhancement

Reviewing recent studies, we find that many kinds of nanoparticles have been widely used in biosensors. Here, we group nanoparticles into four families - metal nanoparticles, semiconductor nanoparticles, magnetic nanoparticles, and all other types (including polymer nanoparticles, silica nanoparticles, and so on). All these nanoparticles can be used in biosensors, as long as the particle surface is modified with specific functional groups. Since different families of nanoparticles, and sometimes nanoparticles of the same family, can play different roles in biosensor systems, we attempt to identify the most representative properties taken on by different nanoparticles, either in a group or individually. In Figure

Figure 6 Locating US "Nanoparticles in Biosensors" research over a base map of science

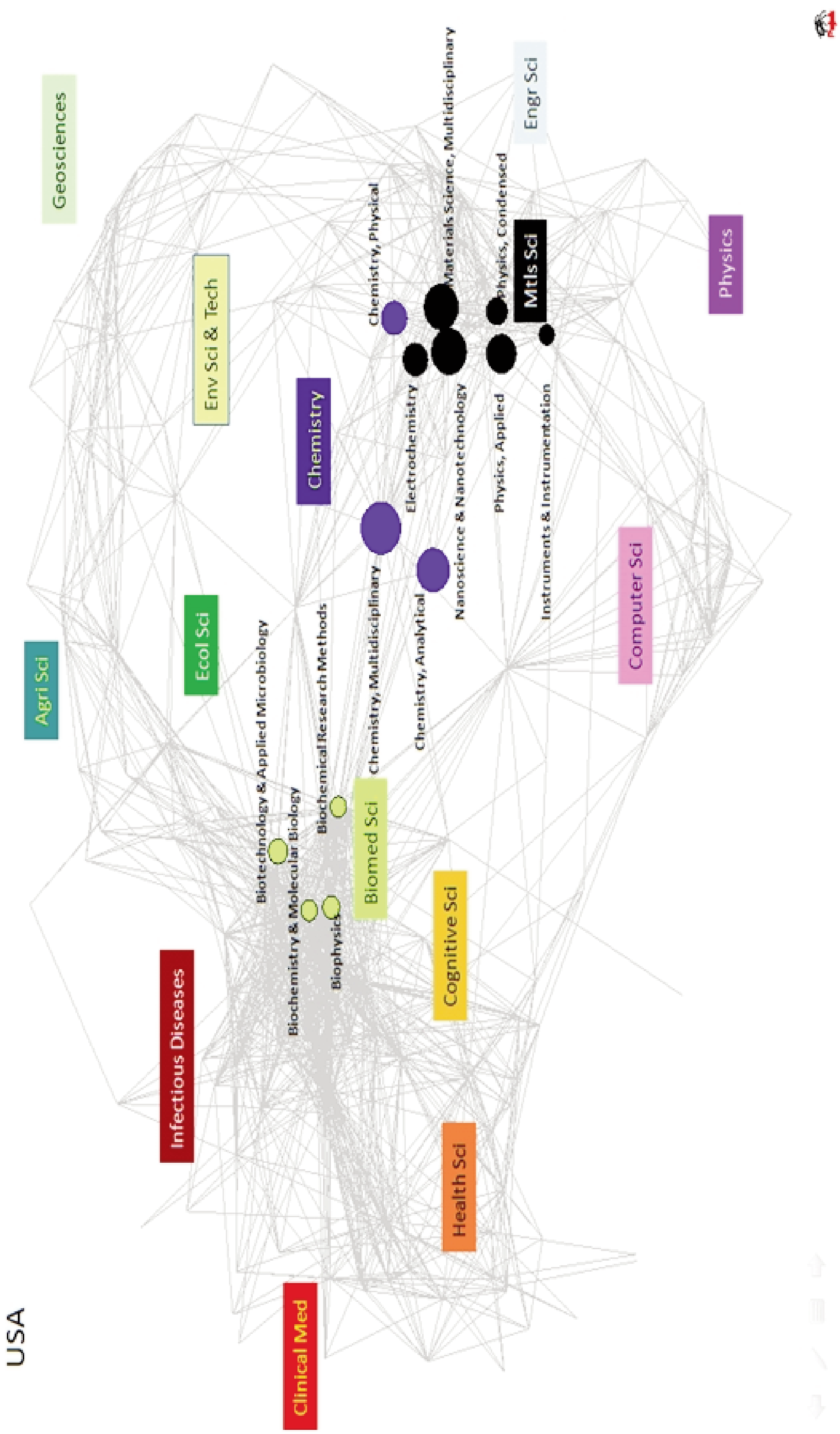

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Figure 7 Locating China "Nanoparticles in Biosensors" research over a base map of science

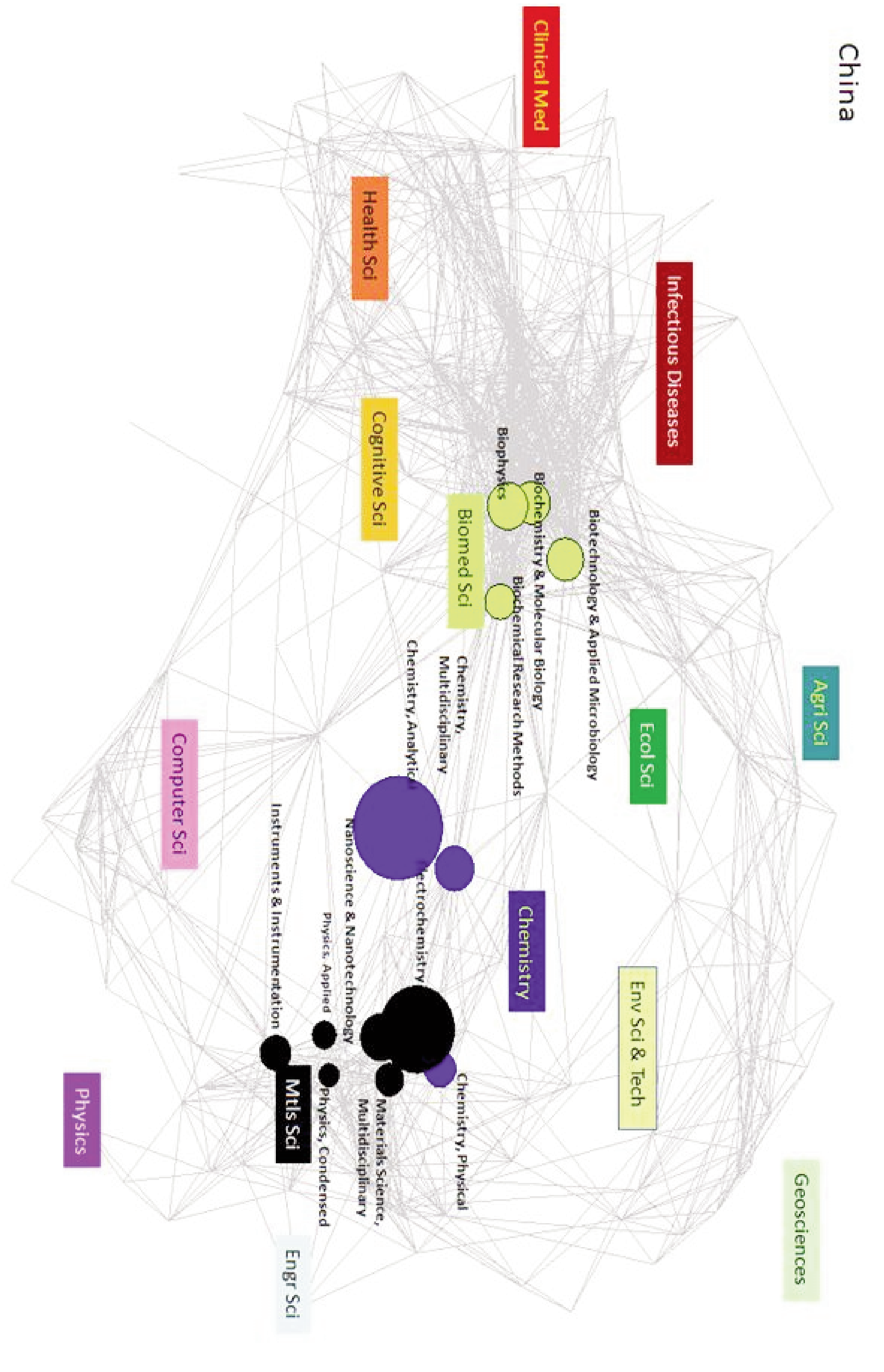

Table 1 "Nanoparticles and Biosensors" research emphases: USA and China
[Based on SCI dataset for 2005 through part-year 2008]

#		330	141
	Subject Category	China	USA
328	Chemistry, Analytical	57%	21%
226	Electrochemistry	40%	12%
126	Nanoscience & Nanotechnology	12%	24%
107	Chemistry, Multidisciplinary	11%	30%
101	Materials Science, Multidisciplinary	6%	23%
74	Biophysics	12%	6%
72	Chemistry, Physical	7%	13%
71	Biotechnology & Applied Microbiology	10%	7%
67	Physics, Applied	4%	17%
50	Biochemistry & Molecular Biology	10%	5%
47	Instruments & Instrumentation	7%	5%
42	Physics, Condensed Matter	3%	9%
40	Biochemical Research Methods	7%	5%

8, we summarize the detailed ties from the most frequently researched nanoparticles to their unique properties, and to their possible enhancement of biosensing. Figure 8 reveals the extremely promising prospects of specific nanoparticles in designing new and improved biosensors by using their unique chemical and physical properties.

Our search results show that biosensors composed with nanoparticles do purport to provide advantages in their sensitivity, stability, accuracy, selectivity, and so on. For instance, improved accuracy and stability of biosensors were demonstrated by using nanoparticles as the solid support and carrier of biological components, such as proteins and DNA (Lynch et al., 2007). This improvement benefits from the small physical size of nanoparticles, which minimizes the conformational and activity change of the biological components. In addition, biosensors with improved detection limits and selectivity have been developed by making use of the exceptional catalytic effect of Pt and Au nanoparticles (Luo et al., 2006). Furthermore, biosensors capable of highly sensitive and stable detection of multiple cancer markers were enabled by the high fluorescent quantum yield and enhanced photostability of semiconductor nanoparticles such as CdS and CdSe quantum dots (Medintz et al., 2005). We mention that many polymer nanoparticles (e.g. polystyrene) offer not only direct bioconjugation processes, but also promising biocompatibility. Therefore, we expect the polymer family of nanoparticles to play increasing roles in biosensing applications.

An important trend in current research is using composite nanoparticles with combined properties of polymer, semiconductor, and metal nanoparticles for multifunctional applications. Composite nanoparticles are mainly in the form of core-shell structures. Heavily researched ones include silver-polystyrene particles (Wu et al., 2003) and magnetite-dextran particles (Pankhurst et al., 2003).

In terms of percentage of the aforementioned four kinds (metal, semiconductor, magnetic, polymer) of nanoparticles, metal nanoparticles dominate (Figure 9). Before 2002, only metal and magnetic nanoparticles were investigated for biosensor enhancement. Although semiconductor and polymer nanoparticles were employed to enhance the functions of biosensor systems later, these

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Figure 8 Nanoparticle – property – enhancement cross-chart

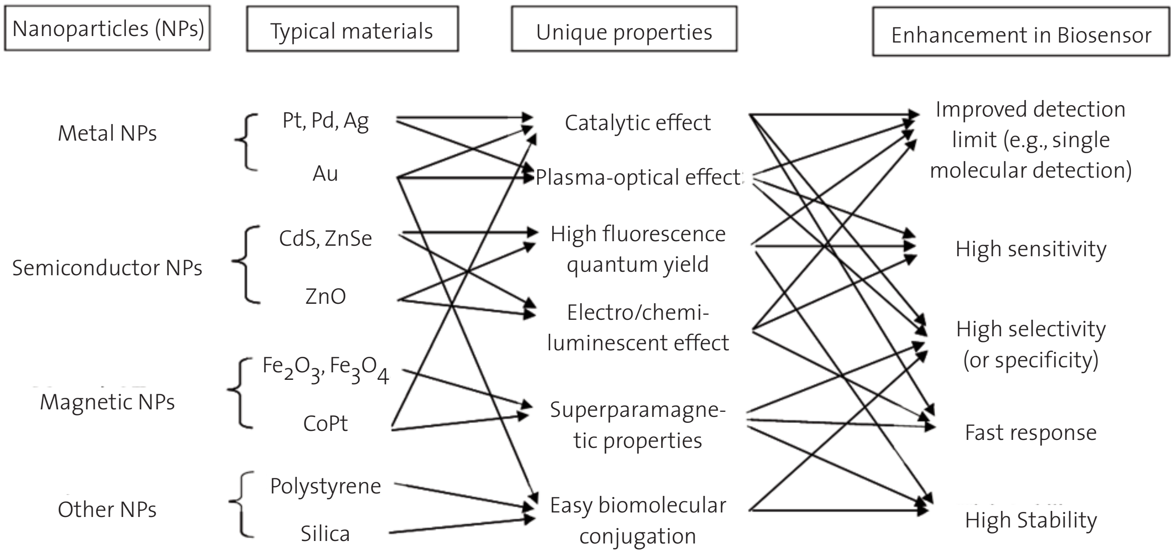

Figure 9 Percentage of annual nanoparticle-enhanced Biosensors publications by nanoparticle type. Databases used: Science Citation Index, 2001-2008 (estimated).

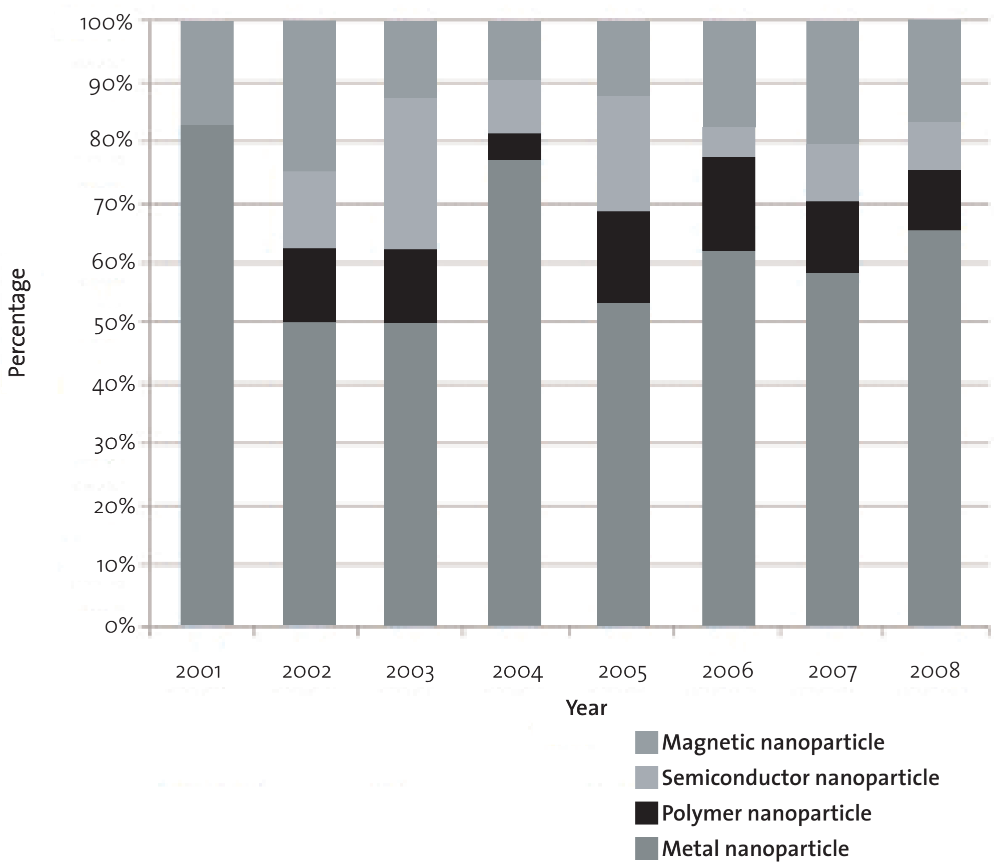

Figure 10 Cumulative publications of 3 typical metal nanoparticles applied in biosensors. Databases used: Science Citation Index, 2001-2008 (estimated).

three kinds of nanoparticles are still relatively minor components of this research domain. To probe a level deeper, we identified that metal nanoparticles constitute a big family, including Pt, Ag, Au, Pd, Cu nanoparticles and so on. This could be a major reason for its high profile in nanoparticle-enhanced biosensors. Turning to the publications counts of typical metal nanoparticles applied in biosensors (Figure 10), we conclude that gold (Au) nanoparticles are the most frequently used. The gold nanoparticles publications count has kept increasing from 2001 to 2008. However, the other two metal nanoparticles, platinum and silver, are only becoming popular in recent years. Noticeably, platinum nanoparticles appear to be an emerging nanoparticle which is increasingly popular since 2007 in constructing biosensors. Due to high surface free energy, gold nanoparticles can adsorb biomolecules strongly and play an important role in the immobilization of biomolecules for biosensor construction (Cai et al., 2001). In addition, the combination of the catalytic properties of gold nanoparticles with the specificity of biomolecular interactions can result in the construction of highly sensitive and selective sensor systems (Xian et al., 2005). Furthermore, gold nanoparticles have been shown integrated with carbon nanotubes to form nanohybrids to modify biosensors with improved indirect detection of enzymes (Cui et al., 2008).

As for the prominent research fields of nanoparticle-enhanced biosensors, we selected five kinds of biosensors based on the biological components used for bio-recognition in the sensing scheme. In order to capture the character of this research, we focus on their publications numbers in our SCI dataset during most recent 4 years (2005 through 2008 part year). Figure 11 shows that the publications counts of these 5 nanoparticle-enhanced biosensors are increasing over the years. Enzyme-based biosensors are at the top followed by immunosensors, chemical substance-based biosensors, genome sensors, and organism and cell-based biosensors.

We present these data to suggest to technology analysts and managers the potential to generate valuable CTI. Again, we reiterate that engagement of technical experts is essential to identify the nuances and implications of such empirical information.

Discussion

This paper has examined R&D on nanoparticle-enhanced biosensors and employed bibliometric analyses as a means to help forecast R&D

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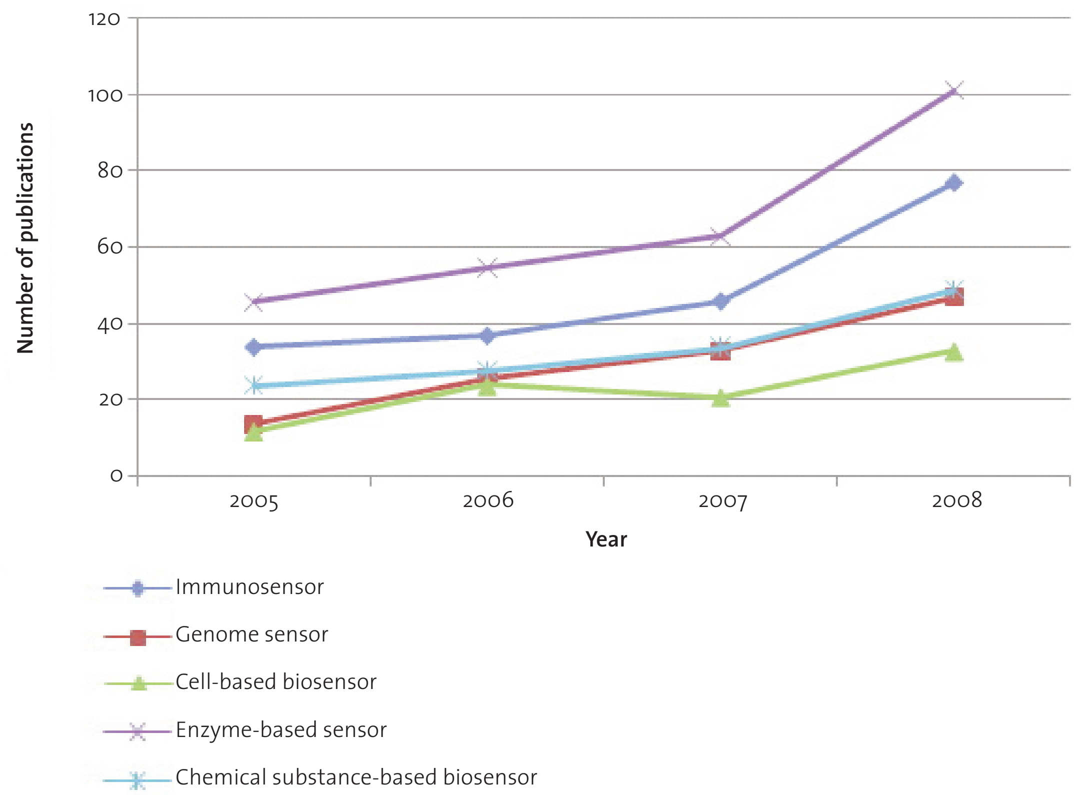
Figure 11 Cumulative publications of nanoparticle-enhanced biosensors in recent 4 years
Databases used: Science Citation Index, 2005-2008 part year



trends and identify the emerging nanoparticle roles in biosensors. According to the results of the trend growth models, the R&D activities appear likely to increase over the next few years. Moreover, nanoparticles show greater potential to improve the performance of biosensors than do other nanomaterials.

In addition, a combination of quantity (publication) and quality (citation) analysis for nanoparticle-enhanced biosensors helps position the leading countries in this research field. Science overlay mapping helps us see the different emphases of nanoparticle-enhanced biosensors research between the US and China. We noted the potential complementarity in Chinese chemistry and US physics emphases in this R&D. R&D managers might well want to extend such analyses to profile the research emphases of particular organizations. By identifying particular specializations and research strengths, they can identify potential technology development partners. Such research outreach is becoming increasingly essential as "Open Innovation" becomes increasingly important (Chesbrough, 2006; Huston and Sakkab, 2006). This is especially so in today's difficult economy.

Nanoparticle-enhanced biosensors present a highly cross-disciplinary research arena. This suggests value in exploring the relationships further. Is research concentrated in particular Subject Categories being fully utilized by researchers in other domains? What is the cooperative research network? For instance, are there conferences to bring together the biomedical researchers with the chemists, the materials scientists, and the physicists, to share cutting edge knowledge that could come to bear on nano-enhancement of various biosensors? For the technology manager, what can you do to facilitate cross-field and cross-institutional research knowledge transfer? Our perspective, based on these bibliometric analyses, is that this field is ripe for stimulated research knowledge exchange. The variety of nanoparticles, multiple functions, and diverse applications suggest that R&D managers should actively reach out and exploit cross-area results.

Researchers incorporate nanoparticles into

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biosensors to improve the performance of existing and potential sensing applications. We analyzed the increasing focus on specific functions of nanoparticles and their ties to promising enhancement in biosensors. These specific functions include catalytic, plasma-optical, quantum, electro/chemiluminescent, and superparamagnetic effects. One type of nanoparticle can play different roles in different biosensor systems, and it can also play more than one role in the same biosensor system. Different types of nanoparticle-enhanced biosensors analyzed include enzyme-based biosensors, immunosensors, chemical substance-based biosensors, genome sensors, and cell-based biosensors. We identified gold nanoparticles as especially promising for biosensor enhancement and probed their applications in various biosensors using specific or combined functions they possess. A future course of investigation would involve developing enhanced methods for discerning special functions of different types of nanoparticles in biosensor systems. Our observation that "nano in biosensors" research has become increasingly specific – in terms of particular materials and particular functional gains – is a key indicator that this technology is "emerging" (Watts and Porter, 1997). When research shifts from the general to the specific, this is a key benchmark of maturation.

In closing, we note an important caution. Before basing business decisions on such research profiling and forecasting, one would want to obtain expert opinions by researchers and business people conversant with the topic (Two senior researchers and several others have reviewed and enhanced our analyses). Experts can help build upon these results to suggest additional linkages to related research domains to explore. Experts can also help refine the searches and refocus the inquiry to better understand patterns in specific aspects of this emerging technology.

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References

Boyack, K. W., Klavans, R., Börner, K. (2005): Mapping the backbone of science. *Scientometrics*, **64**(3), p. 351-374.

Cai, H., Xu C., He PG., Fang YZ. (2001): Colloid Au-enhanced DNA immobilization for the electrochemical detection of sequence-specific DNA, *Journal of electroanalytical chemistry*,**510**(1), p. 78-85.

Chen, C. (2003): *Mapping Scientific Frontiers: The Quest for Knowledge Visualization*, Springer, London.

Chen, J.R., Miao YQ., He NY., Wu XH., Li SJ. (2004): Nanotechnology and biosensors, *Biotechnology Advances*, **22**(7), p. 505-518.

Chesbrough, H.W. (2006): *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School, Cambridge, MA (paperback edition).

Cui, R.J., Huang, H.P., Yin, Z.Z., Gao, D., and Zhu, J.J. (2008): Horseradish peroxidase-functionalized gold nanoparticle label for amplified immunoanalysis based on gold nanoparticles/carbon nanotubes hybrids modified biosensor, *Biosensors and Bioelectronics*, **23**(11), p. 1666-1673.

Daim, T.U., Rueda, G.R., Martin, H.T. (2005): Technology forecasting using bibliometric analysis and system dynamics, *Technology Management: A Unifying Discipline for Melting the Boundaries*, **31**(4), p.112-122.

Daim, T.U., Rueda, G.R., Martin H.T., Gerdsri P. (2006): Forecasting emerging technologies: use of bibliometrics and patent analysis, *Technological Forecasting & Social Change,* **73**(8), p. 981-1012.

Eto, H. (2003): Interdisciplinary Information Input and Output of Nano-technology Project, *Scientometrics*, **58**(1), p. 5-33.

Grodal, S., and Grid T. (2008): Cross-Pollination in Science and Technology: Concept Mobility in the Nanobiotechnology Field. Paper presented at the NBER Conference on Emerging Industries: *Nanotechnology and NanoIndicators*, May, 2008, Cambridge, MA, USA

Huston, L., and Sakkab, N. (2006): Connect and Develop, *Harvard Business Review*, (3), p. 58-66.

Khanna, V.K. (2008): New-generation nano-engineered biosensors, enabling nanotechnologies and nanomaterials, *Sensor Review*, **28**, p. 39-45.

Kim, T. H., Park, I. K., Nah, J. W., Choi, Y. J., and Cho., C. S. (2004): Galactosylated chitosan/DNA nanoparticles prepared using water-soluble chitosan as a gene carrier, *Biomaterials*, **25**, p. 3783-3792.

Leydesdorff, L., and Rafols, I. (Forthcoming): A Global Map of Science Based on the ISI Subject Categories, *Journal of the American Society for Information Science and Technology*. Preprint [http://users.fmg.uva.nl/lleydesdorff/map06/texts/map06.pdf].

Loveridge, D., Dewick, P., and Randles S. (2008): Converging technologies at the nanoscale: The making of a new world? *Technology Analysis & Strategic Management*, **20** (1), p. 29-43.

Luo, X.L., Morrin, A., Killard, A.J., Smyth, M.R. (2006): Application of nanoparticles in electrochemical sensors and biosensors, *Electroanalysis*, **18**(4), p. 319-326.

Lynch, I., Cedervall, T., Lundqvist, M., Cabaleiro-Lago, C., Linse, S. and Dawson K.A. (2007): The nanoparticle–protein complex as a biological entity; a complex fluids and surface science challenge for the 21st century, *Advances in Colloid and Interface Science,* **134**, p. 167-174.

Martino, J.P. (2003): A review of selected recent advances in technological forecasting, *Technological Forecasting and Social Change*, **70**(8), p. 719-733.

Medintz, I. L., Uyeda, H. T., Goldman, E. R., and Mattoussi, H. (2005): Quantum dot bioconjugates for imaging, labelling and sensing, *Nature Materials*, **4**, p. 435-446.

Meyer, M. (2006): What Do We Know About Innovation in

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Nanotechnology? Some Propositions About an Emerging Field Between Hype and Path-Dependency, Paper presented at the 2006 Technology Transfer Society Conference, September 27-29, Atlanta, Georgia.

National Science and Technology Council (1999): *Nanostructure Science and Technology: A Worldwide Study*, R.W. Siegel and M.C. Roco. Washington DC, National Science and Technology Council.

Pankhurst, Q. A., J. Connolly, S. K. Jones, and J. Dobson. (2003): Applications of magnetic nanoparticles in biomedicine, *Journal of Physics-London-D Applied Physics*, **36**, p. 167-181.

Porter, A.L., and Rafols, I. (forthcoming): Is science becoming more interdisciplinary? Measuring and mapping six research fields over time, *Scientometrics*.

Porter, A.L., Roper, A.T., Mason, T.W., Rossini, F.A., and Banks, J., (1991): *Forecasting and Management of Technology*, John Wiley, New York.

Porter, A.L., and Youtie, J., Shapira, P., and Schoeneck, D.J. (under submission) How Interdisciplinary Is Nanotechnology?, *Journal of Nanoparticle Research*.

Porter, A.L., Youtie, J., Shapira, P., and Schoeneck, D.J. (2008): Refining Search Terms for Nanotechnology, *Journal of Nanoparticle Research*, **10** (5), p. 715-728.

Rafols, I. and Meyer, M. (forthcoming), Diversity and network coherence as indicators of interdisciplinarity: case studies in bionanoscience, *Scientometrics*.

Roco, M. C., and Bainbridge, W.S. (2003): *Converging technologies for improving human performance: Nanotechnology, biotechnology, information technology and cognitive science*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Roco, M. C. (2008): Possibilities for global governance of converging technologies, *Journal of Nanoparticle Research*, **10** (1), p. 11-29.

Shipway, A.N., Katz E., Willner, I. (2000): Nanoparticle Arrays on Surfaces for Electronic, Optical, and Sensor Applications, *Chemphyschem*, **1**(1), p. 18-52.

Van Raan, A.F. J. (Ed.) (1988): *Handbook of Quantitative Studies of Science & Technology*, North Holland, Dordrecht. See also website: http://www.cwts.nl/

Watts, R.J., Porter, A.L., Newman, N.C. (2001): Innovation forecasting using bibliometrics, *Competitive Intelligence Review*, **9**(4), p. 11-19.

Watts, R.J., and Porter, A.L. (1997): Innovation Forecasting, *Technological Forecasting and Social Change*, **56**, p. 25-47.

Wu, D., Ge, X., Huang, Y., Zhang, Z., and Ye, Q. (2003): -Radiation synthesis of silver–polystyrene and cadmium sulfide–polystyrene nanocomposite microspheres, *Materials Letters* **57**, p. 3549-3553.

Xian, Y.Z., Hu, Y., Liu, F.,Xian, Y., Wang H.T., Jin L.T. (2005): Glucose biosensor based on Au nanoparticles-conductive polyaniline nanocomposite, *Biosensors and Bioelectronics*, **21**(10), p. 1996-2000.

Youtie, J., Shapira, P., Porter, A.L. (2008): Nanotechnology publications and citations by leading countries and blocs, *Journal of Nanoparticle Research*, **10**(6), p. 981-986.

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Research Section

Knowledge sharing in heterogeneous collaborations – a longitudinal investigation of a cross-cultural research collaboration in nanoscience

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In times of globalization and rapidly developing R&D systems, the importance of international collaborative research activities increases, leading to a growing number of heterogeneous collaborations. Especially considering the cultural diversity of such collaborations, intensive cross-cultural knowledge sharing becomes a prerequisite for collaborative success. This paper investigates personal and cultural incentives and barriers influencing the intention to share knowledge of Chinese and German collaborators in an academic setting, employing a linear regression analysis and Chow tests. We can demonstrate that the factors sense of self-worth, loss of knowledge power, guanxi and face saving have an influence on an individual's intention to share knowledge. Further we find significant differences in our Chinese and German subgroups that can be related to cultural impacts. The obtained results provide practical and theoretical implications for the improvement of cross-cultural knowledge sharing in collaborative R&D project.

1 Introduction

Nowadays, researchers are facing highly complex problems, rapidly changing technologies and a dynamic growth of knowledge, due to the expansion of science on several axes, e.g. geographical, economical, multidisciplinary and multinational axis (Galison and Hevly, 1992). Often, individual academic scientists can no longer provide all of the expertise and resources necessary to address large research projects (Hara et al., 2003). Furthermore, these characteristics of modern research encourage scientists to get involved in collaborative research (Sooho and Bozeman, 2005). Generally, research collaborations[1] can emerge between companies (C-C), companies and universities/research institutes (C-U) or universities (U-U).[2]

In particular, increasing global competition disposes companies to take advantage of synergy effects by intensifying global colla-

1) Misleadingly, the terms 'cooperation' and 'collaboration' are often used synonymously. Further similar terms for example are: 'alliance', 'confederacy', 'joint-venture', 'coalition', or 'partnership' (Müller, 2006). Cooperation is characterised by "an interaction process in which the individuals share a common goal and interact in a coordinated way". Coordination means some kind of superordinated entity that exerts influence on the proceedings of each group member with regard to the common goal (Gronau, 2002). On the contrary, collaboration does not need such a coordination function. Collaboration just "means that people work together to achieve a single common result in which contributions of individuals are unified" (Han, 1997).

2) In this paper we subsume research institutes and universities.

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boration (Lam, 1997). Thereby, growth, expansion, exchange and generation of knowledge and technology represent the main reasons for joint C-C research activities (Campione, 2003; Odenthal et al., 2002).

The intentions of collaborators to strive for C-U collaboration differ. In addition to capitalizing on cost savings and access to the latest technology, companies utilize this kind of collaboration to open up cost-effective recruiting channels, to access laboratory usage, to share risks for basic research and to stabilize long term research projects (Azarloff, 1982; Bonaccorsi and Piccaluga, 1994; Cyert and Goodman, 1997; Rohrbeck and Arnold, 2006). In contrast, universities engaging in C-U collaborations strive for the enhancement of teaching, followed by achievement of funding and enhancement of reputation. Further motivations supporting collaborative behavior are to be found in the possibility of exchanging knowledge with industrial researchers, access to empirical data and job opportunities for graduates (Hurmelinna, 2004; Meyer-Krahmer and Schmoch, 1998).

However, in all types of collaborations and especially in academic ones knowledge sharing represents a main incentive e.g. by means of getting access to external knowledge on the one hand. On the other hand knowledge sharing is a prerequisite for successful collaboration (Hara et al., 2003; Niedergassel and Leker, 2008; Qian et al., 2008). Knowledge sharing has been in the focus of research for more than a decade and can be defined as the deployment of knowledge from a source to a recipient in communication (Berends et al., 2006). Following Nonaka, we define knowledge as justified true belief (Nonaka, 1994). Since knowledge is subjective and related to an individual's experiences, knowledge sharing is embedded in a certain cognitive and behavioral context (Michailova and Hutchings, 2006). Qian et al. identified personal and cultural factors that impact on knowledge sharing (Qian et al., 2008). Niedergassel developed a conceptual framework with influencing factors for knowledge sharing in collaborative R&D projects (Niedergassel, 2009). He hypothesizes an influence of knowledge tacitness, knowledge newness, physical proximity, frequency of personal communication, trust between partners, pre-existing relationships, interdependency of partners, redundancy of knowledge sets and closeness of partners on knowledge sharing (Niedergassel, 2009).

While knowledge sharing in C-C collaborations has been widely discussed in the existing body of literature (Abrams, 2003; Cantner and Meder, 2007; Hansen, 1999; Hansen, 2002; Kaser and Miles, 2002; Lam, 1997; Levin and Cross, 2004; Reagans and McEvily, 2003), less effort has been made in analyzing knowledge sharing in academic collaborations (Hara et al., 2003; Niedergassel, 2009). In times of globalization and rapidly developing R&D systems, academic researchers increasingly strive for geographically distributed collaborations (Galison and Hevly, 1992; Hara et al., 2003). This leads to a constantly growing number of heterogeneous collaboration.[3] Generally, heterogeneous collaborations are characterized by an inequality of the collaborating partners. Heterogeneity can occur on several dimensions. First, depending on contract situations between collaborators, unequally distributed hierarchy can cause heterogeneity. Second, heterogeneity can arise in research disciplines, e.g. when researchers from different scientific backgrounds are working on interdisciplinary projects. Third, the geographic distribution of the partners' research basis can cause heterogeneity. Fourth, company and/or national culture can differ between collaborating partners, leading to heterogeneity.

In sight of the discussed increase in geographically distributed collaborative partnerships, especially cultural heterogeneity can cause serious difficulties in collaborative knowledge sharing activities. Thus, the understanding of cultural influences on knowledge sharing behavior is gaining importance. Still, only few studies analyzed cross-cultural knowledge sharing and they exclusively focused on C-C collaborations. Chow et al., for instance, analyzed the impact of collectivism versus individualism on the knowledge sharing behavior of Chinese and U.S. American individuals (Chow et al., 2000). Similarly, Michailova and Hutchings compared knowledge sharing in Russia and China focusing on collectivism/individualism and universalism/particularism (Michailova and Hutchings, 2006). Zhang et al. on the other hand investigated the impact of in-group/out-group affiliation on knowledge sharing in a cross-cultural setting (Zhang et al., 2008), which Chow indicated as well (Chow et al., 2000). Referring

3) Heinze and Kuhlmann define heterogeneous research collaboration as collaboration across institutional boundaries (Heinze and Kuhlmann, 2006). However, we expand the scope beyond the organizational dimension.

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to Chow, Michailova and Hutchings, Ardichvili emphasized the importance of the cultural factors collectivism/individualism, in-group/out-group orientation, fear of losing face, and the importance of status and power distance, in his research on culture-specific barriers to knowledge sharing in China, Russia and Brazil (Ardichvili et al., 2006).

Contributing by filling the research gap regarding cross-cultural knowledge sharing in academic settings, we investigate different intentions to share knowledge in the first Chinese-German research collaboration on Nanoscience. Particularly, we focus on personal and cultural factors impacting the collaborators' intention to share knowledge, employing a longitudinal research approach.

In the course of this paper, we first describe our research framework. Second, we present cultural factors differing between Chinese and German societies. Third, the Social Exchange Theory will be discussed and used to explain knowledge sharing behavior. Afterwards, we will present our hypotheses concerning the factors potentially impacting the intention to share knowledge. Subsequently, we will characterize our methodology, followed by a presentation of the results. Finally, a discussion and conclusion will summarize the findings of this paper, providing recommendations and practical guidelines for improving the process of knowledge sharing.

2 The Transregional Collaborative Research Centre: a heterogeneous collaboration

The "Transregional Collaborative Research Centre" (TRR 61) represents the first academic Chinese-German research collaboration on Nanoscience and is entitled "Multilevel Molecular Assemblies: Structure, Dynamics and Function". Participants within the TRR 61 are the University of Münster (Germany), the Centre for Nanotechnology (CeNTech), the Centre for Nonlinear Science (CeNoS), the Tsinghua University (Beijing, China), the Chinese Academy of Science, the Interdisciplinary Research Centre for Cooperative Functional Systems (FOKUS) and the Chinese National Centre for NanoScience & Technology (NCNST, Beijing/China). Inspired by natural systems and their properties, chemists, physicists and biologists are working on the interdisciplinary field of functional molecular and nano object assemblies. Participants of the TRR 61 are hierarchically equal and their knowledge is accessible for everybody within the TRR 61. The TRR 61 demonstrates heterogeneity on the disciplinary, the cultural and the geographical dimension, representing an ideal opportunity to investigate cultural impacts on knowledge sharing activities.

3 Cultural differences between China and Germany

Based on an analysis of Geert Hofstede (5D-model) concerning five cultural dimensions (Power Distance Index, PDI; Individualism, IDV; Masculinity, MAS; Uncertainty Avoidance Index, UAI; Long-Term Orientation, LTO),[4] Germany and China feature opposed parameter values in all dimensions, except Masculinity. The scores of China and Germany in Hofstede´s 5D-model are presented in Figure 1.

The PDI of China (80) is higher than the PDI in Germany (35), indicating a higher level of inequality of power and wealth in the Chinese than in the German society. Moreover, in China subordinates are unlikely to approach and contradict their supervisor in a direct way, while German subordinates will do so more likely (Hofstede and Hofstede, 2007).

The IDV scores are considerably higher in Germany (67) than in China (20), meaning that the German society is oriented towards individualism and the Chinese society is oriented

4) A detailed description can be found in Hofstede (2007):

- "PDI: Power distance is defined as the extent to which the less powerful members of institutions and organizations within a society expect and accept that power is distributed unequally.
- IDV: Individualism is the opposite of collectivism. Individualism stands for a society in which the ties between individuals are loose: a person is expected to look after himself or herself and his or her immediate family only. Collectivism stands for a society in which people from birth onwards are integrated into strong, cohesive in-groups, which continue to protect them throughout their lifetime in exchange for unquestioning loyalty.
- MAS: Masculinity is the opposite of femininity. Masculinity stands for a society in which emotional gender roles are clearly distinct: men are supposed to be assertive, though, and focus on material success; women are supposed to be more modest, tender, and concerned with the quality of life. Femininity stands for a society in which emotional gender roles overlap: both men and women are supposed to be modest, tender, and concerned with the quality of life.
- UAI: Uncertainty avoidance is defined as the extent to which the members of institutions and organizations within a society feel threatened by uncertain, unknown, ambiguous, or unstructured situations.
- LTO: Long-term orientation is the opposite of short-term orientation. Long-term orientation stands for a society that fosters virtues oriented towards future rewards, in particular perseverance and thrift. Short-term orientation stands for a society that fosters virtues related to the past and present, in particular respect for tradition, preservation of 'face', and fulfilling social obligations."

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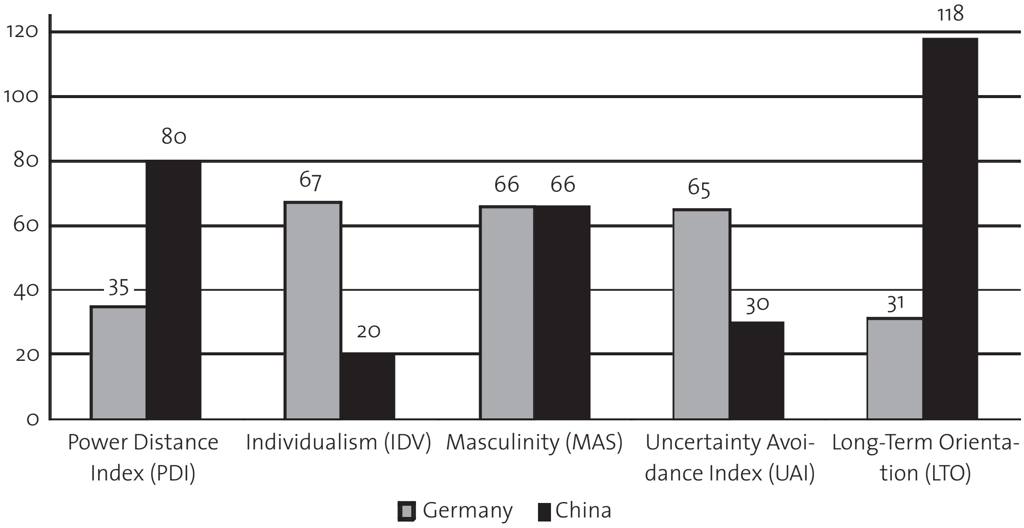
Figure 1 Comparison of Chinese and German scores in Hofstede´s 5D-model.



towards collectivism. Thus, in the individualistic Germany tasks always prevail over personal relations and vice versa in the collectivistic China. According to Hofstede, Chinese-German cooperation shows differences in social and group orientation, respectively. Whereas the German managers' way of thinking and operating is affected by individualism, Chinese managers orient their behavior towards collectivism (cf. IDV) (Valentine and Godkin, 2001).

Basically, this effect is derived from utterly heterogeneous political orientations, as well as from the importance of the family, traditionally founded in the long history of China (Ho, 1976). On this basis it is conjecturable that the collaboration propensity will be more pronounced for Chinese (Birnholtz, 2007).

China and Germany show equal scores (66) in masculinity, representing equal occurrence of clearly distinct emotional gender roles. In contrast, considerable differences emerge in the factor UAI. The scores in the UAI are higher in Germany (65) than in China (30). This indicates that there are more formal laws, informal rules and work regulations controlling the rights and duties of individuals in Germany than in China. In countries showing a low degree of uncertainty avoidance like China, one believes that many problems can be resolved without rules and that rules should only be established if absolutely necessary. Furthermore, in countries with a high degree of uncertainty avoidance orientation individuals like to be always busy and hard working or at least like to be seen so, while in low uncertainty avoidance countries individuals are able to work hard when needed, but they are not "driven by an inner urge toward constant activity" (Hofstede and Hofstede, 2007).

The greatest difference between the Chinese and the German culture according to Hofstede is found in LTO. China has the highest score (118) of all countries and Germany (31) is ranked with a low LTO score. Hence, culturally based differences between China and Germany in the concept of time are expected. Thereby, in contrast to Germans, Chinese do not think about time in terms of "time is money". Since in China time appears as a relatively unlimited and cheap good, Chinese are more focused on the long-term outcome rather than on obtaining short-term success as it is to be found in Western countries (Wilpert and Scharpf, 1990).

Besides the Hofstede dimensions, cross-cultural researchers emphasize further important factors for the Chinese culture, namely guanxi (simply translated as 'personal connections/relationships') and the concept of face (Easterby-Smith and Malina, 1999; Ho, 1976; Jarman, 2001; Jiwen and James, 2007; Qian et al., 2008; Wilpert and Scharpf, 1990). Further factors affecting cross-cultural collaborative effectiveness are differing concepts of quality, differing respect for age and hierarchy and the use of third language communication (mainly English) (Wilpert and Scharpf, 1990). According to previous research on cross-cultural knowledge sharing, e.g. studies conducted by Ardichvili, Michailova and Hutchings

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or Zhang, we argue that guanxi and the concept of face exert main impacts on knowledge sharing processes (Ardichvili et al., 2006; Michailova and Hutchings, 2006; Zhang et al., 2008). Thus, guanxi and the concept of face are discussed in detail in the following paragraphs.

Guanxi is mostly described as a form of interpersonal relationships and connections unique to the Chinese culture. Due to the high value of harmony in the Confucian oriented Chinese society, Chinese tend to emphasize good relationships in their social environment (Qian et al., 2008). Luo describes six traits that offer a comprehensive understanding of guanxi (Luo, 1997). First, guanxi is based on a utilitarian concept and therefore bonds individuals by exchanging favors rather than feelings. A guanxi relation not necessarily involves friends, however, if possible friends are preferred (Dunning and Kim, 2007). Ties based on guanxi are easily broken when they are not perceived to help in achieving goals. Second, guanxi means reciprocal exchange of favors and frequently tends to favor the weaker relation partner (Alston, 1989). Third, guanxi is transferable in the way that if A has guanxi with B, and A has guanxi with C, he can suggest B to C or vice versa. Fourth, guanxi is operating on the individual level and thus a highly personal concept. Hereby, trust, honesty, reciprocity, respect and social status are the essential features (Davies et al., 1995). In China, interpersonal loyalty is often more important than organizational affiliation or legal status (Dunning and Kim, 2007). Fifth, guanxi is directed to long-term interpersonal associations and interactions. Sixth and lastly, guanxi has an intangible quality, i.e. individuals who share guanxi ties are committed to each other by an "informal and unwritten code of trust, forbearance, reciprocity and equity" (Dunning and Kim, 2007). Disrespecting the virtues of guanxi can easily cause serious damage to an individual's social standing and respectability.

The social standing of an individual is closely connected to the amount of 'face' an individual can claim for him/herself. Even though the concept of face is universally applicable to rank an individual's standing in his social environment, the Chinese interpretation of face is specifically oriented to status and fixed role behavior (Wilpert and Scharpf, 1990). According to Leung and Chan, face is the "respect, pride and dignity of an individual as a consequence of his/her social achievements and the practice of it" (Leung and Chan, 2003). Cardon and Scott argue that face in China is an essential component of communication and relates to a person's image and status within a social structure, while Westerners' view of face is fairly simple and separated from communication (Cardon and Scott, 2003). Face has versatile characteristics. First, an individual's face has a certain quantity, which can be increased by hard work, benefiting society, superior intellectual knowledge, accumulation of wealth and exemplary behavior, for instance (Brunner et al., 1989). Second, face has a positional aspect, i.e. the face position of individuals is generated by their social network and connections (Hwang, 1982). The larger the network and the more powerful the members connected to an individual the higher the face position. Third, face has a moral dimension, representing the confidence of society in the integrity of an individual's character (Leung and Chan, 2003). Fourth, face has a dimension related to one's prestige and reputation achieved through success and ostentation (Brunner et al., 1989). Fifth, in social interactions Chinese generally focus on saving face, giving face and avoiding a loss of face to others always under the unwritten law of reciprocity (Leung and Chan, 2003; Qian et al., 2008; Wilpert and Scharpf, 1990). Sixth and lastly, face can be transferred, i.e. buying face or borrowing face is a common praxis meaning that an individual may ask another one with a high social standing to intervene on his behalf, where the individual has not enough face (Cardon and Scott, 2003). Concluding, one has to note that Chinese collaboration partners might use face-related communication strategies to save or give face to others, e.g. indirectness, intermediaries on the one hand and praising or requests on the other (Cardon and Scott, 2003). Despite the critics to Hofstede's survey and dimensions (for instance: Baskerville, R.F. (2003)) his framework has found broad acceptance and is often applied in academic research.

4 Research construct and hypothesis

The use of collaboration as a tool of science became an essential prerequisite particularly in "big science", which is characterized by large-scale projects dealing with complex, rapidly changing problems and dynamic and highly specialized knowledge (Galison and Hevly, 1992; Hara et al., 2003). Moving from closed research to open research or even open innovation approaches, external knowledge

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sourcing and knowledge sharing become important requirements for universities (Lichtenthaler and Ernst, 2006). Often such collaborations are affected by "diversity of nationality, gender, ethnicity or profession" (Melin, 2000). Especially geographically distributed collaborators have to cope with further specific challenges, such as providing effective communication channels (e-mail, computer-networks, phone calls, etc.) and overcoming difficulties in project coordination to assure success (Birnholtz, 2007; Cummings and Kiesler, 2003; Cummings and Kiesler, 2005; Finholt, 2003). Otherwise, ideas or information pertaining to research and measuring instruments cannot be exchanged. However, sharing knowledge across long distances still remains complicated (McFadyen and Cannella Jr, 2005).

Social Exchange Theory and knowledge sharing

Whenever, deciding whether to participate in knowledge sharing activities, rational individuals will consider costs and benefits of such interactions (Qian et al., 2008). Therefore, the Social Exchange Theory (SET) can be employed to explain such situations. The SET argues that the exchange between individuals is a fundamental form of behavior and based on cost-benefit principles (Homans, 1961). Furthermore, Homans introduced psychological concepts like expectations and rewards and Blau introduced the concept of social reward, bridging the gap between individuals and society (Blau, 1964). Thibaut and Kelley propose that e.g. anticipated reciprocity and expected gain in reputation motivate individuals to participate in social exchange activities (Thibaut and Kelley, 1959). In contrast to economic exchange, social exchange occurs without specific obligations, i.e. roles or contracts. Thus, individuals do others a favor via such exchanges with the expectation of some future return, even without having a definite guarantee of this return. These characteristics match the knowledge sharing concept. Hence, we argue that knowledge sharing could be regarded as a kind of social exchange.

The SET is often applied to knowledge sharing processes as a theoretical basis (Bock et al., 2005; Niedergassel, 2009). Kankanhalli employed SET to investigate individual behavior in knowledge sharing (Kankanhalli et al., 2005). She focused on 'costs and benefits' according to SET for the analysis of incentives and barriers in knowledge sharing. Chua for instance employs a multi-person game-theoretic framework, however, he emphasizes reciprocity in knowledge sharing, declaring consistency with SET (Chua, 2003). Constant et al., using SET, argue that self-interest is an impeding factor for knowledge sharing (Constant et al., 1994). Bartol and Srivastava analyze how to design effective rewards for knowledge sharing via social exchange (Bartol and Srivastava, 2002).

Employing SET in our investigation of knowledge sharing behavior we conduct an economic analysis of noneconomic social exchanges (Emerson, 1976), thus we argue that applying the terms incentives and barriers for knowledge sharing as a noneconomic social exchange instead of the economic exchange terms benefits and costs is more appropriate. Hereby, we especially focus on individuals' personal incentives and barriers and cultural impacts that could enhance or reduce their intention to share knowledge. Particularly, we developed four hypotheses.

In literature, the sense of self-worth seems to be a main incentive for an individual to share knowledge. Individuals are more willing to participate in knowledge sharing activities if they believe that their contribution is valued by others (Cabrera and Cabrera, 2002). Since participants can evaluate the usefulness of their knowledge through feedback in knowledge sharing activities, they can achieve an enhancement of their feeling of self-worth (Bock et al., 2005; Qian et al., 2008). Due to the individualistic orientation of the German culture, we argue that the sense of self-worth is more important to Germans than to Chinese.

Besides, giving and receiving feedback as a facilitator of knowledge sharing should be more direct and distinctive in Germany due to the lower power distance index. Thus we hypothesize:

Hypothesis 1: The sense of self-worth has a stronger positive influence on the intention to share knowledge in the German group than in the Chinese group.

On the contrary, a main barrier could be the loss of knowledge power caused by sharing of an individual's unique knowledge. Previous studies suggested that individuals might be afraid to lose their competitive advantage by sharing knowledge, which they gained little by little throughout experience, failure and frustration and which enables them to exceed their colleagues' performance (Kankanhalli et al., 2005; Qian et al., 2008). Although knowledge sharing could benefit themselves and the project, those might hold onto their knowledge if they believe to receive greater benefits by doing so (Davenport and Prusak, 2000). Due to the German tendency towards individualism, where everybody looks after himself and individual success is often more important than group success we hypothesize:

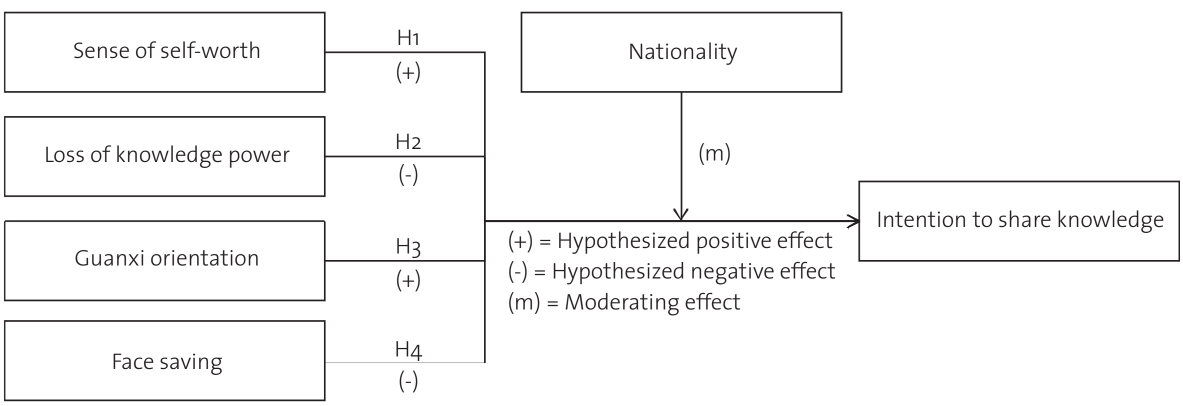
Hypothesis 2: The loss of knowledge power has a stronger negative influence on the intention to share knowledge in the German group than in the Chinese group.

In addition, cultural differences can cause difficulties and asymmetry in knowledge sharing (Lam, 1997; Zhang et al., 2008). Due to the different ways in which knowledge and skills are generated, organized, shared and utilized in different societal settings, one can expect an impact of culture when it comes to cross-cultural knowledge sharing (Lam, 1997; Zhang et al., 2008). Interpersonal networks and connections have an important influence on knowledge sharing (Weir and Hutchings, 2005). Further, social ties, including trust and rapport have a positive impact on knowledge sharing (Qian et al., 2008). Besides, Kotlarsky and Oshri argued that guanxi would promote knowledge sharing between partners (Kotlarsky and Oshri, 2005). A study conducted by Qian et al. in China demonstrates that guanxi orientation has a positive relationship with the intention to share knowledge (Qian et al., 2008). Since Chinese are very eager to maintain good relationships with people in their environment, they have a high guanxi orientation. Thus we hypothesize:

Hypothesis 3: The guanxi orientation has a stronger positive influence on the intention to share knowledge in the Chinese group than in the German group.

The amount of face an individual has can vary constantly (Ho, 1976). During the course of social interactions like knowledge sharing an individual's face could be enhanced or diminished (Qian et al., 2008). Ardichvili et al. proposed that the desire of face saving is a barrier in knowledge sharing processes (Ardichvili et al., 2006). Accordingly, Qian et al. found a negative influence of face saving on the intention to share knowledge in their study (Qian et al., 2008). Individuals could be afraid that the knowledge they intend to share might be incorrect. Hence, sharing incorrect knowledge displays their ignorance and would thereby cause a loss of face. Therefore, individuals who try to save face would probably not participate in knowledge sharing activities. Furthermore, in order to save face people might restrict their behavior even to the extent of avoiding contact with others (Qian et al., 2008). Since the concept and the consequences of face are a more salient characteristic of the Chinese culture, we hypothesize:

Figure 2 Research concept and hypotheses.



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Hypothesis 4: Face saving has a stronger negative influence on the intention to share knowledge in the Chinese group than in the German group.

Figure 2 summarizes the discussed hypotheses.

5 Data collection and measures

Due to the fact that our research project is part of the research objective TRR 61 itself, we have a unique opportunity to gather data on a chronological sequence of activities that occur throughout the collaboration. A standardized online questionnaire was developed in a two stage process. First, a literature review was performed to identify adequate constructs. In the questionnaire, we used existing scale items from previous studies where applicable and adapted these to the context of cross-cultural academic collaboration where necessary. Regarding the factor *sense of self-worth*, we employed the scale of Bock et al. (Bock et al., 2005). *Loss of knowledge power* was measured by the scale of Kankanhalli (Kankanhalli et al., 2005). *Guanxi orientation* was measured by the scale of Zuo (Zuo, 2002). We reformulated two of the six items to adapt them to the cross-cultural context. Concerning the factor *face saving* we used the scale introduced by Cheung et al. (Cheung et al., 2001). Finally, we employed the three-item scale by Ryu to measure the *intention to share knowledge* (Ryu et al., 2003). The response format was a 5-point Likert scale (ranging from 1 ´*I strongly disagree*´ to 5 ´*I strongly agree*´).

Second, a pretest was performed by sending the questionnaire to selected university scientists, resulting in minimal changes (see Appendix for an overview of used items and constructs; the original questionnaire contained additional items not presented in this paper). All TRR 61 scientists were approached by personalized emails. A reminding email was sent out after 20 days, a second reminder was sent out after another 20 days and the survey was terminated 60 days after our first approach. Overall, we could obtain 49 responses, representing a response rate of 80%. 6 datasets had to be eliminated due to incomplete answers, leading to a final sample size of N = 43 (n_{China} = 17; $n_{Germany}$ = 26).

6 Analysis and results

In the first step of our analysis, we conducted a factor analysis to determine the structure of the employed constructs. Unidimensionality of the constructs was assessed employing an exploratory factor analysis. Cronbach's alpha values were used to evaluate the reliability of the measures (Cronbach, 1951). We could show unidimensionality for all constructs except face saving, which did not exceed the commonly suggested threshold value of .70 (see Appendix for factor loadings and Cronbach's alphas). However, to maintain the richness of the analysis, we decided not to further purify these constructs. Besides, we assessed the discriminant validity of the constructs by comparing variance extracted (VE) percentage with the squares of the correlation estimates, as proposed by Fornell and Larcker (Fornell and Larcker, 1981). Discriminant validity could only be demonstrated for loss of knowledge power and guanxi orientation. However, the global criteria and more than 50% of partial criteria are met; thus, all constructs are retained for further analysis.[5] The goodness-of-fit can be considered acceptable for the overall model (GFI = .969; AGFI = .960; RMR = .072).

Harman's single factor test was employed to address the issue of common method bias. The test indicates substantial common method bias if only one single factor emerges from exploratory factor analysis or one general factor accounts for more than 50% of the covariance between the measures. We could find neither of these conditions applying Harman's single factor test to our sample.

In the second step, we constructed linear regression models with *the intention to share knowledge* as the dependent variable for each factor, i.e. *sense of self-worth, loss of knowledge power, face saving and guanxi orientation.* Our hypotheses indicate differing impacts of the factors on the *intention to share knowledge* depending on the cultural background. Accordingly, a statistical method to test the effect of a variable on the direction or the strength of a relation between an independent and a dependent variable is a moderator analysis (Baron and Kenny, 1986). In our moderator analysis the dependent variable is

5) First generation criteria: Variance explained in Exploratory Factor analysis > 50%, Factor loading > .40, Cronbach's alpha > .60. Second generation global criteria: GFI > .90, AGFI > .80, RMR < .10. Second generation partial criteria: Item reliability > .40, Construct reliability > .60, Average percentage of variance extracted > .50, fulfillment of Fornell-Larcker criterion (Fornell and Larcker, 1981).

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the *intention to share knowledge*, the independent variables are *sense of self-worth, loss of knowledge power, face saving* and *guanxi orientation* and the moderating variable is *nationality*. Further, we followed the framework for identifying moderator variables developed by Sharma (Sharma et al., 1981). According to Hambrick, we conducted Chow tests to test our hypotheses (Hambrick and Lei, 1985).

The Chow test for homogeneity of regression results is a straightforward method to observe differences in regression results and found broad acceptance (Hambrick and Lei, 1985). First, we ran separate regressions for the two subsamples. Second, we ran the regressions for the total sample. The values of interest were the sum of squared errors for the total sample and the subsamples. If the errors obtained from the subsamples are small relative to the errors of the total sample, a moderating effect can be assumed. In Table 1, results for the four different regression models are reported.

For the interpretation of the Chow test we used a F-statistic table (Backhaus, 2006). If significant differences are found, nationality can be considered a moderator that operates through the error term, often also called 'homologizer' (Sharma et al., 1981). All variance inflation factors (VIFs) in our linear regression models were well below the widely accepted threshold value of 10 (Hair, 2006).

Regarding the *sense of self-worth*, splitting into subsamples results in an improvement of the adj. R^2 value in the German subsample and a decrease of the R^2 value in the Chinese sample. The standardized regression coefficient is higher in regression model of the German subsample. However, the Chow test was not significant, thus Hypothesis 1 has to be rejected. The *sense of self-worth* equally influences the *intention to share knowledge* in the two subsamples.

For the factor *loss of knowledge power* we find considerable differences. Again, we find an improved adj. R^2 value in the German and a decreased adj. R^2 value in the Chinese subsample. Further, we can find the hypothesized negative influence of *loss of knowledge power* on the *intention to share knowledge* in the total sample and the German subsample, but not in the Chinese subsample, where this regression model is not significant. The Chow test is significant at $p < .01$, supporting Hypothesis 2. As expected, the *loss of knowledge power* has a negative influence on the *intention to share knowledge* in the German subsample, while the *loss of knowledge power* has no influence on the *intention to share knowledge* in the Chinese subsample.

Separation into subsamples regarding *guanxi orientation* results in an improvement of the model fit in both subsamples. The adjusted adj. R^2 rises from .705 to .757 in the Chine-

Table 1 Results of linear regression analysis and Chow tests: intention to share knowledge as dependent variable.

	Total sample			Chinese group			German group			Sub-groups different?
Variables	Beta	R^2	Adj. R^2	Beta	R^2	Adj. R^2	Beta	R^2	Adj. R^2	
Sense of self-worth	.872**	.761	.755	.844**	.713	.694	.885**	.783	.774	No
Loss of knowledge power	-.493*	.243	.225	.310	.069	.036	-.736**	.541	.522	Yes**
Guanxi orientation	.844**	.712	.705	.879**	.772	.757	.850**	.722	.711	Yes*
Face saving	.278	.077	.055	.538*	.289	.242	.172	.030	-.011	No

Notes: N = 43; n_{China} = 17; $n_{Germany}$ = 26; *significant at $p < .05$; **significant at $p < .01$; F-values for Chow tests from Backhaus (2006).

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se subsample and to .711 in the German sample, respectively. The standardized regression coefficients as well increase from .844 to .879 and .850 in the Chinese and German subsamples. The Chow test is significant at the level of $p < .05$, providing support for Hypothesis 3. Thus we demonstrated that the influence of *guanxi orientation* has a stronger influence on the *intention to share knowledge* in the Chinese than in the German group.

Lastly, we find an improvement of the adj. R^2 value in the Chinese subsample and a decrease of adj. R^2 in the German subsample, segmenting into subgroups in the regression model with *face saving* as the independent variable. Furthermore, *face saving* has only a significant influence on the intention to share knowledge in the Chinese subsample. Nevertheless, none of the three regression models demonstrates the hypothesized negative influence. Additionally the Chow test is not significant, disproving Hypothesis 4.

7 Discussion and conclusion

This study offers several interesting findings regarding personal and cultural impacts on the process of knowledge sharing in cross-cultural collaborative R&D projects. Particularly, the regression models allow us to identify success factors and barriers influencing the intention to share knowledge of collaborating researchers, contributing to the existing body of literature by considering an academic and cross-cultural perspective. Furthermore, we find considerable differences in the influencing factors between Chinese and German groups that can be related to cultural impacts.

The *sense of self-worth* demonstrates an equally positive influence in both subsamples on an individual's *intention to share knowledge*. However, while the Germans' individualistic orientation and the low power distance index as a facilitator of giving feedback could enhance the importance of self-worth in Germany, the Chinese desire to gain face as a facilitator to increase one's *sense of self worth* could explain the importance of this construct in the Chinese group. Nevertheless, we could show the importance of *sense of self-worth* for the *intention to share knowledge* in a cross-cultural academic setting, supporting the findings of Bock et al. and Qian et al. (Qian et al., 2008). Hence, researchers in collaborative projects should establish frequent feedback rounds, in which past knowledge sharing activities are analyzed in a way that individuals see how their contribution in knowledge sharing processes has improved the projects' performance. Such discussions would allow participants to increase their *sense of self-worth* and would further have a positive impact on their *intention to share knowledge*, enhancing future knowledge sharing activities.

Significant differences emerge in the regression model with *loss of knowledge power* as the independent variable. In the German subsample we could demonstrate a negative influence of *loss of knowledge power* on the *intention to share knowledge*. The German society is characterized by an individualistic orientation. We argue that this orientation enhances the fear of losing competitive advantages, even in academic settings. On the contrary, in the Chinese subsample *loss of knowledge power* has no significant influence on the *intention to share knowledge*. However, previous research in a Chinese setting could show that *loss of knowledge power* has a negative influence in knowledge sharing processes in an economic setting (Bock et al., 2005; Qian et al., 2008). Interestingly, we cannot support Qian's findings in our academic setting, implying that Chinese academic researchers are not afraid to lose competitive advantages through knowledge sharing. Instead, by sharing superior intellectual knowledge scientists could gain face, which is highly important in Chinese societies (Brunner et al., 1989). Besides, Kankanhalli et al. could not prove their hypothesized negative impact of *loss of knowledge power* in knowledge sharing processes in their setting either (Kankanhalli et al., 2005). Further examinations regarding setting impacts could give new impetus to the concept's continuous development.

As hypothesized, the *guanxi orientation* has a significantly stronger positive influence on the *intention to share knowledge* in the Chinese subgroup. Furthermore, in the Chinese group *guanxi orientation* has the strongest influence on the *intention to share knowledge* in all regression models, highlighting the outstanding social relationship orientation. Thus, we could demonstrate that a cultural factor has a larger impact on knowledge sharing processes than personal factors, supporting findings of Qian et al.. As Qian et al. further pointed out, Chinese try to create a harmonious atmosphere, which enables knowledge sharing in the first place and facilitates the building of reciprocal relationships (Qian et al., 2008). Surprisingly, the standardized cor-

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relation coefficient of .850 in the German subsample is also considerably high. Accordingly, social relations have an important influence on the *intention to share knowledge* in the German subsample, too. Niedergassel, for instance, demonstrated in a German academic setting that knowledge sharing is enhanced if the relationship between collaborators is particularly close (Niedergassel and Leker, 2009). However, the Chinese *guanxi orientation* is a unique phenomenon and has to be closely considered when striving for collaboration with Chinese partners. Maintaining a good relationship to Chinese partners by exchanging favors and following the unwritten law of reciprocity is a key strategy for successful collaboration (Davies et al., 1995; Dunning and Kim, 2007; Lockett, 1988; Valentine and Godkin, 2001; Zhang et al., 2008).

Finally, we could not demonstrate the hypothesized negative effect of *face saving* on the *intention to share knowledge* in neither of the subgroups. Furthermore, the Chow test is not significant, disproving our hypothesis. Thus, we cannot support the findings of Qian et al., who could demonstrate a negative influence of *face saving* and a positive influence of face gaining on the intention to share (Qian et al., 2008). Therefore, we argue that multiple facets of the concept of face have to be considered. However, Zhang et al. pointed out that saving face is less important to Chinese when interacting with foreigners, since one can only lose face to members of one's social environment (Zhang et al., 2008). Accordingly, Ardichvili et al. argue that the impact of the concept of face was weaker than expected in their study, too (Ardichvili et al., 2006). They suggest, that Chinese feel rather comfortable asking questions and contributing to discussions if such interactions improve project performance (Ardichvili et al., 2006). Further, Ardichvili et al. reason that face saving is more a concern for older Chinese (Ardichvili et al., 2006). Nevertheless, we still believe that the concept of face has a strong impact on any interaction in collaborative activities with Chinese partners. Thus, we emphasize that one should carefully focus on consequences and implications of face, when collaborating with Chinese partners. For instance, giving face, i.e. doing something that enhances someone else's reputation or prestige by praising, gift giving or concessions can improve the performance of collaborations with Chinese partners (Cardon and Scott, 2003).

While offering many interesting findings, this study also possesses some limitations requiring consideration. Our study is based on a comparatively small sample size and we focused on a knowledge generation oriented academic setting, thus generalizing our results to economic situations may not be appropriate. However, we will conduct qualitative interviews to support the findings of our quantitative analysis. Besides, we especially focused on Chinese cultural factors, though future research should investigate cultural characteristics of western societies that might influence knowledge sharing processes. Generally, strategies, non-monetary rewarding and incentive systems facilitating knowledge sharing should be developed and discussed more deeply.

Despite the limitations we still believe to make a valuable contribution to the existing body of literature on cross-cultural knowledge sharing in innovation, technology and collaboration management, particularly considering the academic partners´ point of view and the increasing importance of collaborative activities with partners from China.

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References

Abrams, L.C., Cross, R., Lesser, E. and Levin, D. Z. (2003): Nurturing Interpersonal Trust in Knowledge-Sharing Networks, *Academy of Management Executive*, **14** (4), p. 64-77.

Alston, J.P. (1989): Wa, Guanxi, and Inhwa: Managerial Principles in Japan, China, and Korea, *Business Horizons*, **32** (2), p. 26-31.

Ardichvili, A., Maurer, M., Li, W., Wentling, T., and Stuedemann, R. (2006): Cultural Influences on Knowledge Sharing through Online Communities of Practice, *Journal of Knowledge Management*, **10**, p. 94-107.

Azarloff, L.V. (1982): Industry-University Collaboration: How to Make It Work, *Research Management*, **25** (3), p. 31-35.

Backhaus, K., B. Erichson, W. Plinke and R. Weber (2006): Tabellenanhang, in: *Multivariate Analysemethoden: Eine anwendungsorientierte Einführung,* Springer, Berlin, p. 809-813.

Baron, R.M. and Kenny, D.A. (1986): The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations,

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Journal of personality and social psychology, **51** (6), p. 1173-1182.

Bartol, K.M. and Srivastava, A. (2002): Encouraging Knowledge Sharing: The Role of Organizational Reward Systems, *Journal of Leadership and Organizational Studies*, **9** (1), p. 64-76.

Baskerville, R.F. (2003): Hofstede never studied culture, *Accounting, Organizations and society*, **28**(1), p. 1-14.

Berends, H., van der Bij, H., Debackere, K., and Weggeman, M. (2006): Knowledge Sharing Mechanisms in Industrial Research, *R&D Management*, **37** (1), p. 85-95.

Birnholtz, J.P. (2007): When Do Researchers Collaborate? Towards a Model of Collaboration Propensity in Science and Engineering Research, *Journal of the American Society for Information Science and Technology*, **58** (14), p. 2226-2239.

Blau, P.M. (1964): *Exchange and Power in Social Life*, Wiley: New York.

Bock, G.-W., Zmud, R.W., Young-Gul, K., and Jae-Nam, L. (2005): Behavioral Intention Formating in Knowledge Sharing: Examining the Roles of Extrinsic Motivators, Social-Psychological Forces and Organizational Climate, *MIS Quarterly*, **29** (1), p. 87-111.

Bonaccorsi, A. and Piccaluga, A. (1994): A Theoretical Framework for the Evaluation of University-Industry Relationships, *R&D Management*, **24** (3), p. 229-247.

Brunner, J.A., Chen, J., Sun, C., and Zhou, N. (1989): The Role of Guanxi in Negotiations in the Pacific Basin, *Journal of Global Marketing*, **3** (2), p. 7-24.

Cabrera, Á. and Cabrera, E.F. (2002): Knowledge-Sharing Dilemmas, *Organization Studies*, **23** (5), p. 687-710.

Campione, T.J. (2003): Making Research Collaborations Succeed, *Research Technology Management*, **46** (4), p. 12-15.

Cantner, U. and Meder, A. (2007): Technological Proximity and the Choice of Cooperation Partner, *Journal of Economic Interaction and Coordination*, **2** (1), p. 46-65.

Cardon, P.W. and Scott, J.C. (2003): Chinese Business Face: Communication Behaviors and Teaching Approaches, *Business Communication Quarterly*, **66** (4), p. 9-22.

Cheung, F.M., Leung, K., Zhang, J.-X., Sun, H.-F., Gan, Y.-Q., Song, W.-Z., and Xie, D. (2001): Indigenous Chinese Personality Constructs: Is the Five-Factor Model Complete?, *Journal of Cross-Cultural Psychology*, **32** (4), p. 407-433.

Chow, C.W., Deng, F.J., and Ho, J.L. (2000): The Openness of Knowledge Sharing within Organizations: A Comparative Study of the United States and the People's Republic of China, *Journal of Management Accounting Research*, **12** (1), p. 65-95.

Chua, A. (2003): Knowledge Sharing: A Game People Play, *Aslib Proceedings*, **55** (3), p. 117-129.

Constant, D., Sproull, L., and Kiesler, S. (1994): What's Mine Is Ours, or Is It? A Study of Attitudes About Information Sharing, *Information System Research*, **5** (4), p. 400-421.

Cronbach, L.J. (1951): Coefficient Alpha and the Internal Structure of Tests, *Psychometrika*, **16** (3), p. 297-334.

Cummings, J.N. and Kiesler, S. (2003): Multidisciplinary Scientific Collaborations, in: *Proceedings of the International Conference on Information Systems*: Seattle. p. 296-303.

Cummings, J.N. and Kiesler, S. (2005): Collaborative Research across Disciplinary and Organizational Boundaries, *Social Studies of Science* **35** (5), p. 703-722.

Cyert, R.M. and Goodman, P.S. (1997): Creating Effective University-Industry Alliances: An Organizational Learning Perspective, *Organizational Dynamics*, **25** (4), p. 45-57.

Davenport, T.H. and Prusak, L. (2000): Working Knowledge: How Organizations Manage What They Know, Harvard Business School Press: Boston.

Davies, H., Leung, T.K.P., Luk, S.T.K., and Wong, Y.-h. (1995): The Benefits Of "Guanxi": The Value of Relationships in Developing the Chinese Market, *Industrial Marketing Management*, **24** (3), p. 207-214.

Dunning, J.H. and Kim, C. (2007): The Cultural Roots of Guanxi: An Exploratory Study, *World Economy*, **30** (2), p. 329-341.

Easterby-Smith, M. and Malina, D. (1999): Cross-Cultural Collaborative Research: Toward Reflexivity, *Academy of Management Journal*, **42** (1), p. 76-86.

Emerson, R. (1976): Social Exchange Theory, *Annual Review of Sociology*, **2**, p. 335-362.

Finholt, T.A. (2003): Collaboratories as a New Form of Scientific Organization, *Economics of Innovation & New Technology*, **12** (1), p. 5-26.

Fornell, C. and Larcker, D. (1981): Evaluating Structural Equation Models with Unobservable Variables and Measurement Error., *Journal of Marketing Research*, **18** (1), p. 39-50.

Galison, P. and Hevly, B. (1992): The Many Faces of Big Science, in: *Big Science: The Growth of Large Scale Research*, Stanford University Press, Stanford, CA, p. 1-14.

Gronau, N. (2002): Kollaborative Engineering Communities - Architektur und Integrationsansätze, in: *Proceedings der Multikonferenz Wirtschaftsinformatik*, Mertens, P.: Nürnberg. p. 1-15.

Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L. (2006): Multivariate Data Analysis, Pearson Prentice Hall: Upper Saddle River, NJ.

Hambrick, D.C. and Lei, D. (1985): Toward an Empirical Prioritization of Contingency Variables for Business Strategy, *Academy of Management Journal*, **28** (4), p. 763-788.

Han, Y. (1997): Software Infrastructure for Configurable Workflow Systems: A Model Driven Approach Based on Higher Order Object Nets and Corba, Wissenschaft und Technik: Berlin.

Hansen, M.T. (1999): The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits, *Administrative Science Quarterly*, **44** (1), p. 82-111.

Hansen, M.T. (2002): Knowledge Networks: Explaining Effective Knowledge Sharing in Multiunit Companies, *Organization Science*, **13** (3), p. 232-248.

Hara, N., Solomon , P., Kim, S.-L., and Sonnenwald, D.H. (2003): An Emerging View of Scientific Collaboration: Scientists' Perspectives on Collaboration and Factors That Impact

Collaboration, *Journal of the American Society for Information Science and Technology*, **54** (10), p. 952-965.

Heinze, T. and Kuhlmann, S. (2006): Analysis of Heterogenous Collaboration in the German Research System with a Focus on Nanotechnology., Frauenhofer ISI discussion papers: *Innovation system and policy analysis*, (6), p. 1-22.

Ho, D.Y.-f. (1976): On the Concept of Face, *The American Journal of Sociology*, **81** (4), p. 867-884.

Hofstede, G. and Hofstede, G.J. (2007): *Cultures and Organizations: Software of the Mind*, McGraw-Hill: New York.

Homans, G.C. (1961): Social Behaviour: Its Elementary Forms, in: *International Library of Sociology and Social Reconstruction*, Routledge and Kegan Paul, London.

Hurmelinna, P. (2004): *Motivations and Barriers Related to University-Industry Collaboration - Approbability and the Principle of Publicity*, UC Berkeley.

Hwang, C.H. (1982): Studies in Chinese Personality: A Critical Review, *Bulletin of Educational Psychology*, **15**, p. 227.

Jarman, F. (2001): Opportunities and Problems of Intercultural Communication and Cooperation for Small and Medium Enterprises, in: *Synergien durch regionale Netzwerke / von lernenden Organisationen zur lernenden Region - Dokumentation des Projekts Netzwerk für Arbeit im Rahmen der Gemeinschaftsinitiative Adapt der Europäischen Union,* Wesely, W., Expressum Verlag, Hannover, p. 259-272.

Jiwen, S.L. and James, D.W. (2007): Guanxi as Impetus? Career Exploration in China and the United States, *Career Development International*, **12** (1), p. 51-67.

Kankanhalli, A., Tan, B.C.Y., and Kwok-Kee, W. (2005): Contributing Knowledge to Electronic Knowledge Repositories: An Empirical Investigation, *MIS Quarterly*, **29** (1), p. 113-143.

Kaser, P.A.W. and Miles, R.E. (2002): Understanding Knowledge Activists' Successes and Failures, *Long Range Planning*, **35** (1), p. 9-28.

Kotlarsky, J. and Oshri, I. (2005): Social Ties, Knowledge Sharing and Successful Collaboration in Globally Distributed System Development Projects, *European Journal of Information Systems*, **14** (1), p. 37-48.

Lam, A. (1997): Embedded Firms, Embedded Knowledge: Problems of Collaboration and Knowledge Transfer in Global Cooperative Ventures, *Organization Studies*, **18** (6), p. 973-997.

Leung, T.K.P. and Chan, R.Y.-K. (2003): Face, Favour and Positioning a Chinese Power Game, *European Journal of Marketing*, **37** (11/12), p. 1575-1598.

Levin, D.Z. and Cross, R. (2004): The Strength of Weak Ties You Can Trust: The Mediating Role of Trust in Effective Knowledge Transfer, *Management Science*, **50** (11), p. 1477-1490.

Lichtenthaler, U. and Ernst, H. (2006): Attitudes to Externally Organising Knowledge Management Tasks: A Review, Reconsideration and Extension of the NIH Syndrome, *R&D Management*, **36** (4), p. 367-386.

Lockett, M. (1988): Culture and the Problems of Chinese Management, *Organization Studies*, **9** (4), p. 475-496.

Luo, Y. (1997): Guanxi and Performance of Foreign-Invested Enterprises in China: An Empirical Inquiry, *Management International Review (MIR)*, **37** (1), p. 51-70.

McFadyen, M.A. and Cannella Jr, A.A. (2005): Knowledge Creation and the Location of University Research Scientists' Interpersonal Exchange Relations: Within and Beyond the University, *Strategic Organization*, **3** (2), p. 131-155.

Melin, G. (2000): Pragmatism and Self-Organization: Research Collaboration on the Individual Level, *Research Policy*, **29** (1), p. 31-40.

Meyer-Krahmer, F. and Schmoch, U. (1998): Science-Based Technologies: University-Industry Interactions in Four Fields, *Research Policy*, **27** (8), p. 835-851.

Michailova, S. and Hutchings, K. (2006): National Cultural Influences on Knowledge Sharing: A Comparison of China and Russia, *Journal of Management Studies*, **43** (3), p. 383-405.

Müller, J. (2006): *Kooperationen und die Wettbewerbsfähigkeit von Unternehmen*, J. W. Goethe-Universität: Frankfurt am Main.

Niedergassel, B. and Leker, J. (2008): Tacit vs. Explicit – the Role of Different Knowledge Dimensions in Collaborative R&D Projects, in: *Conference Proceedings XIX ISPIM*: Tours.

Niedergassel, B. (2009): *Knowledge Sharing in Collaborative R&D Projects,* Institut für Betriebswirtschaftliches Management im Fachbereich Chemie und Pharmazie, WWU Münster.

Niedergassel, B. and Leker, J. (2009): Tacit and Explicit Knowledge Sharing in Collaborative R&D Projects, in: *Conference Proceedings* IAMOT: Orlando.

Nonaka, I. (1994): A Dynamic Theory of Organizational Knowledge Creation, *Organization Science,* **5** (1), p. 14-37.

Odenthal, S., Säubert, H., and Weishaar, A. (2002): *Strategische Partnerschaften - Mehr Erfolg mit dem neuen Partnering-Ansatz*, Gabler Verlag: Wiesbaden.

Qian, H., Davison, R.M., and Jibao, G. (2008): Impact of Personal and Cultural Factors on Knowledge Sharing in China, *Asia Pacific Journal of Management*, **25** (3), p. 451-471.

Reagans, R. and McEvily, B. (2003): Network Structure and Knowledge Transfer: The Effects of Cohesion and Range, *Administrative Science Quarterly*, **48** (2), p. 240-267.

Rohrbeck, R. and Arnold, H.M. (2006): Making University-Industry Collaboration Work - a Case Study on the Deutsche Telekom Laboratories Contrasted with Findings in Literature, in: *Conference Proceedings XVII ISPIM Networks for Innovation*: Athens, Greece. p. 1-11.

Ryu, S., Ho, S.H., and Han, I. (2003): Knowledge Sharing Behavior of Physicians in Hospitals, *Expert Systems with Applications*, **25**, p. 113-122.

Sharma, S., Durand, R.M., and Gur-Arie, O. (1981): Identification and Analysis of Moderator Variables, *Journal of Marketing Research*, **18** (3), p. 291-300.

Lee, S. and Bozeman, B. (2005): The Impact of Research Collaboration on Scientific Productivity, *Social Studies of*

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Science, **35** (5), p. 673-702.

Thibaut, J.W. and Kelley, H.H. (1959): *The Social Psychology of Groups,* Wiley: New York.

Valentine, S. and Godkin, L. (2001): United States Expatriates in China: The Impact of Cultural and Managerial Differences, *International Journal of Management*, **18** (4), p. 482.

Weir, D. and Hutchings, K. (2005): Cultural Embeddedness and Contextual Constraints: Knowledge Sharing in Chinese and Arab Cultures, *Knowledge and Process Management*, **12** (2), p. 89-98.

Wilpert, B. and Scharpf, S.Y. (1990): Intercultural Management - Joint Ventures in the People´s Republic of China, *International Journal of Psychology*, **25** (5/6), p. 643.

Zhang, Q., Ribiere, V.M., and Thippaya, C. (2008): The Impact of Group Relation on Knowledge Sharing: A Cross-Cultural Study, in: *Strategic Knowledge Management in Multinational Organizations*, O´Sullivan, K., Information Science Reference, Hershey, p. 40-52.

Zuo, B. (2002): The Chinese Relation Orientation: Concept and Its Measurement, *Journal of Central China Normal University (Humanities and Social Sciences)*, (1), p. 74-80.

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Appendix

Appendix 1 Constructs, items, factor loadings, Cronbach's alphas, VE.

Questionnaire items	*Loading*
Sense of self-worth (5 items, Cronbach's alpha = .936 VE = .803)	
My knowledge sharing would help other members in the organization solve problems.	.942
My knowledge sharing would create new opportunities for the organization.	.868
My knowledge sharing would improve work processes in the organization.	.921
My knowledge sharing would increase productivity in the organization.	.864
My knowledge sharing would help the organization achieve its performance objectives.	.883
Loss of knowledge power (4 items, Cronbach's alpha = .892 VE = .756)	
Sharing my knowledge makes me lose my unique value in the organization.	.810
Sharing my knowledge makes me lose my power base in the organization.	.892
Sharing my knowledge makes me lose my knowledge that makes me stand out with respect to others.	.909
Sharing my knowledge makes me lose my knowledge that no one else has.	.862
Guanxi orientation (6 items, Cronbach's alpha = .874 VE = .622)	
We expect that our friends will help us in our social life.	.638
Our society is composed of a kind of personal relation net.	.748
I enjoy life that includes human concern and kindness.	.860
Personal relations are an important resource in career development.	.664
People should get on with each other harmoniously.	.863
I will try to build a good relationship with my colleagues and supervisors.	.917
Face saving (3 items, Cronbach's alpha = .571 VE = .541)	
I pay a lot of attention to how others see me.	.617
I am usually very particular about the way I dress because I do not want others to look down on me.	.765
I feel a loss of face when others turn down my favor.	.810
Intention to share knowledge (3 items, Cronbach's alpha = .921 VE = .865)	
I will make an effort to share knowledge with my colleagues.	.924
I intend to share knowledge with my colleagues when they ask.	.914
I will share knowledge with my colleagues.	.951

Notes: N = 43; Confirmatory factor analysis was performed using AMOS 16.0. Goodness-of-fit measures for the overall measure model are: GFI = .969; AGFI = .960; RMR =.072.

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Research Section

Technological trajectories and multidimensional impacts: further remarks on the nanotechnology industry

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The article discusses various views on the emergence and impacts of nanotechnology. It proposes a multidimensional framework for analyzing the different technological, economical, environmental and social dimensions of nanotechnology. The research method consists of a three step investigation of both the positive and negative impacts of nanoscience and nanotechnology on different Brazilian stakeholders. From the insights provided by a group of experts it was possible to design a survey instrument that was applied to 59 Brazilian nanobiotechnology researchers. The survey results show that, on the one hand, nanotechnology is expected to lead to economic development, product development, business competitiveness, greater job specialization, less pollution, improvements to the health system and extended life expectancy. On the other hand, however, nanotechnology may cause specific forms of contamination due to nanotechnological manipulation, more layoffs, massive industrial restructuring, and other potential risks. Both perspectives would suggest the need for a regulatory framework to deal with the uncertainty and ensure a regular pathway for the stakeholders to be able to exploit this technology to its full potential.

Introduction

Scientific and technological novelties have always been challenging for mankind. New technology brings with it numerous opportunities and great apprehension. In this context, there is a natural interest in emerging technologies, such as biotech, cognitech and nanotech. If, on the one hand, new technological applications normally offer increased opportunities, higher living standards, and lead to the redefinition of social and cultural paradigms, on the other hand, as they lead to the breakdown of previous social rules, they always create a sensation of discomfort and insecurity.

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It is essential to prepare the scientific community so that it can provide up-to-date information and new insights to facilitate the dissemination of any new technology, reducing the risk of misunderstanding either the benefits or the negative impacts. As an example, Shellenberger & Nordhaus (2004) have shown that environmental research failed to forecast negative impacts (such as global warming). Another example was the alarming delay between the onset of the social and economic impacts of GMOs (genetically modified organisms) and the initiation of the scientific debate on the subject.

The last five years have seen a significant growth in nanoscience and nanotechnology developments from academic publications and patents to multiple industrial and economic applications. The benefits are extended through new applications in chemistry, materials, electronics, computing, medicine and pharmaceuticals, among others. Due to its overall and horizontal range of applications, nanotechnology has already become inevitable.

The expected positive impacts of nanotechnology range from a technological revolution in the manufacturing process, new employment skills, and the emergence of new industries, to a variety of economic opportunities. However, many of the expected impacts are not exactly clear to the different stakeholders. Moreover, doubts still remain regarding the safety of the nanotechnology for human health and the ecological system. It is claimed that the nanometric size of new molecular structures in itself represents a threat due to the ease with which their action mechanism can spread within life systems, causing contamination and toxicity.

Given this, there is an urgent need to discuss the ways in which social, environmental and economic certainty can be increased. It is our belief that such changes could be better monitored and harmful effects better predicted and controlled, if an enhanced concept of Freeman & Perez´s (1988) techno-economic paradigm, based on the multidimensional interlinking of agents and different outcomes, is used.

Evolutionary Economics (Dosi, 1991; Pavitt, 1992) suggests that any on-going technology is dependent on a path, in which it is possible to foresee its future development. In the case of a new technology it is harder to predict their development path as their path is unknown. The lack of knowledge and the inherent uncertainty of any new venture certainly enhance doubt and create fear. Any new technology will obviously engender both positive and negative impacts. To better understand this issue, it is necessary to understand the entire phenomenon from a technical/economic perspective, while it is also imperative to incorporate new dimensional sights, such as the social and the environmental perspectives.

This paper proposes to identify, through extensive research carried out within the Brazilian nanobiotechnology research network, the potential benefits and threats to the economy, society and environment offered by the emergence of nanoscience and nanotechnology.

This paper includes five more sections: The next, section two, will address the emergence of new technologies in general. Section three focuses on the path of nanotechnology and its positive and negative impacts. Sections four and five are dedicated, respectively, to the methodology and the results obtained from the research effort made during 2004 and 2008. The final remarks are in section six.

The Emergence of New Technologies and Development

The Schumpeterian tradition suggests that the successful spread of innovation throughout the economy and society will generate a new cycle, value creation and wealth. Freeman and Perez (1988) defined any major new technological breakthrough as a new techno-economic paradigm.

This kind of analysis, in which different revolutionary periods are perceived primarily from a techno-economical perspective, has proven to be of limited use when dealing with the complexity of the real world (Perez, 1993). That is why, for example, it was hard for environmentalists to predict impending events, such as global warming and biotech hazardous products, of recent industrial innovations. Ignoring precise test validation, companies violated ethical principles and only considered economic returns (Shellenberger and Nordhaus, 2004; ETC Group, 2004).

In order to deal with a complex world, significant changes are required to the definition of development when attempting to understand an emerging new technology. The current debate, which is actually contributing towards broadening that definition, is primarily focused on research into sustainable development (Asheim, Buchholz and Tungodden, 2001; Banerjee, 2003; Bansal, 2003; Borron and Murray, 2004; Greaker, 2003; Spangenberg, 2004).

In fact, depending on the intensity of the innovation cycle, both positive and negative impacts are felt over a multitude of dimensions. If it is intense, as in the case of revolutionary technologies, the impacts are not restricted only to the economic dimension, but will certainly extend to other dimensions, such as the social and environmental ones.

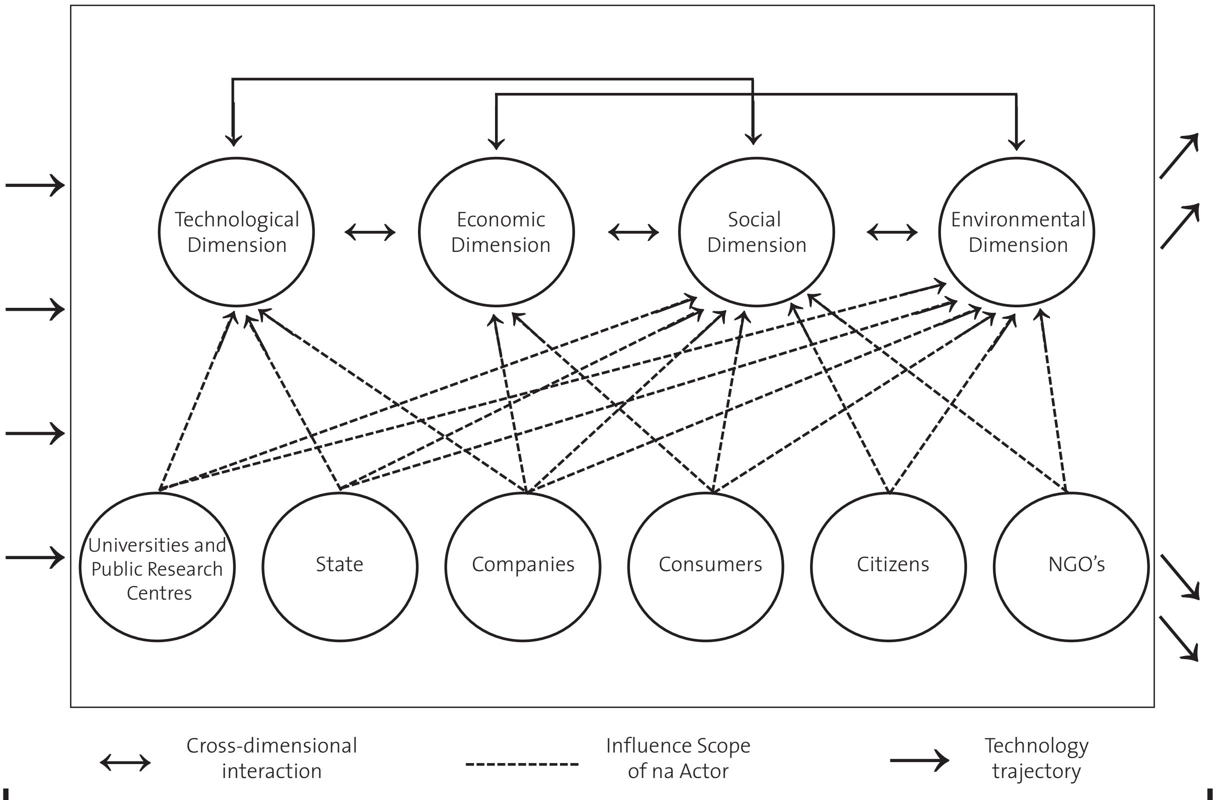
In order to cope with these nonlinear impact flows, it is important to provide a general concept to incorporate them. Since the classical definition of the techno-economic paradigm only partially fulfils the task, Zawislak et al (2006, p.4) have enlarged the concept of development as to be:

"a set of actions that can ensure the best conditions for mankind's survival, which can be deployed into different dimensions, such as better tools and techniques to solve problems (technological dimension), an increase in wealth generation (economic dimension), wide comprehensive welfare for the society (social dimension), and natural resource conservation (environmental dimension)."

This multidimensional approach (i.e. technological and economic dimensions plus social and environmental ones) better reflects the complexity of the contemporary technology scenario.

This approach emphasizes the role of different relevant agents, such as the individual, organizations, or groups of organizations, as engines for and/or the consequence of change. This situation suggests that the scope of analysis that explains the existence and the systemic role of any individual or organization should be enlarged to consider their different interlinkages (Nielsen, 2001). If, on the one hand, these actors may fulfil a more significant role in a certain dimension, on the other hand, they can also play simultaneous roles in different dimensions. The major stakeholders are universities and public research centres, companies, the State, consumers, citizens and non-governmental organizations (NGOs) (Marques, 2008).

Figure 1 Multidimensional model for the analysis of the impacts of new technology



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This complex system is better understood by considering the cross impacts of the different dimensions and their respective interlinked stakeholders, who undergo possible general effects (both positive and negative) of a new technological trajectory. Figure 1 shows how the multidimensional model for the analysis of new technology impacts works.

Since we are dealing with technological impacts, technology itself is the primary driver in the achievement of economic development. From this multidimensional perspective and considering that new technology is increasingly general purpose in nature, its diffusion throughout society normally leads to (Bresnaham & Trajtemberg, 1995; Carlaw & Lipsey, 2002; Carlaw et. al, 2005):

1) more complex forms, with undeniable increases in productivity;
2) a new range of applications;
3) a wide range variety of economic results;
4) and the emergence of a diversity of new products and technological processes.

However, many different paths can be followed. First, the use of new technology implies positive effects in the economic dimension, by establishing productivity growth and wealth creation (Schumpeter, 1934; Solow, 1957; Nelson & Winter, 1982). Second, it also implies negative effects like, the disappearance of economic sectors, increases in new investments, the exclusion of existing businesses in the market, as well as more difficulty on distributing wealth, generating employment and standards of competence (Tobin, 1989; Furtado, 2001).

In order to fully comprehend the phenomenon, besides understanding the impacts of new technology on the economic dimension, it is also necessary to understand how it affects the social and the environmental dimensions.

Normally, the mainstream society continues to follow as old concept of development that adheres to a different pattern of generating social benefits and exploiting natural resources. But as new industries and products emerge, a new social structure is needed. New cultural behaviour and attitudes change expectations and profiles. It is as if a new kind of society emerges within the old as a result of new techno-economic trends. New behaviour also leads to new environmental impacts.

Martinet and Reynaud (2004) have shown, for example, that deforestation for commercial use has impacted on water resources, soil and world climate; in some regions, the looming desertification has caused soil erosion and infertility, the extinction of species, and shrinkage of the agricultural area. In fact, the impacts are all interlinked, and generate significant direct and indirect technological costs, and the emergence of new sub-patterns and the search for new technical solutions.

In the opinion of experts, nanotechnology is an emerging general purpose technology. The forthcoming nanorevolution needs to be better understood (Carlaw et al. 2005; Elsi, 2005; Roco & Bainbridge, 2006).

Nanotechnology: Trajectories and Impacts

Nanotechnology is the group of technologies resulting from scientific discoveries made in different fields of knowledge, such as chemistry, physics, biology, material and computational engineering, where the dimension of manipulation is nanometric (Nanologue, 2006). In essence, nanotechnology consists in the ability to manipulate matter at an atomic scale, in order to create structures with a differentiated molecular organization and different properties (Crandall, 1997).

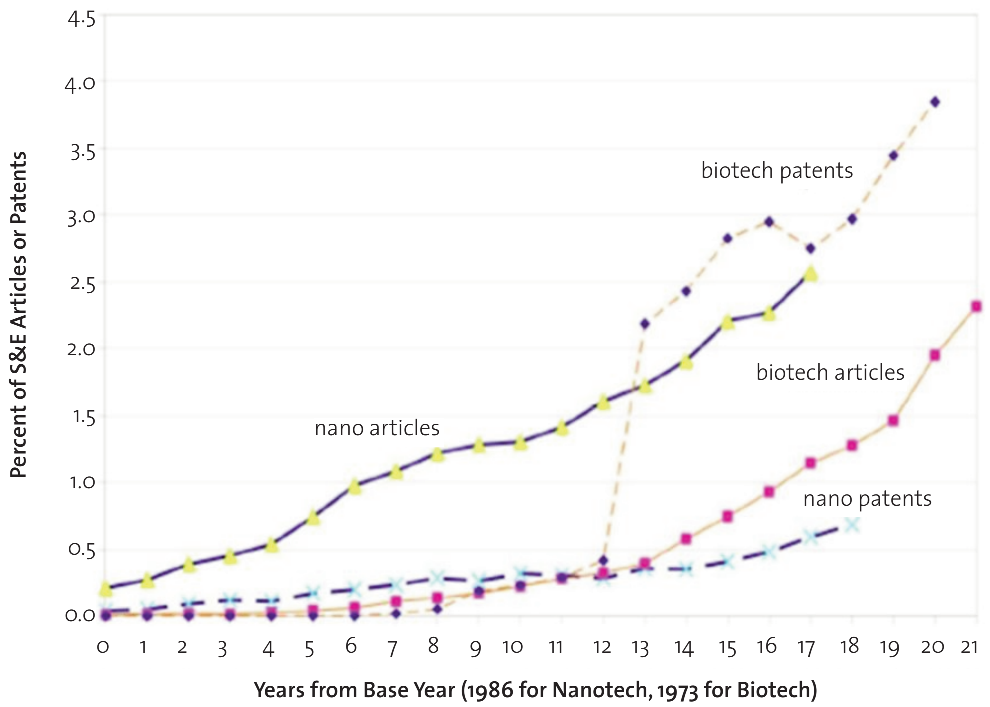
Regarding that material property, nanotechnology has the potential of creating several technical applications with impacts in many different economic sectors. One example is the carbon nanotube that promise to enable lighter, stronger materials that can be used in civil construction, heavy machinery, car manufacturing, electronics industry and so many others (Nanologue, 2006). This variety of applications makes it difficult to evaluate and measure the impacts of nanotechnology using the traditional linear view (NIST, 1999; Royal Society/Royal Academy of Engineering, 2004).

Nanotechnology as an Emerging Technological Trajectory

When analyzing the development of nanotechnology and its various spill-overs, publishing (articles) and patenting (number of patents) are interesting ways of measuring the timelag that occurs between the publication of scientific findings to the patenting of technological applications (Zucker & Darby, 2005).

This timelag can be clearly seen by comparing the number of articles and patents involving nanotechnology vis a vis biotechnology

Figure 2 Comparison of indicators (biotechnology versus nanotechnology) Source: Zucker and Darby (2005)



(of which Genetically Modified Organisms is a significant example), as shown in Figure 2 below.

Between 1983 and 1990, the number of articles dealing with nanoscience and nanotechnology grew exponentially, doubling roughly every 7.3 years. Between 1991 and 2005, however, the rate of new publications increased considerably, doubling every 3.3 years (Zucker and Darby, 2005; Kaiser, 2006). With biotechnology research and applications, the results are almost the same: exponential growth. Observing the biotech time lag pattern, it is interesting to note that there was an increase in number of related patents several years after the expansion in the number of new papers.

By following the trends shown in Figure 2, the same pattern can be expected to take place with nanotechnology.

This idea is reinforced by Zanetti-Ramos and Creczynski-Pasa (2007) for whom the growing number of articles published suggests significant investments in research. Consequently, Fishbine (2002) claims that research stimulates investments in nanotechnologies reaching figures that surpass billions of dollars.

Research leads to new investment and stimulates new entrants in the business of nanoscience and nanotechnology. According to Kingon et al. (2004), in 1999 the number of new entrants whose main products or services were based on nanotechnology was around 100. However, this figure has now surpassed 1,000 in only 3 years. Moreover, according to Alves (2004), 15 years from now, the estimated annual production of products based on nanotechnology will be in the range of 1 trillion dollars, a value that will require the employment of at least 2 million workers in this sector.

These figures are sufficiently important to draw attention to the debate on the predictability of nanotechnology. It is particularly important since the expected negative impacts of nanotechnology include applications that would be potentially harmful to mankind, such as the capacity to build mass destruction weapons (Marques, 2008). These potential negative impacts cast doubt on the safety of nanotechnology in terms of human health and various biological chains (Nanologue, 2006).

Multidimensional Impacts

The problem with nanotechnology is not

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just related to size but, instead, whether it is safe and controllable. This has led to a new debate, which addresses the consequences of the nanotechnology. This debate covers the technological, economic, social and environmental dimensions of the impacts of nanotechnology.

Regarding the technological dimension, it is necessary to asses the impact on the pace of progress in nanoscience and the diversity of its technological applications. This evolution will raise the level of professional skills and enhance scientific discoveries and future scenarios for the nanotechnology trajectory.

Regarding the possible variables involved in the economic impact of nanotechnology on the various agents it is necessary to consider the level of economic development, the average level of profitability, the degree of optimization of the use of inputs, the average prices of new products in relation to those of a previous technological generation, the level of manual labour required to establish the new paradigm, as well as the cost of living and income distribution.

The social dimension involves the impact of nanotechnology on the level of employment in various economic sectors, the level of welfare created, and the progress made with its application in human health.

Finally, the environmental dimension concerns the degree of environmental pollution, the degree of contamination, the destruction of different existing biomes and the conservation of natural resources.

This complex scenario demands a new regulatory framework to control the pace of nanotechnological development in a fair manner. If such a regulatory framework is delayed, nanotechnology could come to be seen in a negative light. It is necessary to stress that a regulatory framework may lose its capacity to guide the development of the technology, thus becoming incapable of controlling its spread and that of its associated dangers.

To prevent such an "unstoppable" trend, it is worth carrying out a cross study of the major events that have characterized the emergence of previous revolutionary technologies. The opinions of experts and the perceptions of the actors involved are useful in identifying the most relevant impacts of nanotechnology and represent an important guideline for a future regulatory framework.

Important questions are raised within this debate such as: what are the major impacts emerging from nanotechnology? When will they occur? What is the right timing for regulation?

Methodology

In an effort to analyze the technological trajectory of nanotechnology and its possible impacts a two-fold, in-depth study and a survey were carried out. The research was conducted in three different stages between October 2004 and May 2008. In the first stage, experts in nanotechnology, from various analytical perspectives, were asked to identify the potential impacts of nanotechnology. In the second stage, a survey was conducted among the researchers belonging to the Brazilian Nanobiotechnology Network. The third stage consisted in an effort at reconfirming the data by interviewing businessmen involved in and affected by the application of nanotechnology.

Stage 1: Interviews with Experts in Nanotechnology

Sixteen experts from diverse fields of knowledge and experience were interviewed. They were selected in a non-probabilistic way from the areas of basic sciences, engineering, social sciences, ethics, politics, and representatives of non-governmental and commercial organizations. The experts were: 6 researchers (Biotechnology, Physics, Chemistry, Materials, Pharmacology, Sociology); 1 catholic priest who is a federal congressman; 1 federal judge; 1 international NGO representative; 6 Brazilian government representatives (from CNPq, FINEP, 2 MCT, MMA and Embrapa); and 1 businessman.

They were interviewed using a semi-structured questionnaire dealing with the potential impacts of nanotechnology that, in their opinion, may actually occur.

From the collected data, a set of impacts was listed showing the potential general effects from nanotechnology on the technological, economic, social and environmental dimensions. This list gave rise to 35 statements that were used in the survey instrument.

Stage 2: Survey

The focus of this survey was the Nanobiotechnology Network, which operated between 2003 and 2005, with members from 18 national and state institutions from eight Brazilian states

In an effort to facilitate the understanding the interlinked effects, the statements relating to the application of nanoscience and nanotechnology were limited to the field of nanobiotechnology, and two specific economic sectors: cosmetics and pharmaceuticals. Both sectors have a high level of R&D investment (around 10% of sales) and also, due to the already mastered scientific capability of designing new molecular structures, are accelerating the launch of new products.

The sample consisted of members of the Brazilian Nanobiotechnological Network (an institutional research and development network formed by the Brazilian National Council for Scientific and Technological Development – CNPq – of the Ministry of Science and Technology – MCT). The Network consists of 92 PhD researchers; 59 of whom returned the questionnaire (64% return rate). They were contacted by telephone and e-mail in order to reduce time and costs involved.

The sample profile shows that 93.2% of surveyed researchers are primarily related to public institutions, and the remaining 6.8% related to private institutions.

Regarding the type of institution, 86.4% are from universities, 11.9% from technology centres and 1.7% from foundations. By using the Lattes-CNPq database it was possible to identify each professor's areas of knowledge in relation to nanotechnology (Lattes, 2006). Thus, researchers with recognised expertise in physics constitute 25.4% of respondents, chemistry 22%, biology 33.9% and pharmacology 18.6%.

Using the data collected in stage I, a survey instrument (questionnaire) was elaborated which included a four-step Likert scale, where the level of agreement of the respondent varied from a lower limit, represented by the number one (1) –meaning "I totally disagree" – to an upper limit, represented by the number four (4) – meaning "I totally agree". The use of this scale required the researcher to position himself in relation to a determined aspect of the subject. Appendix shows the general results (percantage) for all statements. Furthermore, the results will be presented as means (m) and standards-deviation (s) of the total of responses to the four-step Likert scale.

The statements followed the order of the multidimensional model, where the first part dealt with the technological dimension, followed, in sequence, by the economic, social and environmental dimensions.

Stage 3: Interviews with Businessmen

The second exploratory in-depth study was conducted with five representatives from companies within the cosmetic and pharmaceutical industries. It was decided to restrict the research to companies geographically established in Brazil.

This phase consisted on comparing the outcomes from the survey (scientific and technological-based study) with the points of view offered by the companies (profit-oriented impression) in order to deal with real possible effects and impacts of nanotechnology on the dimensions under consideration.

In order to identify companies with inhouse R&D into nanotechnology that could provide representatives for interviews the Brazilian Innovation Agency (FINEP) was consulted. As a result, five companies were selected and their respective representatives were interviewed using a semi-structured questionnaire.

Analysis of the Results

The analysis of the results is divided into three sections. First, the impacts, as perceived by the experts in the interviews are presented and then divided into seven domains. In the second section, the survey statistics are described following the order of the four nanotechnology impact dimensions, the impacts on stakeholders, and the need for a regulatory framework for nanotechnology. The final section shows the perceptions of entrepreneurs in relation to potential impacts of nanotechnology.

Impacts Determined from Interviews with Experts

The research findings shows that nanotechnology affects the stakeholders involved both positively and negatively. However, although it is impossible to identify the full consequences, it is possible to outline a set of double impacts that may be used to establish a future regulatory framework.

The following section contains a summary of the foreseen impacts. As can be seen, new businesses, new products and new materials will certainly lead to new productions systems and yet unknown social impacts.

Integration and substitution of technology

Nanotechnology will provide a wide range

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of new applications, based on either in-use technology or completely new applications. As a general purpose technology, nanotechnology is fully able to create or to enhance novelty within almost every scientific domain.

New scientific research areas, new kinds of raw materials, new products and new industries, will lead to a new individual, organizational and collective behaviour.

The replacement of existing principles and techniques is, perhaps, the most important impact. Obsolescence will affect business competiveness, employment perspectives and social wealth. Since it is almost impossible to mechanically replace obsolete technological and competence structures for new ones, outdated knowledge and practices will be erased from different communities. It is unlikely, for example, that the workers from the traditional metal-casting industry will simply be employed by new steel injection companies.

The cost of the shift to a new educational and professional paradigm will change State and university institutional structures. Once-valued skills may not necessarily be applicable to new technology.

New products and business

The new technological standards will certainly change the way in which matter is manipulated. Since nanotechnology deals with physical structures at the molecular level, a whole range of new products can be imagined and developed. As a consequence of this technological innovation, a variety of new businesses will emerge.

Not only new companies with, as yet unknown, new product alternatives, but also existing businesses will profit from the opportunities provided. R&D capabilities will reach new levels, both in terms of the specific skills of personnel and in terms of laboratory structures, thus requiring greater expenditure on R&D. Sectors and companies with less investment capability will tend to fall behind in this new technological trajectory.

Since nanoscience and nanotechnology are new fields, companies will certainly need to establish new patterns of open innovation with universities and technocentres. Equally, to avoid the misuse of principles and techniques, research and laboratory procedures will need to be redesigned.

New products will lead to new patterns of consumer behaviour. It is expected that new products will appear with significant advantages in terms of quality, reliability and price. However, major doubts have emerged in relation to the issue of consumption. Since particle manipulation is the very essence of nanotechnology, consumers may be exposed to different and unknown forms of contamination and environmental change. The risk to health is greater the more invasive is the product, such as food, drugs or cosmetics.

State agencies, NGOs and citizen's organizations will face new challenges to understand, prevent and avoid any possible negative impacts.

Extraction of raw material

One of the most important positive impacts is the complete change in the supply of raw materials. Nanotechnology has the potential to replace traditional extraction by synthetic production and, thus, to effectively reduce environmental impacts. This touches on one of the basic pillars of capitalism, i.e. the exacerbated use of natural sources of inputs.

According to the experts, this major shift will completely change the structure of value chains. Reductions in raw material and logistics costs, as well as in other transaction costs will to lead to a reorientation of business strategies. There will be a shift from supply to demand oriented strategies, where new products, with new price relations, will become easier to obtain, not only because they may become cheaper, but also due to the reduction in procurement and sales.

New materials, new logistic and operational structures, new products and new consumer behaviour will give rise to new industrial production chains, where productivity, efficiency, quality and cost will reach new standards.

However, as with any new production process, the extraction of the raw material demanded by nanotechnology will require new safety and hazard-free structures. As yet there are no standardized technical procedures to ensure safety with nanomanipulation; therefore nanoproduction is certainly one of the major challenges to be overcome. Universities, research centres, industrial organizations and NGOs have a key role to play in this quest.

Changes in the mode of production of common products

Nanoproduction, as stated above, is one of – if not - the major challenge for business ventures seeking to take advantage of nanotechnology. While new materials, new applications and new products are perfectly imagina-

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ble, the problem remains as to how to use, apply and produce them.

It is not merely a question of quality or productivity. It is more a question of how to concretely produce stable nanometric structures. Size has not yet been fully mastered and many nanoproducts are still micrometric products. Moreover, there is still a knowledge gap in relation to inert and active matter. While new nanoelectronic devices have already been successfully produced in the semiconductor industry, there remains a problem in bionanotechnology sectors, such as chemicals.

University-based scientific research, especially in engineering, will face great challenges in the next ten years. Society, as a whole, is still waiting for new nanoproduction technologies. Until then, traditional production process will be adapted to new nanotechnology products. And here lies a high risk of creating a negative impact, as traditional production processes may not be fully adequate to deal with nanometric structures. In the cosmetic industry, the unstable scale of the nanometric liposome in dermocosmetics can be expensive for costumers or harmful for human health, since if they are too big they may be useless, while, if too small, they may reach the bloodstream and produce undesirable side effects.

It will be difficult for State regulatory agencies to deal with such uncertainties.

Impact of automation on employment

As a result of the challenges that come with nanoproduction, automation seems to be absolutely necessary to achieve competitive productivity and high quality standards in nanometric products. Since it is almost impossible to use traditional manufacturing procedures, labour tasks will certainly change.

Even highly trained personnel will probably find themselves out of the work. On the one hand, the above-mentioned gap between scientific knowledge and technical practice is hard to be filled using their existing skills. On the other hand, there is still a lack of people with sufficient experience in the new technology to efficiently work in nanoproduction.

Because of the rapid pace at which nanotechnology is being adopted in many sectors, new investment will probably be much more equipment oriented then competence oriented. Therefore, nanotechnology is likely to reduce job generation and so affect welfare and undermine social relations.

Here, government and NGOs seem to have an important role; in developed countries, to avoid high rates of unemployment and, in emerging economies, to guarantee balanced investments in new technology and new industrial sectors.

Generation of hazardous particles

This is, perhaps, the classic negative impact. The “nanofear” effect is based much more on ignorance than on reality. The popular idea that nanostructures will invade human bodies and then dominate the world is science fiction, but there are hazards involved.

Since people lack of information, consumer behaviour will remain sceptical. This certainly affects the demand for new products and, thus, the success of the new companies based on nanoproduction. In fact, the ease with which nanoparticles could penetrate living systems, both human and natural resources, could effectively cause damage to health, contamination, pollution and degradation. However, the extent to which this can happen is not fully measurable. For example, as has happened with agro-toxins, cumulative and chronic effects may only come to light many years later.

Once again, in this area regulatory agencies and NGOs have a major role to play. The State should increase expenditure on research, prevention and control, while NGOs should dedicate themselves to gathering relevant information and increasing public awareness. This is why a new regulatory framework is urgent.

Until further information is available, the care taken by civil society will prevail over blind confidence in this new technology.

Impact on health systems

Here, once again, there is an evident double effect. The discovery of new medical procedures and drugs are the most valuable developments of nanoscience, though, at the same time, the risk of contamination remains high.

On the one hand, medical research is pointing to a whole new world of possibilities. New treatments, new cures, new devices, new techniques can and will make use of new nanoscience and nanotechnology-based developments and devices. Moreover, further extending the human life span is a long-held dream of mankind. Improved human health and life quality are without doubt the most hoped outcomes of nanotechnology.

On the other hand, if this is achieved, society as a whole and the State will benefit. Public health services will enhance quality and redu-

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ce expenditure, since new upcoming nano-based treatments are expected to be more accurate than existing procedures. That is why most R&D expenditure made by private companies is still being cantered on the medical, pharmaceutical and cosmetic industries.

The Survey

In this stage of the study, 35 statements – that were based on the experts opinions, referring to both the positive and negative impacts of nanotechnology, and that were formulated into a survey instrument which was sent to the Brazilian nanobiotechnology network researchers – are presented one by one according to their specific dimensions.[1]

Technological Dimension

From the data collected, for example, the mean of the responses to the first statement shows that the researchers tend to believe (m = 2.6) that nanotechnology can provide unlimited solutions to many of the problems faced by society, and almost all (m = 3.9) believe that research in nanotechnology will open new frontiers for knowledge and new scientific discoveries (see Table 1).

Regarding the impact of nanotechnology on the process of product development, most of the researchers (m = 2.93) believe that the time between a product's development and its launch will be reduced.

Yet, the analysis of the standard deviation shows that there is wide variance in the responses to the majority of the statements concerning the technological dimension, which may suggest a certain level of doubt in relation to the real potential of nanotechnology, notably in terms of what products will look like.

Economic Dimension

Most of the researchers strongly believe that nanotechnology will stimulate the growth of new industries and the disappearance of old ones, it will also require investment in professional training for future employees, and will increase R&D expenditure (see the results in Table 2)

Moreover, they believe that nanotechnology could increase the level of employment in the economy, since most of the researchers disagree that nanotechnology will be a factor leading to the exclusion of the low-income-population (m = 1.85).

Another aspect pointed out by the researchers was that the expense involved in treating waste from nanotechnology will be lower when compared to other technologies (m = 1.94). It may also lead to a rise in spending on health care, as nanotechnological products will be more expensive than conventional products.

In contrast, the researchers strongly believe in the need for investments in nanotech-

Table 1 Technological Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Offers unlimited solutions to many of the society's problems.	2.60	0.89
Nurtures technological integration at levels previously unimaginable.	3.50	0.68
Opens new research and knowledge frontiers.	3.90	0.31
Requires the creation of new laboratory procedures.	3.36	0.70
Creates a path for the raw material synthesis.	3.19	0.61
May reduce the development time of a new product.	2.93	0.70

1) Statistical tests were applied to cross-reference data. The first set of statistical tests used was intended to verify whether the sample was subject to a normal distribution. Thus, the homogeneity test and the Kolgomorov-Smirnov test showed that in all the research questions the answers did not show normal distribution. Hence, the nonparametric Kruskal-Wallis test was applied, because statistical techniques are best suited for use with small samples in the absence of normal distribution (MENDENHALL, 1990). The Kruskal-Wallis test revealed the existence of statistically significant differences in the responses from the surveyed researchers due to their different fields of knowledge. The test showed that all the questions received answers of little statistical significance ($p > 0.01$), concluding that there are differences in responses between the knowledge areas surveyed in all dimensions.

Table 2 Economic Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will facilitate the emergence of new industries.	3.64	0.51
May increase employment levels in the economy.	3.00	0.63
Will require investment in professional training for future employees.	3.67	0.47
May cause the disappearance of industries that do not apply nanotechnology.	1.91	0.80
May increase the spending level on measures to prevent the problems caused by nanotechnology waste.	1.94	0.74
May provide lower cost raw materials for industry.	2.78	0.78
Offers the possibility of unlimited scale of production of consumer goods.	2.27	0.85
Requires increased investment in research and development by enterprises.	3.65	0.51
May lead to more expensive health insurance plans.	1.98	0.83
The treatment of waste from nanotechnology will cost more than any other.	1.94	0.74
The nanotechnology-based products will be more expensive than other products.	2.20	0.73
Will be a factor leading to the exclusion of the low-income population.	1.85	0.79

Table 3 Environmental Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will assist in reducing pollution in general.	2.88	0.74
It is pollutant to humans and to the environment.	1.79	0.73
Will increase environmental awareness and researcher ethics.	2.25	0.88

nology-qualified-labour (m = 3.65). In the in-depth interviews (stage 1), labour representatives mentioned that such investment will not be only operational but also technological, that is, the workers performing routine activities in the production process will be affected as well as higher ranking staff, and the technical positions will have to hold the necessary knowledge in nanotechnology.

The economic dimension also revealed a wide range of responses to most of the statements. This demonstrates the difficulty involved in forming a position about the potential of a new technology. This happens because of the certainty that nanotechnology demands higher investments in professional qualification (m = 3.67), due to the variation in the physical properties of matter, which leads to a need for greater knowledge specialization.

Environmental Dimension

There is considerable doubt regarding the possible environmental impacts (see Table 3). The interviewed researchers believe in reduction of pollution in general (m = 2.88). Moreover, they disagree that nanotechnology is harmful to the human race and to the environment (m = 1.79), and with a high level of uncertainty (s = 0.88) they tend to disagree that nanotechnology will induce higher environmental consciousness and researcher ethics (m = 2.25).

The standard deviation among the environmental issues is high, which demonstrates a certain degree of uncertainty about the potential benefits of the new technology for the environment.

Social Dimension

The social impact is influenced by other impacts, in both positive and negative ways. However, most of the researchers believe that nanotechnology will be able to improve the quality of life among the population and that

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it might lead to further extension of the human life span (respectively, m = 3.58 and m = 3.13). But they disagree that, currently, nanotechnology has a negative image among the population (m = 1.69) and that it may cause harm to human health (m = 2.02).

The expectation that nanotechnology will bring benefits to the population is, thus, generally confirmed. The interviewed researchers seem to expect a great deal from the nanotechnological revolution, reflecting the transforming role of the scientific discoveries in the society (see Table 4).

Implications for the Regulatory Framework

The interviewed researchers agree (m = 3.37) that the laws and rules should help prevent any potential negative impact from nanotechnology. However, they are not fully in accordance that the standards of ethical conduct of researchers should be stricter with nanotechnology (m = 2.54 and s = 1.00). This may indicate a certain fear within the academic community regarding the risks of misusing the expected potential of nanotechnology (see Table 5). This is, perhaps, better explained if one considers the fact that they are also doubtful over the standardization of laboratory procedures and health care researchers should be stricter with nanotechnology (m = 2.66 and s = 0.95). However, respondents agree with tightening control of the manipulation of nanotechnology by lab workers in order to prevent health risks. This shows some concern about the possibility of contamination by nanotechnology, with a similar proportion who agree that nanotechnology could pollute the biological chain and cause harm to human health.

Here, once again, the standard deviation is high, reinforcing the perception of uncertainty.

Impact on the Stakeholders

In the course of introducing a new techno-economic paradigm several stakeholders influence and are influenced by the technological innovation process.

Questioned as to whether nanotechnology will negatively impact the stakeholders, the surveyed researchers strongly disagree (m = 1.12 and s = 0.37) that this could happen to the scientific community, industry and companies, consumers, the population, governments, and NGOs (see Table 6).

Moreover, in almost all the statements regarding the impacts on the stakeholders the standard-deviation tends to be low, which suggests the scientific community has a positive concept of nanotechnology.

Table 4 Social Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
May improve the population's quality of life.	3.58	0.56
Nowadays, nanotechnology has a negative image among the population.	1.69	0.89
May extend the human life span.	3.13	0.69
May cause damage to human health.	2.02	0.68

Table 5 Implications for the Regulatory Framework

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Laws and rules should prevent any potential negative impact from nanotechnology.	3.37	0.85
Regulation may restrain private investment in nanotechnology.	2.43	0.91
The ethical principles governing researchers should be stricter with nanotechnology.	2.54	1.00
The laboratory procedures and health care standards for researchers should be stricter with nanotechnology.	2.66	0.95

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Table 6 Impact on the Stakeholders

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will negatively impact on the scientific community.	1.12	0.37
Will negatively impact on industry and companies.	1.26	0.57
Will negatively impact on the population.	1.19	0.40
Will negatively impact on consumers.	1.19	0.40
Will have more negative than positive impacts on governments.	1.20	0.40
Will negatively impact on non-governmental organizations	1.50	0.77

Yet the highest standard deviation (s=0.77) is related to the impacts of nanotechnology on non-governmental organizations (NGOs), which may reflect a certain fear on the part of the scientific communities related to the actions of more critical NGOs that emphasized the negative aspects of Genetically Modified Food technology.

Impacts According Businessmen

While R&D expenditures on nanotechnology is steadily growing in developed countries, in Brazil, the number of companies that have initiated a nanotechnological trajectory is still very low. In our research, only five representatives of such companies were interviewed. Even with the small sample of the representatives from the business world, the impact of nanotechnology outlined in the interviews corresponds with the expectations identified by the experts interviewed in the previous step in this study.

Technological impacts

The technological impacts of nanotechnology are (and will) be significant in several industrial sectors, particularly in the pharmaceutical industry, as shown by the four respondents from this sector.

Nanotechnology is expected to reduce the risks involved in product development to help change the paradigm within the pharmaceutical industry from a process of trial and error to one which is planned, and focused on specific uses of the new active ingredient. In this industry, nanotechnology research is motivated by the special features it appears to offer. On-going research can be divided into two types: the scientific and technological.

The scientific search for new compounds, whether synthetic, vegetable or animal, can generate new drugs. Despite the tremendous advances in biotechnology, the fine chemicals industry still employs the traditional synthesis of substances technique. Nanotechnology offers the opportunity to synthesize the molecules from which substances are made.

The technological research involves the search for new forms of administration and absorption, and longer lasting action of the drug in the body and seeking ways to enhance and restrict the action of the drug at an exact point in the body in order to increase the chances of effective action and reduce side effects. The first discoveries involving the application of nanotechnology are taking place within technological research.

In this section, applications are broken down into the categories of drug action control process, the extent of treatment by synthetic drugs, enhancement of active healing and disinfecting systems, the scope and effectiveness of external (equipment and techniques) and internal (in vivo) diagnosis, new synthesis production processes, new techniques for controlling the dimension of the production process, among others.

The Brazilian cosmetics industry has only two companies capable of designing nanotechnology-based products. A representative of one of these companies asserted that research into nanotechnology offers a number of technological benefits such as increased productivity during the release of the active cosmetics on human skin, increasing the effectiveness of the cosmetic effect on the surface of human epidermis, slowing the aging of human epidermis, increasing the efficiency and effectiveness of the cosmetic action of

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sunscreen achieved by the combination of functional properties in the cosmetic product (in addition to maintaining the quality of the skin, the cosmetic can change the colour itself in accordance with changes in indicators of the environment such as temperature), among other impacts.

In addition to the impacts on specific technological industries, impacts of greater magnitude were indirectly mentioned, such as unlimited solutions, technology integration, new procedures, creation of new materials and cutting the time required for product development.

Economic Impacts

For both industries, respondents foresee that nanotechnology will save the active ingredient per unit of output, enable faster development of new and efficient products, create jobs for highly qualified professionals (PhDs and researchers), increase competition between companies in different sectors, require higher levels of initial investment for R & D, permit the development of more productive processes, among other impacts.

Social and Environmental Impacts[2]

The reasons given by the interviewees for this were: ignorance of the matter, difficulty anticipating uncertain events (since at the time of the interviews, all the potential products were in the early or intermediate stages of development), and fear that an opinion might impede the path of some innovation strategies.

Unlike the experts, the company representatives do not have clear opinions about impacts on social and environmental dimensions. In general, the consideration of environmental and social concerns in the development of new technologies is relatively new in Brazilian companies, which means that they do not create adequate condition for further nanotechnological innovation.

Regarding this issue, the most plausible conclusion is that the initial investment in nanotechnology, as estimated by these companies, may be significantly increased by the ignoring/exclusion of the social and environmental impacts. Business decisions are increasingly influenced by other types of stakeholders (such as unions, NGOs, etc.) in technologically innovative projects, in addition to traditional stakeholders (employees, customers, suppliers and government). This tends to lead to a lack of a close quality control during the process of developing a new technology or product.

Discussion: Towards a New Regulatory Framework

The present study examined the technological, economic, environmental and social dimensions of nanotechnology. In order to perceive the different interlinked effects and relations, a three-fold study was conduced within different communities. Experts representing different social stakeholders, nanobiotech researchers and some businessmen were consulted in an attempt to shed light on uncertainty surrounding the possible impacts of nanotechnology.

It is our belief that the different insights indicate the possibilities that nanotechnology may provide. The experts seem to be more cautious regarding which impacts are positive and which are negative. Although the researchers are much more optimistic, it seems that their views are based much more on "wishful thinking" than on conviction. The researchers, being directly involved in new scientific and technological discovery, naturally stress the theoretical benefits of any upcoming technology. Finally, the businessmen are much more concerned with the short term rather than the long term results.[3]

However, they all seem to agree with some conclusions. Nanotechnology will certainly lead to the growth of new industrial sectors, requiring increased spending in R&D and new professional skills. Moreover, the new drugs, new treatments and new materials resulting from the nanotechnological revolution will change quality of life for mankind. New products seem to offer a whole new range of value perception and profitability.

Negative impacts were also commonly perceived, especially in terms of the impacts on human health and the growth in unemployment. These two drivers fall within the soci-

2) These impacts were included together in this section because none of the respondents identified any positive or negative social or environmental impacts arising from nanotechnology.

3) It is noteworthy that the type of field research influences the results. It is our belief that, an important limitation of this study was the use of different investigative methods for each community. And, thus, two limitations emerged: the researchers were too optimistic about the application of nanotechnology; and five company representatives is too small a sample to draw generalizations and consistent comparisons. However, even with these limitations, the results show that the impacts identified in the field study are in line with observations made in the literature in relation to nanotechnology.

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al dimension, since they affect public expenditure on maintaining health and social security systems.

Like any other new technology, it is absolutely necessary to have a regulatory framework that ensures the control of any possible harmful impacts. This new framework should consider the commitment of different stakeholders, and the use of and the results from nanotechnology R&D.

Considering the possible impacts listed for Nanotechnology, one can say that universities, in particular, as well as companies and technological centres demonstrate a "commitment" to the new emerging techno-economic paradigm.

There are some significant points that should guide the development of applications and products that relay on nanotechnology, such as: (a) the benefits of nanotechnology must outweigh the highlighted risks in order to reach a wide range of people, both in terms of its use and advantages; and (b) regulation should not overstate the severity of risk, in order not to inhibit investments in the R&D of nanotechnological applications, such as was seen in the case of stem-cell research debate.

A new mode of regulation must, above all, safeguard the rights of consumers and individual citizens. With nanotechnology it should not be different, so that appropriate methods of testing the reliability and safety of products in terms of their effects on human and environmental health need to be developed and introduced. Any product that incorporates nanotechnology should be identified as such and if the advantages, for example, reliability and safety, of such a product are already established they should have preference (e.g. government may subsidize their R&D and production) over products devoid of such technology.

Any regulatory framework should be built within the context of a debate involving all the stakeholders, informed by the technical opinion of scientists, where relations are based on mutual trust and communication is clear and open. All new products should be assessed, considering factors such as the potential risks, interactions with other particles or substances and toxicity, among others. The priority is to evaluate new materials, determine their risk levels and add basic information to establish the regulatory clauses.

References

Alves, O. L. (2004): *Atividade prospectiva em nanotecnologia: desenvolvimento científico da nanociência e nanotecnologia nos últimos 10 anos* (janeiro1994 - julho 2004). Relatório Parcial. Unicamp, 2004.

Asheim, G. B. ; Buchholz, W. ; TUNGODDEN, B. (2001): Justifying sustainability. *Journal of Environmental Economics and Management*, Elsevier, vol. **41**(3), pages 252-268.

Banerjee, S. B. (2003): Who sustains whose development? sustainable development and the reinvention of nature. *Organization Studies*. v. 24, p. 143-180.

Bansal, P. (2003): From issues to actions: The importance of individual concerns and organizational values in responding to natural environmental issues. *Organization Science*, v. **14**, n.5, 510-527.

Boron, S. ; Murray, K. (2004): *Bridging unsustainability Gap: A framework for sustainable development.* Sustainable Development, v. **12**, p.65-73.

Bresnahan, T. F.; Trajtenberg, M. (1995): General purposes technology: engines of growth? *Journal of Econometrics*, v. **65**, pp. 83-108.

Carlaw, K. I.; Lipsey, R.G. (2002): Externalities, technological complementarities and sustainable economic growth. *Research Policy*, v. **31**, pp. 1305-1315.

Carlaw, K; Lipsey, R. G.; Bekar, C. T. (2005): *Economic transformations: general purpose technologies and long term economic growth.* Oxford University Press.

Crandall, B.C. (1997): *Nanotechnology*. London: MIT Press.

Dosi, G. (1991): "Perspectives on evolutionary theory". *Science and Public Policy*, **18**(6):353-61, dezembro.

Elsi. (2005): *Benefits, risks, ethical, legal and social aspects of nanotechnology*. 4 ° Nanoforum Report.

ETC Group (2004): *Down on the farm. The impact of nanoscale technologies on food and agriculture.* Ottawa.

FINEP (2003): *Editais*. Financiadora de Estudos e Projetos. Available in http://www.finep.gov.br, researched in August, 1st.

Fishbine, G (2002): *The investor's guide to nanotechnology and micromachines.* Wiley Finance Series n.107, v.1.

Freeman, C. (1982): *The economics of industrial innovation.* The MIT press.

Freeman, C.; Perez, C. (1988): Structural crises of adjustment: business cycles and investment behavior. in: DOSI, G. et al. (eds.). *Technical Change and Economic Theory*. Pinter, London.

Furtado, C. (2001): *Raízes do desenvolvimento.* Rio de Janeiro, Civilização Brasileira.

Greaker, M. (2003): Strategic environmental policy; eco-dumping or a green strategy? *Journal of Environmental Economics and Management*. v. **45**, p.692-707.

Kaiser, D. (2006): *Notes toward a Nanotech Timeline*. OSTI Working Paper 6-06-001.

Kingon, A. I.; Collins, M. J.; Gentry, S. T.; Bean, A. S.; Wolff, M. F. (2004): Corporate responses to nanoscience and nanotechnology. *Research Technology Management*. v. **47**, pp. 6-8, May/June.

 © 2010 Institute of Business Administration

Lattes (2006): *Lattes Cientific Curriculum Database.* Conselho Nacional de Desenvolvimento Científico e Tecnológico. Brasil, 2006. Available in: < http://buscatextual.cnpq.br/buscatextual /busca.do?metodo=apresentar>, researched in August 10.

Marques, L. F. M. (2008): *Modelo de Análise Mutidimensional para Impactos de Novas Tecnologias: nanotecnologia, economia, sociedade e meio-ambiente.* Doctoral dissertation. Escola de Administração, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Martinet, A.; Reynaud, E. (2004):*Stratégies d'Entreprise et Écologie*. Paris: Econômica, 165p.

NANOFORUM. *4th Nanoforum report: benefits, risks, ethical, legal and social aspects of nanotechnology*. Nanoforum.org, June, 2004. Available in: http://www.ipcc.ch /ipccreports/ar4-wg2.htm, on November, 3rd, 2008.

Nanologue (2006): *Opinions on the ethical, legal and social aspects of nanotechnologies - results from a consultation with representatives from research, business and civil society.* (www.nanologue.net)

Nelson, R. R.; Winter, S. (1982): *An Evolutionary Theory of Economic Change.* The Belknap Press of Harvard University Press, Cambridge (MA).

Nielsen, K. (2001): Institutionalist approaches in the social sciences: typology, dialogue, and future challenges. *Journal of Economic Issues*, 35, 2.

NIST (1999): *Nanotechnology Research Directions: Vision for Nanotechnology R & D in the Next Decade.* National Science and Technology Council, Interagency Working Group on Nanoscience, Engineering and Technology, September.

Pavitt, K. (1992): "Some foundations for a theory of large innovating firm". In: DOSI, G. et al. (Eds.). *Technology and Enterprise in a Historical Perspective*. Oxford, Oxford University Press.

Perez, C. (1983): Structural change and assimilation of new technologies in the economic and social systems. *Futures*, **15**, 357-375.

Perez, C. (2004): Finance and technical change: a neo-schumpeterian perspective. In: Hanusch, H.; Pyka, A. (eds.). *The Elgar Companion to Neo-Schumpeterian Economics*, Edward Elgar, Cheltenham.

Roco, M.; Bainbridge, W. S. (2006): Nanotechnology: societal implications. *Nanotoday*, 493 p.

Royal Society/Royal Academy of Engineering (2004): Nanoscience and nanotechnologies: opportunities and uncertainties. *Report of the Royal Society/Royal Academy of Engineering Working Group*.

Shellenberger, M; Nordhaus, T. *The death of environmentalism: global warming politics in a post-environmental world*, 36p. 2004. Available in: http:// www. thebreakthrough.org/images/Death_of_Environmentalism.pdf - read in July 10, 2005.

Schumpeter, J. A. (1934): *The theory of economic development.* Cambridge, MA. Harvard University Press.

Spangenberg, J. H (2004): *Reconciling sustainability and growth: criteria, indicators, policies.* Sustainable Development. v.**12**, p.74-86.

Solow, R. M. (1957): Technical change and the aggregate production function. *The Review of Economics and Statistics,* **39**, 3, pp. 312-320.

Tobin, J (1989): *Policies for Prosperity: Essays in a Keynesian mode*. 528 p.

Zanetti-Ramos, B. G.; Creczynski-Pasa, T. B. (2008): Nanotechnology development: world-wide and national investments. *Brazilian Journal of Pharmacy.* **89** (2), pp. 95 - 101

Zawislak, P. A.; Andrade, A. M.; Larentis, F.; Machado, C. B. (2008): Inovação, Curva-S e as Ações da Firma: impressões e avanços a partir do setor de videogames no Japão. In: *Proc. XXV Simpósio da Gestão da Inovação Tecnológica*. Brasília.

Zawislak, P. A.; Marques, L. F. M.; Cruz, L. B. (2006): Nanotechnology and the need for a regulatory agenda: towards a broader approach for the technological paradigm leading concepts. In: *Proceedings of 16 IAMOT*, Pequim.

Zucker, L. G.; Darby, M. R. (2005): Socio-economic Impact of Nanoscale Science: Initial Results and Nanobank. *NBER working paper series.*

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Appendix

Findings

Impacts	Totally disagree	Disagree	Agree	Totally agree
Valid percentage				
Technological Dimension				
Offers unlimited solutions to solve many of the society's problems.	15.5	20.7	51.7	12.1
Nurtures the technological integration in not imagined level before.	0	10.5	28.1	61.4
Allows the research to be opened to new knowledge frontiers.	0	0	10.5	89.5
Requires the creation of new laboratorial procedures for experiment's handling.	1.8	7.1	44.6	46.4
Path for the new raw materials creation for industry.	1.8	5.4	64.3	28.6
May reduce the development time of a new product.	1.8	22.8	56.1	19.3
Economic Dimension				
Will provide the appearance of new industries.	0	1.8	31.6	66.7
May increase the employment level in the economy.	0	20	60	20
Will require investment in professional training for future employees.	0	0	32.8	67.2
May cause the disappearance of industries that do not use the nanotechnology applications.	34.5	41.4	22.4	1.7
May increase the spending level on measures to prevent the problems caused by nanotechnology residue.	7.4	50	29.6	13
May provide lower cost raw material for industry.	3.6	32.7	45.5	18.2
Offers unlimited scale possibility of production of consumer goods.	18.2	43.6	30.9	7.3
Requires increased investment in research and development by enterprises.	0	1.7	31	67.2
May increase the population expenditures with health plans.	29.1	49.1	16.4	5.5
The treatment of nanotechnology waste will cost more than any other.	28.3	50.9	18.9	1.9
The nanotechnological products will be more expensive than other products.	14.8	53.7	27.8	3.7
Will be an exclusion factor for the low-income population.	35.2	48.1	13	3.7

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Environmental Dimension				
Will assist in reducing pollution in general.	3.6	23.2	55.4	17.9
It is pollutant to humans and to the environment.	39.3	42.9	17.9	0
Will increase environmental awareness and researchers´ ethics.	21.4	39.3	32.1	7.1
Social Dimension				
May improve the population's life quality.	0	3.5	35.1	61.4
Nowadays, nanotechnology has a negative image to the population.	50.9	32.7	12.7	3.6
May extend human life.	0	18.2	50.9	30.9
May cause damage to human health.	21.8	54.5	23.6	0
Implications in the Regulation				
Laws and rules should prevent potential nanotechnology's negative impacts.	0	3.5	35.1	61.4
The specific regulation may restrain private investments in nano-technology.	50.9	32.7	12.7	3.6
The standardization of researcher's ethical conduct should be stricter with nanotechnology.	0	18.2	50.9	30.9
The standardization of laboratory procedures and researchers health care should be stricter with nanotechnology.	21.8	54.5	23.6	0
Impact on the actors				
Will negatively impact on the scientific community.	89.7	8.6	1.7	0
Will negatively impact on the industry and it's companies.	79.3	17.2	1.7	1.7
Will negatively impact on the population.	81	19	0	0
Will negatively impact on the consumers.	80.7	19.3	0	0
Will have more negative impacts on governments than positives.	80.4	19.6	0	0
Will negatively impact on non-governmental organizations	64.8	22.2	11.1	1.9