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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 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 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 Chinese 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-

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

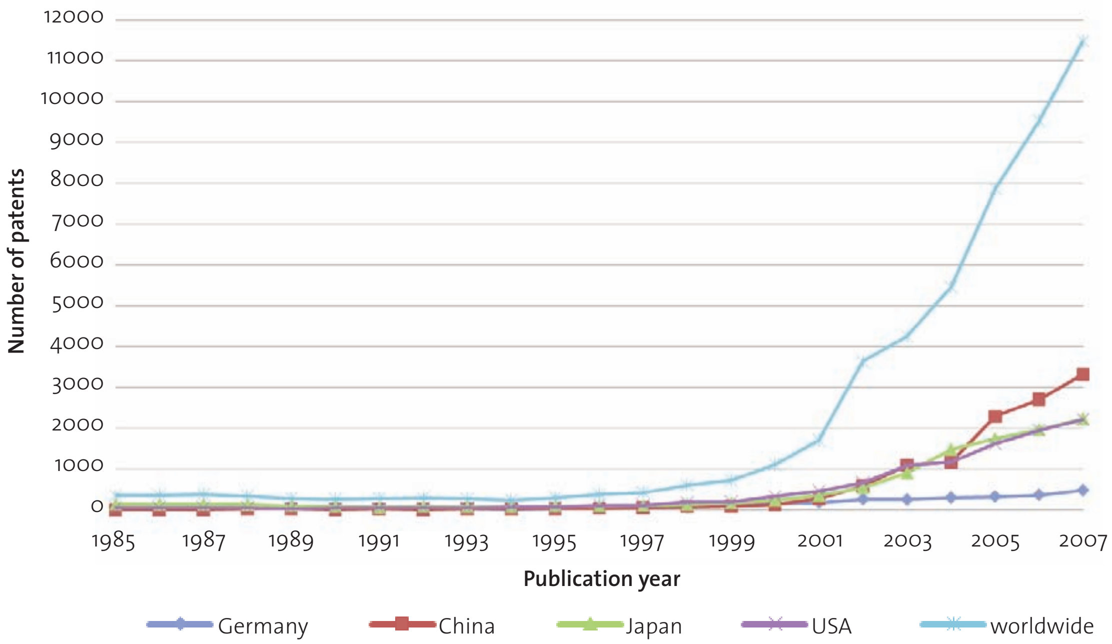
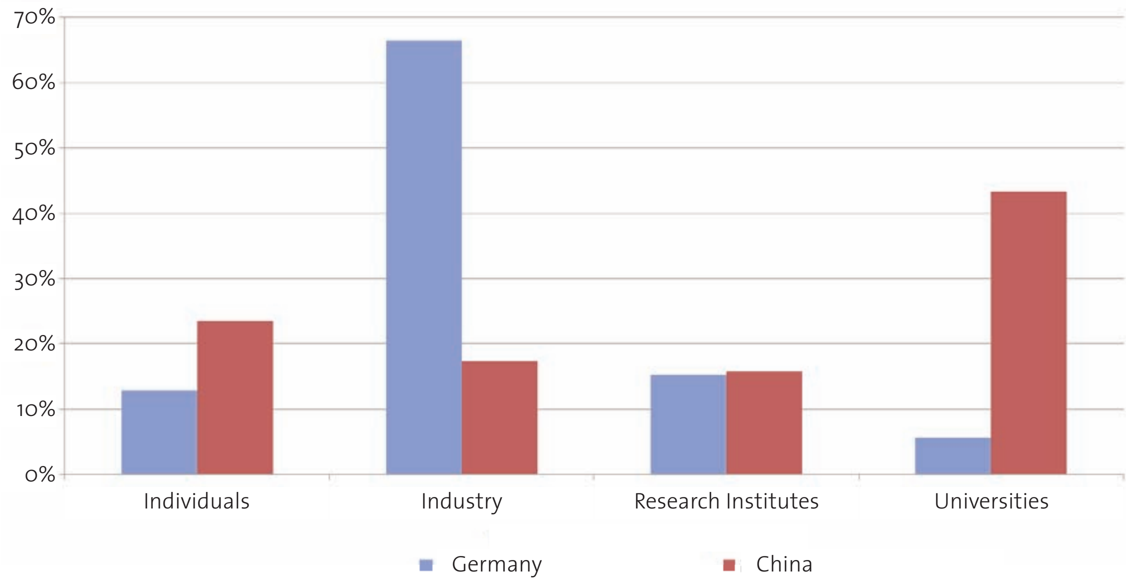


Figure 2 Comparison of patent applicants clusters. Number of patents: 50,549. Source: SciFinder Scholar™, November 2009.



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-

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 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.

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