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The role of patenting activity for scientific research: A study of academic inventors from China's nanotechnology

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ABSTRACT

Scientists from universities are becoming more proactive in their efforts to commercialize research results. Patenting, as an important channel of university knowledge transfer, has initiated a controversy on potential effects for the future of scientific research. This paper contributes to the growing study on the relationship between patenting and publishing among faculty members with China's evidence in the field of nanotechnology. Data from top 32 most prolific universities in patenting are used to examine the relationship, consisting of 6321 confirmed academic inventors who both publish and patent over the time period 1991–2008. By controlling for heterogeneity of patenting activities, patenting experience, institutional affiliation and collaboration with foreign researchers, the findings in China's nanotechnology generally support earlier investigations concluding that patenting activity does not adversely affect research output. Patenting, however, has negative impacts on both quantity and quality of university researchers' publication output, when the assignee lists include corporations or scientists themselves.

1. Introduction

The interacting university–industry relationship has been recognized by not only scholars but also policymakers or practitioners as one of the most important characteristics in a knowledge-based economy. Scientific activities have increasingly played an important role in industrial innovation and more firms are relying on external sources of scientific knowledge generated mainly by universities. Besides other channels of university knowledge transfer like consulting, sponsored research, licensing and spin-offs, university patenting has long been a topic of keen interest in the literature and policy initiatives. The past few years has seen a surge in the number of patents which are generated by academic scientists and granted to universities. More and more scientists produce results which can be both published in academic journals and applied for filing patents.

In recent years, the growing studies have focused on investigating the impacts of academic patenting for the future scientific research. Although the understanding of the effects of university patenting on scientific research remains open to debate theoretically, a large body of empirical studies on evaluating statistically the relationship between patenting and publishing have provided strong evidence that there is no negative effect of patenting activities on publication output of individual academic scientists, especially for star scientists (Agrawal & Henderson, 2002; Azoulay, Ding, & Stuart, 2006;

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Azoulay, Ding, & Stuart, 2007; Breschi, Lissoni, & Montobbio, 2007; Breschi, Lissoni, & Montobbio, 2008; Buenstorf, 2009; Calderini, Franzoni, & Vezzulli, 2007; Carayol & Matt, 2004; Fabrizio & Di Minin, 2008; Meyer, 2006a, 2006b; Murray & Stern, 2007; Van Looy, Callaert, & Debackere, 2006). The general finding is that patenting activity does not affect publishing activities. Meyer (2006a, 2006b) showed that patenting faculty members apparently outperform their non-patenting peers in terms of both quantity and quality of publication in the field of nanotechnology.

As Klitkou and Gulbrandsen (in press) point, the impacts of patenting activity and other types of commercialization for the scientific output are highly context-dependent in the national, university or disciplinary level. A large body of investigations or case studies have concentrated on developed economies, e.g. Meyer (2006a) for three European countries, Murray and Stern (2007) for US, Czarnitzki, Glänzel, and Hussinger (2009) for Germany, Breschi et al. (2008) for Italy, Klitkou and Gulbrandsen (in press) for Norway and Chang and Yang (2008) for Taiwan. Little is known, however, about China's status. To address this, we examined the effects of faculty patenting behavior in a panel dataset of nanotechnology scientists employed at Chinese 32 universities. These universities are representative because they are most prolific in patenting with the patent number larger than 50 during the period of 1991–2008. This field was chosen for three reasons. First, it is widely acknowledged that nanotechnology, as an emerging and rapidly evolving field with the multidisciplinary nature, is perceived as proximate fields of science and technology (Meyer, 2006b). Scientists engaging in this field may have the disciplinary advantage of both publishing and patenting their discoveries. Second, scientific research and technological development in China's nanotechnology has attracted considerable attention from scholars and policymakers all over the world in the past few years. China has emerged as one of the key global players in this field, producing the second largest number of nanotechnology papers following only the United States (Guan & Ma, 2007) and ranking third behind only the United States and Japan in terms of the number of nanotechnology patents granted (Liu & Zhang, 2005). Third, nanotechnology has been identified as a main component and a priority mission area in China's strategic plans for future developments in science and technology and has been given a high level of investment and significant support from central and local governments (Bai, 2005; Hassan, 2005). The reinforce effect or the conflict effect of patenting on future scientific research is increasingly central and of great interest to policy makers and university leaders. Therefore investigating an integrated quantitative perspective on this issue will provide an answer for them.

We focus on the following factors in the context of China. First, we attempt to explore a potential difference between different levels of supporting by governments, by considering whether a researcher comes from the key university and the State Key Laboratory. The key research universities have established themselves as an important source of knowledge for firms (Wu, in press). At the same time, the State Key Laboratories have played a vital role in China's scientific research system (Xue, 2006; Jin et al., 2006). Researchers from there are in a specialized and well-equipped environment and may face with better institutional culture. Second, China's patent laws are designed to grant Intellectual Property Rights (IPRs) on public inventions to the employers emulating the Bayh-Dole Act.[2] The regulation on protecting IPRs of higher education institutions established by Ministry of Education also points that the IPRs of employment inventions produced by a researcher belongs to his affiliated university (Ministry of Education, 1999). Thus most patents invented by faculty members are granted to universities in China. However, there is still heterogeneity of patenting activity (Czarnitzki et al., 2009), such as patents assigned to corporations due to joint or contract research, and assigned to the scientist himself besides the university under certain agreements on sharing revenue. We explore the effects of heterogeneous patenting activities on the scientists' publication output by distinguishing both instances. Third, international scientific collaborations should be controlled in our model since China has benefited greatly from international scientific collaborations in improving its research (Guan & Ma, 2007).

Following several studies on matching the data of publications and patents (Breschi et al., 2008; Boyack & Klavans, 2008; Meyer, 2006a, 2006b), we established inventor–author links and confirmed 6321 academic inventors who both published and patented in the field of nanotechnology over the time period 1991–2008. To further explore the publishing–patenting relationship with respect to China's context, we performed the fixed effects Poisson model. The remainder of this paper is organized as follows. In the next section, we summarize the empirical evidence on the relationship between patenting and publishing to develop our research hypotheses and also describe the related policies on academic patenting in China; Section 3 introduces China's nanotechnology. The dataset and the model used in the paper are described in Section 4. Section 5 presents the results and analysis. Section 6 discusses the findings and their implications; some directions for further study are suggested.

2. Backgrounds and hypotheses

2.1. The relationship between patenting and publishing

Universities had long been seen as open science organizations, providing direct contributions to the creation and public dissemination of knowledge. Over the last 30 years, these tradition missions have been challenged by some emerging

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[2] We mentioned the Bayh-Dole act to show the fact that China has implemented the Bayh-Dole-like laws allowing universities to appropriate publicly funded research results, although the consequences of the Bayh-Dole act is still open to debate (Mowery & Ziedonis, 2002). Evaluating the effects of China's patent system reform on patenting and licensing of university research will be discussed in our later paper.

factors such as new mode of knowledge production, new partnerships, and more varied funding. In a knowledge-based economy, universities are demanded to play more active roles in fostering technology transfer and economic growth through application and commercialization of academic research. The mission of universities has been expanding, no longer simply including education, training and research, but now embracing producing and applying technological innovation. Many universities have adjusted the reward systems or the incentive structures to encourage faculty members to patent their research results and have also established technology transfer offices to manage IPRs.

From a theoretical view, the rise in academic patenting, for universities themselves, may encourage the faster commercialization and exploitation of university inventions from public research and development, generate both industrial funding and licensing income from patents, spur new start ups and protect academic intellectual property. For scientists, patenting activities may bring the following positive consequences: satisfying their curiosity, helping to receive more peer recognition within the community and advance their career, gaining government supporting and additional funding from industry to build more effective and better equipped scientific team, and increasing their personal income (Geuna & Nesta, 2006). However, university patenting has raised a number of concerns on potential negative effects for the future of scientific research, especially for fundamental research. These concerns range from the impact of patenting on the direction of research (basic or applied), the substitution for publishing (reduce quantity and quality of publications), the decline of the quality of both research and teaching, to the effects on the diffusion of and access to publicly funded research results (Baldini, 2008; Van Looy et al., 2006). They are common not only to developed economies, but also to developing countries. Some work shows tradeoffs or conflicts between patenting and publishing, called the anti-common effects or the crowd-out effects. The more involvement of academic researchers in patenting may be possessed of a part of time and energy and make them undertake significantly less basic research, which ultimately result in fewer publications (Chang & Yang, 2008). The patenting process often involves a delay of publications and requires researchers to keep related information confidential at some time, which is a deviation from the academic norm of openness and dissemination of scientific knowledge (Merton, 1968) and also reduce the incentive to publish (Owen-Smith & Powell, 2001). Patenting activity may be detrimental to other researchers' future work, since there are to some extent restrictions on data sharing, open discussion and usage of related research tools. The citation rate for a scientific publication may decline after patents associated with that publication are granted (Murray & Stern, 2007).

Despite such concerns, however, there is a well-documented positive correlation between patenting and publishing activities of academic scientists in the empirical studies. For example, Meyer (2006a, 2006b) explored the relationship between nanoscience publications and nanotechnology patents of three European countries (United Kingdom, Germany, and Belgium) based on inventor–author analysis. His findings supported the above conclusions that patenting activity does not appear to have a negative impact on the publication and citation performance of researchers. More importantly, inventor–authors apparently outperform their non-inventing peers in terms of both publication and citation frequencies. Similarly, Breschi et al. (2008) reported academic inventors published more and better quality papers than their non-patenting colleagues. More specially, positive effect seemed to be stronger for star scientists because at least some of the more prolific and highly cited authors were also presented in the list of patent inventors.

Although a large body of studies clearly showed positive impacts of patenting or other commercialization on publication quantity of academic scientists, the effects of patenting on publication quality are mixed. Agrawal and Henderson (2002) carried out a case study on publishing and patenting activities of faculty members from the Departments of Mechanical and Electrical Engineering at MIT and found that increased patenting activity was positively related to increased rates of paper citations. On the contrary, the study investigated by Murray and Stern (2007) of patent-paper pairs covering the same research result presented that citations to a paper decreased by between 9% and 17% after the patent related to the same content grant. Fabrizio and Di Minin (2008) also reported a decrease in average citations to publications produced by repeat patenters. Thus, the direction of the effects is hard to reach agreement. In sum, we lean to this line of arguments which lead to the following testable hypothesis.

Hypothesis 1. Quantity of publications generated by a scientist will be higher following the application year for a patent by the researcher.

Hypothesis 2. Quality of publications generated by a scientist will decline following the application year for a patent by the researcher.

As Klitkou and Gulbrandsen (in press) point, the impacts of patenting activity and other types of commercialization for the scientific output are highly context-dependent in the national, university or disciplinary level. Furthermore, patent heterogeneity, namely the ownership of patents may play an important role. Fabrizio and Di Minin (2008) provided a further exploration on this issue by characterizing each patent as university-assigned, industry-assigned, or unassigned. Their results presented that besides university-assigned patents, the industry-assigned by faculty were also highly associated with more publications. In consistent with above results, Breschi et al. (2007) also reported that Italian academic inventors were more productive than their non-inventor colleagues. The reasons they explained were the 'individual productivity effect' and the 'resource effect'. Particularly, the 'resource effect' became more clearly visible when patents were owned by industrial partners rather than by universities or the scientists themselves. Even collaborations with co-authors in business were positively related to the publication output of university scientists, as Breschi et al. (2008) pointed. Based on a large sample of German professors active in patenting, Czarnitzki et al. (2009) also distinguished between patents assigned to corporations and patents assigned to nonprofit organizations including individual ownership of the professors themselves. Their findings showed that patents assigned to nonprofit organizations reinforced publication quantity and quality, while effects of patents assigned to corporations were adverse. Finally, our two hypothesizes on heterogeneity of patenting activity are provided:

Hypothesis 3. Both quantity and quality of publications generated by a researcher will present a decline following the application year for a patent by the researcher, if the patent is assigned to corporations.

Hypothesis 4. Both quantity and quality of publications generated by a researcher will be higher following the application year for a patent by the researcher, if the patent is assigned to the researcher himself.

2.2. China's context in scientific research and technological development

Public R&D support plays a critical role in shaping and guiding national innovative capacity of Asian latecomer countries (Hu & Mathews, 2008). The university sector in China has made a remarkable contribution to the reform of China's national innovation system and the growth of China's high-tech industry over the last decade (Xue, 2006). Universities enlarge their missions from education, training and knowledge creation to the commercialization of their research results. However, different supporting levels from governments exist due to limited resource. We attempt to explore these potential differences by considering whether a researcher comes from the key university and the State Key Laboratory.

Since 1998, China's central government has begun to conduct Project 985, which is a constructive project for funding world-class universities in the 21st century. In the initial phase, nine universities, selected as the best universities in China, were given grants in excess of 1 billion Yuan each, over a period of 3 years. The second phase, launched in 2004, expanded the project in cooperation with local government until it has now reached 39 universities. Many participating universities receive tens of millions of Yuan each year. All these universities, regarded as the State Key University, represent almost all the leading universities in China and are expected to be outstanding world-widely, 24 of which fall into our sample.

A large part of the funding goes to not only upgrading of university infrastructure, staff capacity building, construction of research platforms, but also innovations in university operation mechanism, including improving the quantitative evaluation system by faculty members' ability, performance, and contribution. Universities participating in this project have advantages of attracting and bringing together elite scientists, providing professional development of young staff, joint research programs with international leading universities. Thus, researchers from these universities could show a higher academic level on average than those from other universities, especially in some key disciplines. Hence, the preceding discussion suggests the following hypothesis:

Hypothesis 5. Quantity and quality of publications by a researcher from universities participating in Project 985 are higher than other.

Similarly, the main objective of the State Key Laboratories is also to make China's research more visible and outstanding to the global scientific community. The State Key Laboratories have a list of university laboratories currently receiving funding and administrative support directly by the central government. Their construction and management is one of the results of a major S&T system reform in the country (Jin et al., 2006). Chemistry, Physics and Materials science, which make up more than a quarter of all the laboratories and where nanotechnology is classified, are three key disciplinary areas specialized by the State Key Laboratories. They have many important research results in nanotechnology. Researcher from there may face with well-equipped working conditions including library software, digital campus, experimental areas and research stations. Another situation we consider is that these laboratories are significantly more active in utilizing market mechanisms of technology transfer such as patenting, licensing, and consulting. Thus, we expected that quantity and quality of publications by a researcher from the State Key Laboratories are higher than other. Thus, we develop our last hypothesis as follow:

Hypothesis 6. Quantity and quality of publications by a researcher from the State Key Laboratories are higher than other.

3. Nanotechnology in China

Nanotechnology is defined as "understanding and control of matter at dimensions of roughly 1–100 nm, where unique phenomena enable novel applications" (PCAST, 2005). It has been recognized by not only scientists and technology developers but also policymakers as one of the key and transformative technologies of this century. To address the great potential of the emerging technology and promote its development, China's government has identified nanotechnology as one of priority mission areas in its national agenda of science and technology development and escalates investment in its R&D. Such investments have begun to translate into world-class research results, in terms of scientific publications and patents (Bai, 2005; Hassan, 2005). While China has emerged as one of key global players in nanotechnology, Chinese research community in nanotechnology needs to improve its now-limited research influence (Guan & Ma, 2007; Kostoff, Barth, & Lau, 2008; Youtie, Shapira, & Porter, 2008; Zhou & Leydesdorff, 2006). Taking the total number of patents granted as another indicator of research activity in this field, China is behind the developed economies (Hullmann & Meyer, 2003; Li, Lin, Chen, & Roco, 2007). Therefore, China's science and technology authorities have adjusted the evaluation procedure and criteria in order to encourage researchers in universities and public research institutions to publish original articles in international journals with high impact or obtain patents (Jin, Rousseau, & Sun, 2006).

Among many factors in driving the rapid growth in publications, joint research with international colleagues cannot be neglected. It is accepted that joint research could make a contribution to strengthening research capacity of developing countries. For researchers from the largest developing country in the world, establishing cooperative relationships with and keeping in close touch with scientists from US, the EU countries or other major contributors to world science can help them expand their perspectives, improve their research techniques and provide access to the international scientific network, thus highlight both quantity and quality of research output. Guan and Ma (2007) provided an integrated bibliometric analysis of China's influence and position in global nanotechnology research and confirmed a positive effect of international collaboration on citations of publication. Thus, it would expect that the quality of international collaborative papers, especially in cooperation with nanotechnology-advanced countries, is good with higher average impact and citations as compared to rest publications.

Another factor we must consider is that where to publish their discoveries and in which language is an important concern for scientists in China. Recently, a large proportion of papers by China's scientists in nanotechnology have appeared in international journals originated from the scientifically advanced occident countries. The procedure of peer review in international journals creates a desirable exchange between reviewers and authors. This could highlight the original points, improve their writing and raise the quality of papers through the submission, revision and publishing process. Although more and more scientists of China have been paying attention to improving the international visibility of publications, Chinese journals are still the main channels for communicating their research results. To notify, Chinese journals, even those published in English and contained in the Science Citation Index, usually have a smaller readership and a lower international visibility. Thus, in order to address this issue, we distinct from Chinese journals and international journals in the following text when evaluating the performance of individual scientists.

4. Data and models

4.1. Collecting data

Since nanotechnology is an emerging and rapidly evolving field with the multidisciplinary nature, it is difficult to delineate its boundaries and harvest the relevant publications and patents of the field. Different bibliometric search strategies of querying keywords and prominent terms in titles, abstracts and patent claims, are found to collect publications and patents of nanotechnology, including simple term search for the prefix "nano", complex and evolutionary lexical queries, citation analysis, bootstrapping techniques, the use of core journal sets based on Bradford's Law and hybrid lexical-citation methods (Braun, Schubert, & Zsindely, 1997; Glänzel & Meyer, 2003; Leydesdorff & Zhou, 2007; Mogoutov & Kahane, 2007; Schummer, 2004; Zitt & Bassecoulard, 2006). There seems to be no agreements having been made on search approaches of nanotechnology in the above-mentioned studies. For conveniences of retrieving and identifying nanotechnology publications and patents, we employ the search strategy suggested by Porter, Youtie, Shapira, and Schoeneck (2008). Reviewing a variety of search efforts, they provided a two-staged modularized Boolean search strategy, with merits of the comprehensive search words combining with expert panel review and strong ability to search large-scale and multiple databases.

The study exploits a database of nanotechnology patents from the Derwent Innovation Index (DII) and a database of nanotechnology publications from the SCI-Expanded (SCI-E). DII is the most comprehensive database covering the data of the main leading patent-issuing authorities including the United States Patent and Trademark Office (USPTO), Japan Patent Office (JPO), European Patent Office (EPO), World Intellectual Property Organization (WIPO) and Sino Intellectual Patent Office (SIPO). Further, it provides the descriptive titles and concise abstracts rewritten by subject experts linking to full-text primary patent records from a range of full patent sources, which can be retrieved easily and exactly. The latter is a widely accepted database covering most of the important influential journals in natural and medical science, which is used often to assessing the scientific performance of one country from the international perspective.

It should be noted that each record in DII means a Basic Patent defined as a unique invention, enabling a global view of all Equivalent Patents referred to this particular invention in a patent family structure. A patent family is a group of published patent documents relating to the same invention and patented in different countries by way of the priority or priorities of a particular patent document. We treat the invention described in each record as unit of analysis. Applying the search strategy on DII, we harvest more than 180,000 records in the time frame of 1991–2008. The total number of patents obtained by world universities and Chinese universities was 20,522 and 7227 respectively. By incorporating change and variation of assignee names, 32 universities whose total number of patent granted are larger than 50 are found to be most active in patenting nanotechnology. The total number of patents acquired by these universities is 5274, showing a high percentage. These universities are identified as our sample for further investigation. Although the types of patent offices targeted are different, we found that the distribution of patents acquired by these universities was highly skewed, with nearly 93% in SIPO and only 3.6% in USPTO. Researchers from these universities may have the language advantage and also have a lower cost in patenting with SIPO, but the quality and economic value may be lower than with others. Considering that the type of patent office may play a role, we tried to capture it by adding the patent numbers applied with USPTO in our model, but only found the effects insignificantly.

As above, we collect the publication data for them by conducting the search on SCI-E from 1991 to 2008. Based on the current practices in scientometrics, we limited the analysis of publications to research articles, in order to focus on the original research component of the SCI-E database. To include all articles that are relevant to 32 universities, we filtered out

Table 1
Publication and patent numbers of 32 universities most active in patenting.

University	Patent numbers	Publication numbers	University	Patent numbers	Publication numbers
Tsinghua Univ	596	4198	S China Univ Technol	123	710
Zhejiang Univ	492	2917	Peking Univ	120	3305
Shanghai Jiaotong Univ	491	2172	Zhongshan Univ	116	1362
Fudan Univ	380	2618	Xiamen Univ	109	830
Nanjing Univ	224	3732	Nankai Univ	107	1432
Tianjin Univ	195	1113	Wuhan Univ Technol	91	691
Tongji Univ	186	667	Dalian Univ Technol	90	913
Shanghai Univ	166	526	Shandong Univ	86	1825
Beijing Univ Chem Technol	153	744	Xian Jiaotong Univ	83	772
Beijing Univ Sci & Technol	152	105	E China Normal Univ	80	557
Wuhan Univ	147	1527	Univ Sci & Technol China	75	3854
Sichuan Univ	146	1039	Harbin Inst Technol	74	1128
Donghua Univ	144	309	Beijing Univ Technol	62	276
Jilin Univ	142	2924	Hunan Univ	58	858
Dongnan Univ	138	347	Zhongyuan Univ Technol	54	32
E China Univ Sci & Technol	126	795	Shandong Normal Univ	51	259

all papers where at least one author affiliation is located in one of 32 universities and identified more than 28,000 records. Table 1 presents publication and patent data for these selected universities. It should be noted that there are three outliers in ratio of patents/publications: Zhongyuan Univ Technol, Donghua Univ and Beijing Univ Sci & Technol. All of them were developed from the institutes and nowadays concentrate in some engineering fields. Zhongyuan Univ Technol, formerly Zhengzhou Textile Institute, and Donghua Univ, formerly East China Textile Institute of Science and Technology, focus on the study of textile engineering and technology. Beijing Univ Sci & Technol, formerly Beijing Institute of Iron and Steel Technology, is renowned for its study of metallurgy and materials science. Thus these universities pay more attentions to applied research and patenting, showing large extremes in ratio of patents/publications. This interesting information may reflect the different institutional policies concerned with Intellectual Property Right and deserves the further study.

4.2. Approaches of tracing patenting and publishing links

Several approaches based on the informetric structure of publications and patents can be found in bibliometric or technometric studies to trace patenting and publishing links, such as citations, co-activity, classification relations, shared topics (Bassecoulard & Zitt, 2004). The science-based citation based on the patent data is the classic and common way to establish the links, suggested by the pioneering works of CHI-Research (Narin & Noma, 1985) and some extensive works (Glänzel & Meyer, 2003; Schmoch, 1997; Verbeek et al., 2002). But links established through the reference field of patents or publications are suspicious, mainly due to different citation behaviors and different citation motivations among authors, inventors and patent examiners. For example, these links are hardly direct and noisy (Meyer, 2006a) and their strength is somewhat limited (Czarnitzki et al., 2009). Besides this methodology, Murray and Stern (2007) provided another choice by making use of patent-paper pairs to establish linkages. However, patent-paper pairs may limit to some disciplinary in which research results can be served as a simultaneous foundation for future scientific research and commercialization. The approach of establishing links through collaborative knowledge production expressed by inventor–author relations suggested by Noyons, Van Raan, Grupp, and Schmoch (1994) and Meyer (2006a, 2006b), is not novel but much stronger and more meaningful. This approach was also used in Boyack and Klavans's informetric study (2008) to measure interaction between science and technology at the level of individual researchers.

Following above studies, our method used to match two datasets is to link inventor and author name from the same institution. Since DII's name rules are different from SCI-E's, it is difficult to perform a matching procedure based on the abbreviations of inventor names, especially for Chinese name, for example, 'Qian, Y.T.' in SCI-E and 'Qian Yitai' in DII point to the same scientist. Probably, this situation leads to be empty of empirical studies on China's relationship between patents and publications. To solve this, more information about researcher's full name is needed. We extract inventor full names of 5274 patents from the online databases of all responding patent offices and update their abbreviations in our database according to the name rules of SCIE. After matching the data in the same name from the same university only to prevent false connections, we get 6321 inventor–authors ultimately. Although our method is time-consuming in extracting information on full name, identifying name rules and coding for rewriting name abbreviations, it is the only way due to our limited knowledge. It is noted that we may miss some links, but we can ensure every link is identified with precision.

In the next step, we group all these university patents into two types in order to distinguish the different ownership of university patents. The one is assignment to a company, while the other is assignment to the inventor himself. It is worthy to note that the percentages of two types in total patents are nearly 15% and 5% respectively. The distribution of two types by patent application year can be seen in Fig. 1, which seems that numbers of patents assigned to company has been significantly larger than those assigned to individual during recent years.

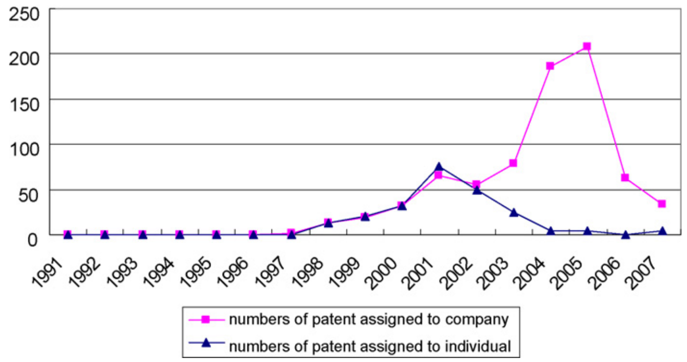

Fig. 1. The distribution of faculties' patents by type of assignee.

4.3. Indicators

This study chooses both patenting and publishing activities by the academic researcher per year as the unit of analysis. Five different bibliometric indicators are developed to evaluate both the scientific productivity of researchers and the impact of their publications, which are illustrated as follows. The first two measures are publication numbers per researcher per year on the basis of full counting and fractional counting, which are also used in Meyer's (2006b) study. Our third publication outcome measure is the publication count per year in international journals, in order to distinct researchers' choice where to publish their discoveries. The last two measures account for the quality of academic publications. The one is the publication count per year weighted by the journal impact factor (JIF) to account for the quality of academic publications. Impact factor is defined as the mean citations of the articles in the journal in a given period (Garfield & Sher, 1963; Garfield, 1972). The Impact factor published annually in the JCR has become a prominent international evaluation tool for assessing the quality, prestige and international visibility of a journal. It is also used to evaluate journal articles (Bordons, Fernandez, & Gomez, 2002; Czarnitzki et al., 2009), research activities (Moed, 2002), and researchers' performance (Kostoff, 1997). In this study, we use it as a proxy to delineate the quality of production of Chinese nanotechnology researchers. The other is that the total number of citations received by publications. Year dummies are used in our econometric models to consider the fact that the impact of a given piece of research varies considerably with the time elapsed since initial publication.

We use two variables to measure patent heterogeneity mentioned above. The first is the number of patents by every academic inventor per year with the co-ownership by his university and a firm, while the second one is the number of patents by every academic inventor per year with inventors' appearance in applicant list. With regard to supporting level from governments, we utilize the information on publications' affiliated institution to identify whether the author comes from the State Key Laboratories based on the institutions' title "State Key Lab" or "Natl Key Lab" and judge whether and when the university participates in Project 985 according to the related information from Ministry of Education's website (as shown in Table 2).

Another variable we pay attention to is the number of publications generated by a researcher per year in his (or her) main science field. Our method of identifying one's main science field is to calculate which field was published most frequently during the period of 1991–2008, since it could reflect where the researcher has devoted his time. It is well known that journals in SCIE are categorized into 22 broad fields, among which there are different publication patterns. Nanotechnology is an emerging and complex field with the multidisciplinary nature and the nano-related journals in SCIE are concentrated in Chemistry, Physics and Materials science. We add this variable to account for variation in the publication pattern across different science fields (Czarnitzki et al., 2009). We assume that more publications a researcher had in his (or her) main

Table 2
University sample participating in project 985.

University	Participating year	University	Participating year
Peking Univ	1999	Wuhan Univ	2001
Tsinghua Univ	1999	Sichuan Univ	2001
Nanjing Univ	1999	Jilin Univ	2001
Fudan Univ	1999	Dongnan Univ	2001
Shanghai Jiaotong Univ.	1999	S China Univ Technol	2001
Xian Jiaotong Univ	1999	Zhongshan Univ	2001
Zhejiang Univ	1999	Xiamen Univ	2001
Univ Sci & Technol China	1999	Dalian Univ Technol	2001
Harbin Inst Technol	1999	Shandong Univ	2001
Nankai Univ	2000	Hunan Univ	2001
Tianjin Univ	2000	Tongji Univ	2002
Beijing Univ Technol	2000	E China Normal Univ	2004

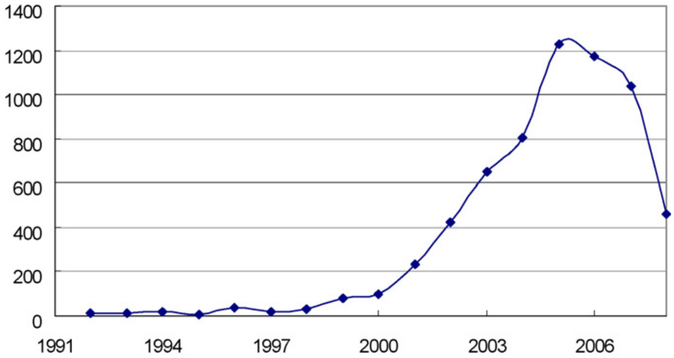

Fig. 2. Distribution of numbers of faculties by their first patent application year.

science field last year, more likely to highlight his (or her) international visibility. We imposed a logarithm form and 1-year lagged value of this variable to control skewness and avoid endogeneity respectively. We also collect the number of internationally coauthored publications produced from the nanotechnology leading countries by every researcher per year to control the impact of international scientific collaborations on the research performance. Based on same considerations, we lag this variable by 1 year.

The last variable is the experience in patenting activity of every researcher, also used in Czarnitzki and his colleagues' study. The experience may help faculty be familiar with patenting procedures, know how to file a patent in an effective way and reduce future cost of patenting. To some extent, patenting experience may counteract the crowd-out effect of patenting activity on publishing activity of faculties. However, too much experience may mean that the faculty has shifted his research agenda towards applied research or commercialization which can produce more patents. Therefore, it is expected that publications follow a non-linear inverted U shape relationship with patenting experience. We use a proxy of the time elapsed since his first patent application to measure patenting experience of every researcher and also include its squared term in the regressions to examine the non-linear relationship. Fig. 2 shows that the majority of faculties have participated in patenting activity since 2000, while only a small part started at the beginning of our investigating period.

4.4. Panel data regression model

To further explore the publishing–patenting relationship in China's context, we perform the fixed effects Poisson model on the unbalanced panel dataset described above. This count panel data model was developed by Hausman, Hall, and Griliches (1984) on explaining patent applications by firms in terms of research and development expenditures. We adopt this econometric model based on three considerations as follows. Firstly, fixed effects model vs random effects model. There is heterogeneity among researchers, but not all heterogeneity among researchers will be reflected in the above observables. So we need to take unobserved effects of faculty members into account, such as individual motivations, skills, effort, and serendipity (Buenstorf, 2009; Czarnitzki et al., 2009). We expect a priori that these important individual unobserved effects are correlated with the right-hand variables. Based on this, the fixed effects model is picked. Furthermore, all of Hausman tests for our data reject Random Effects specifications at the 0.1% level. Secondly, Poisson models vs negative binominal models. It has long been recognized that the basic assumption of Poisson model is equality of the conditional variance and mean, namely equi-dispersion. In the case of over-dispersion, some scholars appropriated the Negative Binominal Models (e.g. Chang & Yang, 2008). However, Wooldridge (1999) had shown some nice and strong robustness properties of the fixed-effects Poisson model. He pointed that the Poisson model makes few restrictions, e.g. its estimator still consistent whenever the restrictive equi-dispersion assumption holds. Compared to the Negative Binominal Models, its functional form is quite flexible when allowing for the possibility of correlation across observed variables and it also provides the calculation of fully robust standard errors to correct the biased standard errors. Thirdly, the fixed-effects Poisson model is a type of count data model but it could also be applied to the situation where the dependent variable is a nonnegative continuous variable (Wooldridge, 2002, p. 676). While the publication full counts, the publication counts of international journals and citation times are actual count data, the publication fractional counts and the journal impact factor-weighted publication counts are not necessarily integers. Thus, the fixed-effects Poisson model is more suitable for our data.

The starting point of the fixed-effects Poisson model is exponential mean function and multiplicative individual specific term as follows:

$$\begin{aligned} &y_{it} \sim P[\mu_{it} = \alpha_i \lambda_{it}] \\ &\lambda_{it} = \exp(x'_{it}\beta), \quad i = 1, \ldots, n; \;\; t = 1, \ldots, T, \end{aligned} \tag{1}$$

where α refers to the individual specific effect.

Table 3
Variable definition and descriptive statistics.

Variable	Definition	obs. = 22,369			
		Mean	S.D.	Min	Max
PFU_{it}	Publication full counts by faculty *i* in year *t*	2.929	3.548	1	93
PFA_{it}	Publication fractional counts by faculty *i* in year *t*	0.603	0.774	0.002	16.993
PIJ_{it}	Publications in international journals by faculty *i* in year *t*	2.736	3.482	0	93
PJIF_{it}	JIF-Weighted publications by faculty *i* in year *t*	6.732	9.874	0	181.556
TC_{it}	Total cites by faculty *i* in year *t*	24.046	59.613	0	1513
$\text{InterCoAuthorPub}_{it}$	Publications with foreign co-authors by faculty *i* in year *t*	0.384	0.930	0	26
$\text{MainScienceFieldPub}_{i,t-1}$	Publications in the researcher's main science field in year $t-1$	1.158	2.148	0	56
ApplicationYear	Application year of patent, for matching the publication year	2005.056	1.909	1992	2007
$\text{FirstApplicationYear}_{i}$	Application year of one's first patent, for calculating his or her experience on engaging in patenting activity	2003.921	2.391	1992	2007
$\text{BPnumber}_{i,t-1}$	Basic Patent numbers by faculty *i* in year $(t-1)$	0.457	1.138	0	52
$\text{CompanyPatentNumber}_{i,t-1}$	Basic Patent numbers with the company assignee by faculty *i* in year $(t-1)$	0.025	0.587	0	48
$\text{IndividualPatentNumber}_{i,t-1}$	Basic patent numbers with the individual assignee by faculty *i* in year $(t-1)$	0.006	0.147	0	12
isKeyUniv_{it}	Whether the researchers from the 985 universities or not	0.836	0.370	0	1
isKeyLab_{it}	Whether publications are affiliated with the State Key Lab	0.362	0.481	0	1
Experience_{it}	Experience of enagaging in patenting acitivity	0.584	1.360	0	15

Taken altogether, our specification is given in Eq. (2):

$$E(y_{it}|x_{it}, \alpha_i) = \alpha_i \exp(x'_{it}\beta). \tag{2}$$

Before performing our empirical analysis, the time window between publishing and patenting must be considered. Scientists engaging in nanotechnology may have the disciplinary advantage of both publishing and patenting their discoveries in parallel. It is assumed that the application date of a patent and the submission date of an article could be seen as the finished time of research work. The former can be easily extracted from DII, while the latter is unobservable in SCIE. To solve this issue, we ran correlation analysis to explore time lags between the dependent variables and patent numbers. The results show the correlation coefficients when taking 1-year lag value are highest among others (see Appendix A). Thus, we time the patent variables by application year and include their 1-year lag value in the regressions. Finally, the definitions of all the variables in our models are shown in Table 3.

5. Empirical analysis

Table 3 also presents some descriptive statistics in the last four columns, namely the means, standard deviations as well as minima and maxima of the variables used in the subsequent regression analysis. On average, each scientist in our sample has nearly 3 scientific publications per year but less than a half patent. Further, the mean of PIJ is approximate to that of PFU, which reflects that publishing research results in international journals has become prevailing in China's scientific community in the field of nanoscience and technology.

Table 4 presents the estimation results of conditional fixed-effects Poisson regressions. The first three columns present the results for the estimation for the publication quantity as measured by PFU, PFR and PIJ respectively. The subsequent columns show the estimated coefficients for PJIF and TC, i.e. the journal-impact-factor weighted publication outcome of the academic inventors and the citations received. Both the standard errors and the fully robust standard errors of the fixed effects Poisson model are reported in brackets, since in the case of over-dispersion, the former are biased and need to be adjusted while the fully robust standard errors is still consistent.

Hypothesis 1 predicts the positive relationship between patenting activity and publication quantity. As shown in left three columns, whatever the indicators is used, the coefficients are all statistically significant and positive. The positive signs suggest that publication quantity and academic patenting are mutually reinforced, thereby supporting Hypothesis 1.

Table 4
Conditional fixed-effects Poisson regressions.

Dependent variables	PFU_{it}	PFR_{it}	PIJ_{it}	PJIF_{it}	TC_{it}
Covariates	Coefficient (std. err.) (Robust std. err.)				
$\text{BPnumber}_{i,t-1}$	0.048	0.051	0.048	0.048	0.064
	(0.005)***	(0.010)***	(0.005)***	(0.003)***	(0.002)***
	(0.007)***	(0.007)***	(0.007)***	(0.007)***	(0.016)***
$\text{CompanyPatentNumber}_{i,t-1}$	−0.048	−0.052	−0.047	−0.056	−0.068
	(0.007)***	(0.015)**	(0.007)***	(0.004)***	(0.002)***
	(0.008)***	(0.008)***	(0.008)***	(0.009)***	(0.017)***
$\text{IndividualPatentNumber}_{i,t-1}$	−0.044	−0.017	−0.035	−0.064	−0.038
	(0.026)	(0.051)	(0.026)	(0.014)***	(0.005)***
	(0.013)**	(0.022)	(0.013)*	(0.017)***	(0.032)
$\text{MainScienceFieldPub}_{i,t-1}$	0.027	0.027	0.027	0.023	0.015
	(0.001)***	(0.003)***	(0.001)***	(0.001)***	(0.001)***
	(0.003)***	(0.003)***	(0.003)***	(0.003)***	(0.005)**
$\text{Experience}_{i,t}$	0.029	0.025	0.025	0.011	0.033
	(0.009)**	(0.019)	(0.009)**	(0.006)	(0.004)***
	(0.013)*	(0.015)	(0.013)	(0.014)	(0.024)
$\text{ExperienceSquare}_{i,t}$	−0.349	−0.318	−0.327	−0.242	−1.156
	(0.097)***	(0.220)	(0.100)**	(0.064)***	(0.051)***
	(0.162)*	(0.178)	(0.169)	(0.166)	(0.323)***
$\text{isKeyUniv}_{i,t}$	0.278	0.297	0.268	0.291	0.360
	(0.028)***	(0.061)***	(0.029)***	(0.022)***	(0.007)***
	(0.061)***	(0.060)***	(0.064)***	(0.067)***	(0.121)**
$\text{isKeyLab}_{i,t}$	0.279	0.245	0.270	0.255	0.215
	(0.012)***	(0.027)***	(0.013)***	(0.008)***	(0.004)***
	(0.017)***	(0.020)***	(0.018)***	(0.021)***	(0.036)***
$\text{InterCoAuthorPub}_{it}$	0.126	0.117	0.129	0.144	0.149
	(0.004)***	(0.008)***	(0.004)***	(0.002)***	(0.001)***
	(0.013)***	(0.012)***	(0.014)***	(0.018)***	(0.024)***
Number of observations	20,725	20,725	20,677	20,500	20,480
Number of researchers	4677	4677	4654	4630	4561
Wald-χ^2	8435.12***	1554.87***	8671.01***	30243.44***	107912.26***
Wald-χ^2 for robust model	2985.17***	2668.70***	3259.42***	3371.22***	9601.52***

Note: (1) Although our sample is 6321 academic inventors, 1644 groups (1644 obs.) dropped because of only one obs. per group. (2) The last three columns are smaller because several groups of all zero outcomes dropped. (3) *Correspond to a 10% level of statistical significance, **correspond to a 5% level of statistical significance, ***correspond to a 1% level of statistical significance.

Hypothesis 2 predicts that the relationship between patenting activity and publication quality would be negative. However, the coefficients for publication quality measured by PJIF and TC respectively are still statistically significant and positive. They show that patenting may have a positive impact on publication quality, thereby rejecting the argument for Hypothesis 2. To summarize, our findings confirm the positive relationship between patenting activity and both quantity and quality, in consistent with some previous studies (Breschi et al., 2008; Czarnitzki et al., 2009; Fabrizio and Di Minin, 2008).

With respect to the heterogeneity of patent ownership, the results are not in line with a positive patent–publication relationship mentioned above. Hypothesis 3 supposes that both quantity and quality of publications generated by a researcher will present a decline following the application year for a patent by the researcher, if the patent assigned to corporations. We find that scientists' engagement in this type of activity has a negative and significant effect on both publication quantity and quality. These results confirm our concerns on publication delay, the anti-commons effect, and restriction on data sharing. This finding is partially consistent with an earlier study by Czarnitzki et al. (2009), who showed a negative but statistically only weakly significant effect of company patents. Hypothesis 4 predicts a positive effect of individual patents on publication activity. But these negative signs still hold when the patent is assigned to the researcher himself. However, one must be careful not to rush to conclusions because the percentage of individual is very small and these negative signs appear significant only if PJIF is applied.

Hypothesis 5 and Hypothesis 6 predict that a researcher from universities participating in Project 985 or the State Key Lab would show a higher level on both quantity and quality of publications. In any cases, the coefficients are positive and statistically significant, thereby confirming our supposition.

We also control some factors which may influence faculty members' research performance and are also presented in previous studies, such as publication counts in one's major science field last year, international co-authorship, patenting experience and its square term. The positive and highly significant coefficients of publication counts in major science field hold in both cases in terms of quantity and quality. In line with Czarnitzki et al. (2009), it confirms our viewpoints that more

Table 5
The results of testing hypotheses.

	Description	Predicting sign	Result
Hypothesis 1	The effect of patent on publication quantity	Positive	Not rejected, positive significantly
Hypothesis 2	The effect of patent on publication quality	Negative	Rejected, positive significantly
Hypothesis 3	The effects of company patent on both publication quantity and publication quality	Negative	Not rejected, negative significantly
Hypothesis 4	The effects of individual patent on both publication quantity and publication quality	Positive	Not rejected, negative unsignificantly
Hypothesis 5	The effects of Project 985 on both publication quantity and publication quality	Positive	Not rejected, positive significantly
Hypothesis 6	The effects of the State Key Lab on both publication quantity and publication quality	Positive	Not rejected, positive significantly

publication output one has in his or her major science field, higher level the publications show in terms of impact factors of journals and citations received. Similarly, international co-authorship with the leading countries helps China's scientists increase their productivity and improve their research impact. In terms of experience measures, we predict a lifecycle effect of faculty members, which means that patenting experience generally leads to less distraction from publication activities, but more experience may reflect the reverse effect. In our models, we confirm a non-linear inverted U shape relationship between patenting experience and scientific research, though weakly significant. Taken altogether, the results of testing hypotheses are illustrated in Table 5.

Finally, we discuss several marginal effects of patent indicators. The marginal effects of basic patents mean that they will increase publication quantity by 5% and publication quality by 6%. However, if patents are assigned to companies, the positive impact of patents may be counteracted. Company patents may result in a reduction of publication quantity of 5% and a reduction of quality of 7%. At the average of the patent variable, the former corresponds to 0.5 less publication full counts, whereas the latter 1.7 less citations to publications. With regard to individual patents, we only discuss their effects on quality as measured by the JIF-weighted publications due to their significant level. The marginal effects of individual patents amount to a reduction of quality of 6%, which corresponds to 0.4 the JIF-weighted publications.

6. Conclusion

This paper contributes to the growing study on the relationship between patenting and publishing among faculty members with China's evidence in the field of nanotechnology. Following an interesting path on matching the data of publications and patents, we firstly establish China's inventor–author links in the field of nanotechnology. 6321 confirmed academic inventors who are co-active in publishing and patenting over the time period 1991–2008 are used to construct panel dataset. By further exploring the publishing–patenting relationship in the fixed-effects Poisson models, our findings support that faculty members who patent their research do not generate fewer publications and lower quality after patenting.

There are several reasons for a positive impact of patenting on the scientific productivity of individual scientists. First, patenting is most often regarded by scientists as a result of new scientific opportunities or by-products of scientific research and also provides the basis for the establishment of new scientific disciplines, especially for the emerging and rapidly evolving field. Individual scientists who participate in patenting activity, have an advantage of being aware of research questions raised by technology. Knowledge of these questions may at the same time be the basis for the establishment of new scientific disciplines and of potentially economic value. This may cause research performed by the patenting scientists to be more efficient and more relevant to the community. Second, patenting process sometimes needs scientists to be closely interactive with industry, which may help them access additional resources. These resources include both technical and financial supporting from industry, free access to expensive scientific instruments, and sharing related data. Much experience in patenting, also, may help them be familiar with patenting procedures, know how to file a patent in an effective way and reduce the time and cost of future patenting. Third, there may be the 'Matthew' effect operable. Since university leaders or laboratory directors have increased faculty members' incentives to patent research results, e.g. including the patent indicators or increasing patent weights in their evaluation procedures in terms of research performance, patenting may bring more peer recognition within the scientific community to individual scientists and advance their career, which probably leads to the improvement of individual research performance. In one word, Scientists become more widely known after patenting, then are invited more to submit papers. It has been seen that more prolific and higher cited scientists are also active in patenting, such as 'star scientists'. Further, patenting scientists may gain more government supporting or additional funding from industry to build more effective and better equipped scientific team. Based on same reasons, not surprisingly, patenting could help to highlight publication quality of individual scientists, measured by citation times or the JIF-weighted publications.

Table 6
Pairwise correlations.

Bpnumber	ln(PFU)	ln(PFR)	ln(PJIF)	ln(TC)	ln(PIJ)
Current value	0.1693*	0.1720*	0.1589*	0.1546*	0.1638*
1-Year lag value	0.2231*	0.2203*	0.2076*	0.1290*	0.2267*
2-Year lag value	0.2149*	0.2068*	0.2035*	0.0654*	0.2135*
3-Year lag value	0.2133*	0.2100*	0.2056*	0.0215	0.2066*

* Correspond to a 1% level of statistical significance.

Although a large number of patents generated by university scientists should be assigned to their affiliated university due to China's patent laws and related regulations, we still find the heterogeneity of patent ownership. By distinguishing between patents assigned to company and patents assigned to the scientist himself, our empirical analysis shows that the positive relationship between patenting and publishing indeed does not hold for two types of patents. Especially, patents assigned to company have a significantly negative impact on publication quantity and quality. A possible explanation is that these patents come from joint or contract research, which requires scientists to delay research results and keep confidential on related information. Thus, collaboration with industry could shift the orientation of scientists away from basic research, where they can produce more and higher quality publications. It is worthy noted that both the percentages of two types of patents are very small. Thus, one needs to be cautious about these conclusions.

Additionally, we control two factors appeared in previous studies in driving the rapid growth in publications or improving research impact of China's scientists, namely different supporting levels from government and international co-authorship with the leading countries. We confirm that the key research universities and the State Key Laboratories have played a vital role in scientific research and technology development of China's nanotechnology and international co-authorship does help China's scientists improve their scientific research.

It should be noted that the interaction between patenting and publishing is dual and complex, which deserves the further study. The effects of publishing on patenting cannot be ignored. Further, the issues on the effects of university patenting include not only quantity and quality of publications but also the contents of academic research. The main limitation of our analysis is that we only identified the effects of patenting activity on quantity and quality of scientific research, which is a rather narrow perspective of the interaction. We acknowledge that it is overloading to put these issues into a single article. It is only our first step in this study. To find an ultimate and comprehensive answer, we need more information from investigation.

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Appendix A.

See Table 6.

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