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The life sciences in German–Chinese cooperation: an institutional-level co-publication analysis

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Abstract This paper analyses the scientific cooperation between German and Chinese institutions in the field of the life sciences on the basis of co-publications published between 2007 and 2011 in Web of Science covered sources. After analyzing the global output of publications in the life sciences, and identifying China's most important international partners on country level, this study focuses on a network and cluster analysis of German–Chinese co-publications on an institutional level. Cleaning and standardizing all German and Chinese addresses, a total of 531 German and 700 Chinese institutions were identified that co-published together in the period under analysis. Disaggregating the institutes of Chinese Academy of Sciences made it possible to obtain more meaningful information on existing co-publication structures. Using VOSviewer the German–Chinese collaboration network in the life sciences is visualized and clusters of similar institutions identified. The seven most important clusters of German–Chinese co-publications partners are briefly described providing background information for funding agencies such as the

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German Federal Ministry of Education and Research or researchers in the life sciences, who wish to establish collaborations with German or Chinese institutions.

Keywords Bibliometrics · Co-publication analysis · Life sciences · German–Chinese cooperation · Social network analysis · VOSviewer

Introduction

In the last 30 years, the People's Republic of China has experienced economic growth at a pace unrivalled throughout the world. Economic trends enabled and entailed efforts in research and development (R&D) making China the second greatest producer of peer-reviewed publications after the US today. China is thus distancing itself from its long-standing image as the 'world's workshop' and starting to catch up with the global knowledge society. This involves massive public sector funding of education and R&D, chiefly through the central ministries in Beijing—for example, the Ministry of Science and Technology (MOST) and the Ministry of Education (MOE)—and the major science academies, such as the Chinese Academy of Sciences (CAS) and the National Natural Science Foundation of China (NSFC). Spending on R&D as a share of gross domestic product (GDP) has increased by a disproportionately high amount in recent years and will rise further in coming years, from 1.4 % in 2007 (OECD 2011) to 2.2 % in 2015 (China's Twelfth Five Year Plan 2011), and to 2.5 % in 2020 (The State Council of China 2006). The Chinese higher education system has also received substantial funding: government spending on education reached around 3.1 % of GDP in 2010, and was to climb to 4 % by 2012. Over the past decades China was able to place Chinese scientists in leading universities and scientific institutions all over the world, primarily in the USA, Europe and other regions within the international science system. Through its broad-based "100 talents programme" by the CAS (Suttmeier et al. 2006) and "1,000 talents plan" by the Chinese Government (Wang 2010), China is currently attracting highly qualified scientists working in Western laboratories—mainly in the USA—back to China, in order to build a science system based on the Western model. Such efforts have placed China in an excellent position to take on a leading role in the global scientific community. While Chinese scientists have already attained a world-class level in some scientific disciplines (such as materials sciences and certain fields of chemistry), China is now setting out to move to the forefront of others. One such discipline is the life sciences, in which China is investing enormous financial and personnel resources (Baeder 2011) so that it can become a world leader in this field.

From a German perspective, the People's Republic of China has been the most important partner in scientific collaboration in Asia initiated in the 1970s, when the Agreement on Scientific and Technological Cooperation (WTZ) was signed between the two countries. In 2009/2010 the German–Chinese Year of Science and Education was celebrated. The German Federal Ministry of Education and Research (BMBF) is interested in intensifying scholarly collaboration with China by supporting existing and establishing new cooperations.

Trends of R&D in China have been described from a quantitative perspective by numerous bibliometric studies emphasizing its enormous growth rates in publication output since the 1990s (e.g. Leydesdorff and Zhou 2005; Glänzel et al. 2008; He 2009; Wan et al.

2009; Fu et al. 2011; Haustein et al. 2011). The BMBF has commissioned bibliometric studies such as Haustein et al. (2009), Frietsch and Meng (2010), Kroll (2010), Haustein et al. (2011), Tunger and Haustein (2009) and Scheidt et al. (2011) to analyze and monitor the development of formal collaboration as reflected in co-publications with China and other Asian partners. Following up on Frietsch and Meng (2010) this paper focuses on the life sciences, which as a field shows above-average growth and China is investing enormous financial and personnel resources in. This has led to the identification of China as an important cooperation partner for Germany. Funding programs are specifically aimed at setting up new partnerships.

Reasons for research cooperation may be cognitive, economic and/or social (De Beaver and Rosen 1978; Schubert and Braun 1990; Luukkonen et al. 1992; Glänzel and Schubert 2007), examples include the need for access to information, equipment, influence or visibility in the scientific community. To measure cooperation between scientists, most quantitative studies concentrate on the formal aspect of scientific cooperation that is reflected in the joint publication of scientific articles. Although co-authorship represents just a part of scientific collaboration, it is an adequate indicator of cooperation between two researchers (Glänzel and Schubert 2007). Many bibliometric studies focus on co-authorship analysis to quantify scientific cooperation between countries, institutions, departments and authors.

A series of bibliometric studies have focused on China's publication output and co-publication partners, and identified an exponential increase in publication output by the People's Republic since the 1990s (e.g. Leydesdorff and Zhou 2005; Glänzel et al. 2008). Glänzel et al. (2008) used bibliometric and potentiometric analyses to demonstrate that the former triad of leading nations in science and technology, formed by the USA, Europe and Japan, has been transformed into a tetrad to include China. He (2009) examined China's collaboration with the G7 countries from 1996 to 2005, and Haustein et al. (2011) investigated China's publications, co-publications and citations in a country-level study of the Asia-Pacific research area. Zheng et al. (2012) analyzed China's international collaborations on the basis of journal articles and patents and Zhou et al. (2009) and Zhou and Glänzel (2010) analyzed Chinese publications output on the level of administrative regions. Other studies focused on particular disciplines or subject fields, e.g. Guan and Ma (2007) analyzed nanoscience, Guan and Gao (2008) bioinformatics, Wan et al. (2009) biochemistry and molecular biology and Fu et al. (2012) focused on traditional chinese medicine. Fu et al. (2011) used essential science indicators to investigate Chinese publication output across all natural science disciplines. Like this study, Frietsch and Meng (2010) focused on the life sciences in China.

This case study evaluates the Chinese publication output in the life sciences between 2007 and 2011. It puts an emphasis on China's collaborations with Germany with the aim of investigating the structure of German–Chinese cooperation as reflected in co-authored publications. After an overview of the output in the life sciences on a macro, i.e. country level, the study focuses on German–Chinese co-publications on the institutional level to gain a detailed insight into existing collaboration structures. Extensive cleaning of institutional addresses was undertaken in order to obtain reliable data that is able to identify key players and important sites in China and Germany. Unlike previous studies (e.g. Frietsch and Meng 2010; Guan and Ma 2007; Fu et al. 2012) the institutes of the Chinese Academy of Sciences (CAS) were disaggregated to obtain more meaningful information on co-publication relationships. VOSviewer mapping and clustering software was used to depict the landscape of German and Chinese institutions co-publishing in life sciences research.

Methods

Database

This analysis of scientific output is based on documents covered by the Web of Science (WoS) and published during the five-year period 2007–2011. The life sciences were defined through the selection of 97 relevant WoS subject categories (see Appendix), The dataset was created in March 2012 and limited to documents classified either as articles, proceedings papers or reviews.

Co-publication relationships were extracted from the addresses of the authors. Co-publications between two countries are defined as publications involving at least one institution from each country (Schubert and Braun 1990; Luukkonen et al. 1992; Glänzel and Schubert 2007). Applying integer counting, each co-publication is counted as one publication for each country involved. The institutional level analysis is based on the subset of the life sciences output co-published by institutions in China and Germany defined as containing at least one German and one Chinese address.

Cleaning of addresses

Cleaning of the institutional addresses involved intensive searches on the web, investigating the structures of institutions. Data was aggregated on the top-level domain of an institution, such as a university, research center or enterprise, collecting all synonyms and address variants of departments, schools and units. Institutions that were part of a society or umbrella organization such as Max Planck Society (MPG), Helmholtz Association of German Research Centers (HGF) or CAS were identified and tagged as such but treated as independent institutions in the co-publication and network analysis. In contrast to previous studies (e.g. Frietsch and Meng 2010; Guan and Ma 2007; Fu et al. 2012), this made it possible to obtain more meaningful information in terms of collaboration structures and identify important sites, such as the various institutes of CAS. In their analysis based on the Essential Science Indicators database, Fu et al. (2011) drew attention to the distortions caused if aggregating institutional addresses on society level in particular for CAS.

Network and cluster analysis

Network and cluster analysis was carried out using VOSviewer software. Due to the reciprocal relationship of co-publications a symmetric square matrix was computed, containing the absolute co-publication strength between the German and Chinese institutions. In order to exclude weak connections, the matrix was reduced, keeping only those connections with at least five co-publications in the period under investigation. This ensures that only the essential actors and connections are contained in the network. As the number of co-publications of two institutions depends on their overall publication output, a relative value should be used to assess their respective similarities. This is particularly essential for clustering—i.e. grouping documents together based on their similarities. Several similarity measures can be used for normalization. VOSviewer has an implemented method known as association strength. For the advantages of this similarity measure especially for bibliometric network and cluster analyses, see van Eck and Waltman (2007, 2010). On the basis of the association strength measure and a freely selectable parameter, which affects the number of the different clusters, each institution was assigned to a cluster.

Results

International output in life sciences research

During the five-year period between 2007 and 2011, over 3.35 million documents were published in the life sciences as defined above. Annual publication output increased steadily resulting in an above average growth rate of the field; while the overall publication growth rate in WoS from 2007 to 2011 was 5.4 %, the output in the life sciences increased by 17.2 % in the same period. While there were 610,475 publications in categories related to the life sciences in 2007, this number had risen to 715,767 by 2011. Figure 1 shows the number of publications per year for the ten countries with the highest publication output in the life sciences at the end of the period under analysis. The USA clearly leads the field in life sciences research (note that the US publications are on secondary axis). With more than 200,000 documents published annually, US authors were involved in almost one-third (31.7 %) of global output in this field in 2011. This is followed by British authors, who contributed 8.7 %, and German researchers, who accounted for 7.3 % of worldwide output in 2011. It is striking to note China's growth rate of 86.7 %. China's output increased from 33,379 in 2007 to 62,307 in 2011, with the result that China has overtaken Japan, Germany and the UK and is now the world's second-largest player in the life sciences.

Over the period of the 5 years analyzed, the strongest countries in life sciences research were the US (32.3 %), the UK (8.1 %), Germany (7.3 %), China (7.2 %) and Japan (5.9 %). Other countries contributing a significant number of publications include Canada (5.0 %), France (4.7 %), Italy (4.5 %), Australia (3.9 %) and Spain (3.8 %).

China's co-publication partners on a country level

China's most important international partner in life sciences research is the USA. 13.3 % of the Chinese publications analyzed had at least one co-author in the USA. This figure is considerably higher than those for other international partners: only 2.8 % of publications involved Japanese partners, 2.4 % had British and 2.1 % Canadian co-authors. At 1.7 %, Germany ranks below Australia (1.9 %) as China's sixth most frequent cooperation partner in terms of absolute output. The strong relationship of Chinese and US researchers can be explained by the leading positions of the two countries in the life sciences in general, but is moreover systematically stimulated by particular collaboration programs. Chinese scientists make up the largest group of visiting doctorates in American laboratories (Finn 2007), and the USA is the most popular destination for Chinese studying abroad. The 100 talents program of CAS (Suttmeier et al. 2006) or the central government's 1,000 talents recruitment program (Wang 2010) target Chinese scientists who have gained top academic qualifications at international—mainly US—institutions to attract them back to China. These connections are reflected in strong co-publication relationships as shown in Fig. 2. Zhou and Glänzel (2010) confirm the strong and increasing bond between China and the US in the sciences overall. While in 1997 29.1 % of Chinese publications in SCI were co-authored by at least one US author, the collaboration had risen to 39.4 % by 2007. The same study showed that Germany ranked fourth on the list of China's most important co-publication partners in 2007, demonstrating that collaboration between Germany and

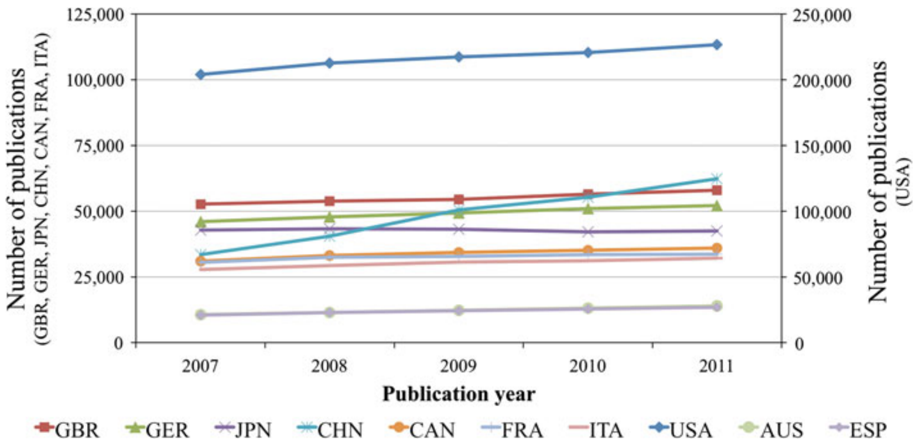

Fig. 1 Number of annual publications in the life sciences per country for the top 10 countries in 2011 (USA, GBR, JPN, CHN, CAN, FRA, ITA, AUS, ESP)

China is weaker in the life sciences (sixth position, compare Fig. 2) than it is in the natural sciences overall. He (2009) also attests to this situation, showing that German–Chinese collaboration is particularly strong in physics and chemistry, but very weak in the fields of biomedical research, neurosciences, and clinical and experimental medicine.

Percentages of international co-publications do, however, depend on the total output of the respective collaborator. Hence, the larger a country is in terms of the number of documents published, the more it is able to co-publish with China. To account for the total publication strength of both collaborators, Salton's measure (Salton and McGill 1986; Glänzel and Schubert 2007), i.e. international collaboration strength, is applied. Co-publication can be measured irrespective of size and thus independently of the total publication output of a country. As shown in Fig. 3, Salton's measure confirms the exceptional strength of collaboration in the life sciences between China and the US and, since the number of co-publications is normalized by the overall output of the countries, it proves that US–Chinese collaboration increased much more substantially than their annual growth in national publication output. With the exception of Japan, where the collaboration strength even slightly decreased at times, overall, the collaboration with the other leading cooperation partners increased as well during the five-year period analysed. This confirms the general trend towards increasing internationalization in the natural sciences (De Beaver and Rosen 1978; Luukkonen et al. 1992; Katz et al. 1996; Wagner et al. 2001), in spite of the fact that the percentage of international cooperations decreased proportionately for several years because the increase in total Chinese output was so vast (Zheng et al. 2012).[1]

With an average value of 0.063, the collaboration strength between China and the USA in the life sciences is substantially higher than it was at the time of He's (2009) study, which investigated China's international co-publications with the G7 countries in several

[1] A survey of Chinese publication data in Web of Science (SCI, SSCI, A&HCI, CPCI-S, document types: article, proceedings paper, review) in the period from 2000 to 2010 showed that the proportion of international co-publications in overall Chinese output decreased each year from 2000 (19.7 %) to 2009 (14.9 %), and only rose again to 18.8 % in 2010. As a comparison, in 2010 the proportion of international co-publications was 45.5 % in Germany and 28.7 % in the USA.

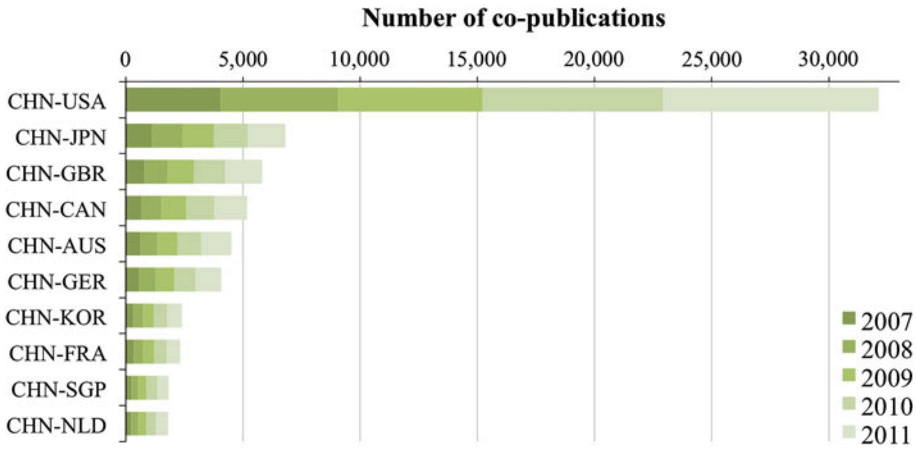

Fig. 2 Absolute number of China's international co-publications with its ten leading international cooperation partners

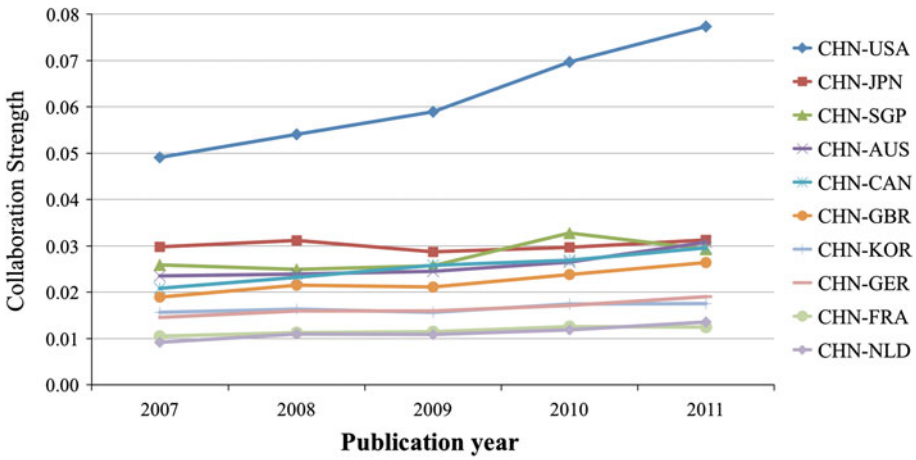

Fig. 3 Annual collaboration strength values between China and its ten leading cooperation partners in 2011

scientific disciplines from 1996 to 2005. In contrast, the collaboration values between China and other G7 countries such as Japan, Germany, France and Italy are remarkably similar in both the present paper and He's (2009) study (see Table 1). This comparison demonstrates that China's cooperation with the USA in the life sciences is particularly exceptional. Moreover, Salton's measure identifies the importance (in terms of output) of smaller partners such as Singapore and South Korea, which can be seen as regional collaborators. In 2011, Germany ranked only as China's eighth strongest partner in the life sciences. This information led the German Federal Ministry of Education and Research (BMBF) to investigate the existing co-operations as measured in co-publications in depth, namely on the level of institutions.

Table 1 Comparison of collaboration strength values between China and the G7 countries, based on He (2009, p. 577) and the present study

Collaboration strength China and G7 countries Disciplines Publication period	He (2009) Natural Sciences (SCI-E) 1996–2005	This study Life Sciences (97 WoS categories) 2007–2011
CHN–USA	0.034	0.063
CHN–JAP	0.029	0.028
CHN–GER	0.018	0.017
CHN–CAN	0.017	0.026
CHN–GBR[a]	0.016	0.023
CHN–FRA	0.011	0.012
CHN–ITA	0.007	0.006

[a] The findings in He (2009) do not relate to the United Kingdom, but to co-publications with England only

Table 2 China's ten most important co-publication partners in Germany together with the corresponding number of Chinese co-publications (P_{CHN}), and Germany's ten most important co-publication partners in China together with the corresponding number of German co-publications (P_{GER}) in the life sciences from 2007 to 2011

China's German partners	P_{CHN}	Germany's Chinese partners	P_{GER}
Univ Heidelberg	283	Peking Univ	300
LMU Muenchen	170	Zhejiang Univ Hangzhou	206
Charite Berlin	162	Huazhong Univ Sci Technol Wuhan	175
Univ Mainz	162	Chinese Univ Hong Kong	157
Tech Univ Muenchen	137	Capital Med Univ Beijing	142
Univ Kiel	119	Univ Hong Kong	141
Univ Duesseldorf	113	CAS-Graduate Univ Beijing	133
Univ Duisburg Essen	113	China Agr Univ Beijing	117
Univ Goettingen	108	Shanghai Jiao Tong Univ	116
Univ Hamburg	108	CAMS-Peking Union Med Coll	115

German–Chinese co-publications on an institutional level

Analyzing co-publications on the meso level, i.e. between institutions, makes it possible to investigate cooperation in depth and derive meaningful information on formal collaboration structures. As this study focuses on the bilateral relationships between Germany and China, the following part of the analysis is based on the 4,009 articles, proceedings papers and reviews co-published in the life sciences between 2007 and 2011 by authors from Germany and China. The journals in which these publications appear are assigned to a total of 161 different WoS categories. The categories with the most publications are "Biochemistry & Molecular Biology" (451 publications), "Plant Sciences" (350), "Environmental Sciences" (314), "Genetics & Heredity" (208) and "Meteorology & Atmospheric Sciences" (201).

The data cleaning of all German and Chinese addresses resulted in the identification of 700 Chinese and 531 German institutions, which had co-published at least once with each other during the period under analysis. The disaggregation of the CAS institutes identified 98 separate CAS sites active in the field of life sciences and co-publishing with at least one institution in Germany. Table 2 lists the ten German and Chinese institutions whose authors co-published most often with Chinese and German colleges, respectively. In Germany, *Heidelberg University* (283 co-publications with Chinese institutions), *Ludwig Maximilians University Munich* (170), *Charité Universitätsmedizin Berlin* (162) and *Johannes Gutenberg University Mainz* (162) are the institutions that published most frequently with a Chinese partner in the life sciences. In China, the most important partners from a German perspective are *Peking University* (300 co-publications with German institutions), *Zhejiang University* in Hangzhou (206) and *Huazhong University of Science & Technology* in Wuhan (175). Publications and co-publications are counted once for each institution involved, with the result that the sum of the publications is higher than 100 %.

A total of 3,824 German–Chinese cooperation pairs were identified on the institutional level. However, 2,582 (67.5 %) of these published only one joint publication within the five-year period under analysis. The number of pairs that produced more than five co-publications came to 294, or 7.7 %, and only 19 (0.5 %) collaborations published together at least 20 times. The strongest German–Chinese cooperation pairs are *Heidelberg University*/*Capital Medical University* in Beijing (82 co-publications), *Heinrich Heine University Düsseldorf*/*Peking University* (44), the *Leibniz Institute for Tropospheric Research* (WGL-Troposphaerenforsch) in Leipzig/*Peking University* (44), the *University of Hohenheim*/*China Agricultural University* in Beijing (41), and *Johannes Gutenberg University Mainz*/the *National Research Center for Geoanalysis* (38) (Table 3).

Mapping and clustering the co-publication landscape

When analyzing data containing relationships between multiple actors, network representations are particularly helpful. They allow structures to be mapped and complex relationships to be visualized. Cluster analysis helps to identify similar actors and group them together. In the present analysis, it is assumed that a network based on joint publications will reflect the landscape of German–Chinese cooperation in the life sciences. The structures will be helpful for policy makers to monitor existing collaborations and for actors in life sciences research to identify potential future cooperation partners in both Germany and China.

As described in the "Methods" section, the network was reduced to keep only those relations of significant strength. The final matrix consists of 200 nodes or, in other words, German and Chinese institutions. The network computed on the basis of this matrix is shown in Fig. 4. The nodes stand for the 200 German and Chinese co-publishing institutions and the edges represent the normalized co-publication strength between the nodes. A total of 26 clusters were identified. However, the number of institutions per cluster behaves in a manner typical of informetric studies: the largest cluster comprises 70 institutions, and thereafter the number of nodes decreases sharply. Eleven clusters comprise only two partners, neither of which is connected to any of the other actors, thus they are only peripheral to the life sciences co-publication network. It is important to note that as cluster size increases, thematic focus becomes less defined and the number of German and Chinese partners involved can vary considerably. Cluster affiliation is integrated in the network graph in Fig. 4 through color-coding. The seven largest clusters are labelled and will be analyzed and interpreted in the following. As the *CAS-MPG Partner Institute for*

Table 3 The 15 strongest German–Chinese co-publication partners together with the corresponding number of co-publications (*P*) in the life sciences from 2007 to 2011

German institution	Chinese institution	*P*
Univ Heidelberg	Capital Med Univ Beijing	82
Univ Duesseldorf	Peking Univ	44
WGL-Troposphaerenforsch	Peking Univ	44
Univ Hohenheim	China Agr Univ Beijing	41
Univ Mainz	CAGS-Natl Res Ctr Geoanal Beijing	38
Univ Duisburg Essen	Huazhong Univ Sci Technol Wuhan	34
Univ Medical Center Schleswig-Holstein	Zhejiang Univ Hangzhou	30
Univ Kiel	Zhejiang Univ Hangzhou	28
WGL-Slg Mikroorg u Zellkulturen	Yunnan Univ Kunming	27
Univ Heidelberg	Huazhong Univ Sci Technol Wuhan	25
HGF-KIT	CAS-Inst Atmospher Phys Beijing	24
MPI-Evol Anthropol	CAS-SIBS-MPG Partner Inst Computat Biol Shanghai	23
LMU	Peking Univ	23
Univ Heidelberg	Chinese Univ Hong Kong	22
Charite	Huazhong Univ Sci Technol Wuhan	22

Computational Biology (PICB)[2] was jointly established as a partner institute of MPG (Max Planck Society) and CAS, the two main science organizations in Germany and China, it enjoys something of a special status in a study of German–Chinese cooperation. As a result, Cluster 4 and PICB are analyzed in greater detail taking into account all of PICB's international co-publication partners.

In order to complement the quantitative network and cluster analysis, funding data has been taken into account. All German–Chinese projects in the life sciences funded since 2007 by BMBF or key German science and intermediary organizations such as the German Research Foundation (DFG), MPG, HGF, Leibniz Association (WGL), Fraunhofer Society (FhG) and German Academic Exchange Service (DAAD) were considered. All in all, 167 German–Chinese projects were evaluated (Sino-German Life Science Platform 2012). Table 4 provides an overview of the subject areas in the life sciences receiving public funding.

The top research location for German–Chinese cooperation projects is Berlin with its various universities and institutions (21 projects), followed by Jena (13 projects, the most notable partner being the *Leibniz Institute for Age Research—Franz Lipmann Institute*), Munich (LMU, TU and the *German Research Center for Environmental Health*, with 9 projects in total) and Heidelberg (8 projects with *Heidelberg University* and the *German Cancer Research Center*, DKFZ). The participation of German actors in bilateral projects reflects the high degree of geographical specificity in the German research scene—in other words, a large number of institutions are involved, including some 39 universities. In contrast, Chinese projects are predominantly concentrated in Beijing—56 German projects have ties with at least one institution in Beijing—and, to a lesser extent, Shanghai

[2] In keeping with the address abbreviations used within this analysis, PICB will be referred to as "CAS-SIBS-MPG Partner Inst Computat Biol Shanghai" in all tables and figures.

Fig. 4 Co-publication network (VOSviewer) showing the seven largest clusters. Each cluster indicates the institutes with the most publications within the network

Table 4 Most common subject areas in publicly funded German–Chinese cooperation projects in the life sciences (a total of 167 projects funded by science and intermediary organizations since 2007 were evaluated; it was possible to assign projects to multiple categories)

Subject area	Number of projects
Medicine—clinical	49
Medicine—basic research	41
Biology—food and agricultural sciences	28
Biology—basic research	23
Biology—application-oriented and biotechnology	13
Medicine—pharmaceutical	6
Traditional Chinese medicine (TCM)	6
Medicine—medical engineering	2

(20 projects). Potential Chinese partners are to be found both in universities and, in particular, in CAS institutes.

The following sections will provide a detailed description of the results of the network and cluster analysis (Fig. 4). The seven largest clusters will be compared in detail with publicly funded cooperation projects, followed by an in-depth analysis of Cluster 4 and the results of a more detailed analysis of all of the international co-publication partners of the PICB. A cross-comparison of the two data sets—i.e. state-funded projects versus co-publications—allows certain conclusions to be drawn, such as whether the key areas in bilateral cooperation identified in the publication analysis correspond to German–Chinese projects.

Cluster 1

Cluster 1, with 70 German and Chinese institutions, is the network with by far the largest number of partners of all the clusters. German actors with the most publications in Cluster 1 are *Heidelberg University*, *LMU Munich* and *Charité* in Berlin. On the Chinese side, the key players are *Peking University*, *Huazhong University* in Wuhan and *Zhejiang University* in Hangzhou.

The most striking feature of this cluster, besides its size, is its heterogeneity. The 2,607 publications by the 70 institutions are assigned to a total of 148 different WoS categories. With 11.1 % of the publications, the category "Biochemistry & Molecular Biology" is the best represented, followed by "Plant Sciences" (9.5 %) and "Environmental Sciences" (5.9 %). Publications in the field of medicine—both clinical and basic research—are strongly represented in the categories of "Pharmacology & Pharmacy" (5.6 %), "Cell Biology" (5.3 %), "Neurosciences" (5.3 %) and "Oncology" (5.2 %). Further investigation revealed that the publications in the "Plant Sciences" category were also closely related to medicine. It is worth noting that around a third of the co-publications with Chinese researchers originated from Prof. Peter Proksch's research group at the Institute of Pharmaceutical Biology and Biotechnology at *Heinrich Heine University Düsseldorf.* Another reason for the cluster's heterogeneity is that large multidisciplinary universities such as *Peking University*, *Heidelberg University*, *Zhejiang University*, *LMU Munich* and *Heinrich Heine University Düsseldorf* are involved in collaboration activities in several fields, rather than being restricted to a single subject area.

Figure 5 shows a detailed view of the cluster. Three of the German research locations in Cluster 1—Berlin, Munich and Heidelberg—are also among the most important research locations for publicly funded projects. Moreover, both independent and publicly funded cooperation projects in these three locations focus on the field of medicine. Unlike Cluster 1, Clusters 2–7 each comprise only around a dozen participants in Germany and China, and concentrate on a narrower range of subject areas than those in Cluster 1.

Cluster 2

The sixteen institutions in Cluster 2 conduct research on interdisciplinary subject areas, from physics and chemistry to the life sciences. One of the key players here is *Mainz University*, which also receives public funding for interdisciplinary projects in the life sciences. The research group headed by Prof. Werner E. G. Müller at the Institute of Physiological Chemistry at *Mainz University* is involved in about a quarter of all publications between Mainz and Chinese institutions, working especially often with Prof. Xiaohong Wang from the *National Research Center for Geoanalysis* in Beijing. Prof. Müller was awarded the Chinese Friendship Award in 2011 for his contribution to German–Chinese cooperation.[3]

[3] Press release from Mainz University, 30 September 2011. http://www.uni-mainz.de/presse/48426.php. Accessed 10 October 2012.

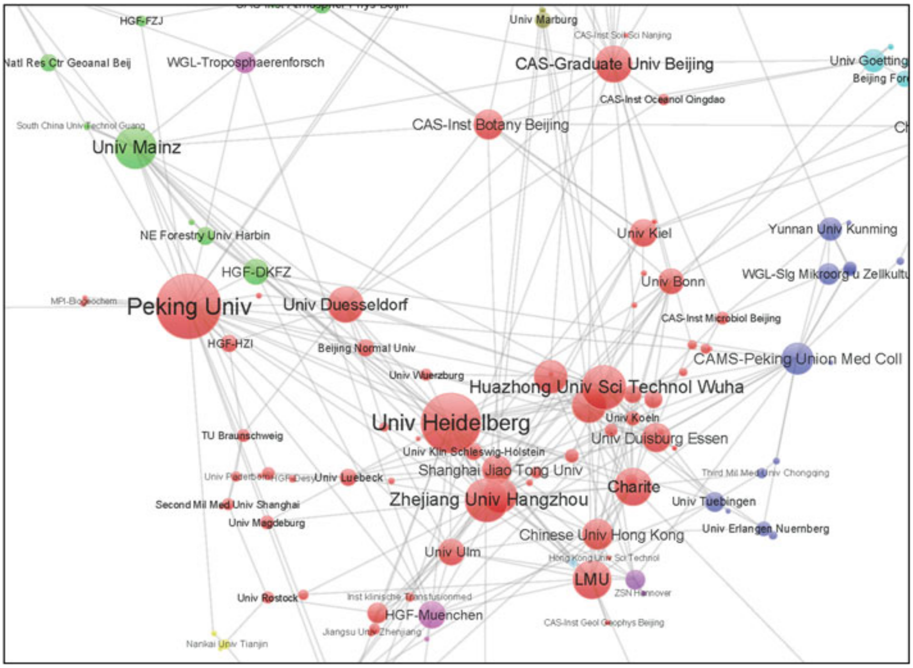

Fig. 5 Detailed view of Cluster 1 (*red*), Cluster 2 (*green*) and Cluster 3 (*blue*)

Cluster 3

Cluster 3 deals with basic scientific and medical issues that extend to various disciplines. This leads to a certain degree of heterogeneity among the institutions involved, which range from the *Leibniz Institute DSMZ—German Collection of Microorganisms and Cell Cultures* (WGL-Slg Mikroorg u Zellkulturen) to the *German Heart Institute Berlin*. Key Chinese actors include *Peking Union Medical College* and *Yunnan University* in Kunming. Figure 5 depicts a relatively large distance between the individual research locations in this cluster, a distance that is mirrored in the cluster's thematic disparity. *Peking Union Medical College*, which is affiliated to the *Chinese Academy of Medical Sciences* (CAMS), is the pivotal institution in the cluster, acting as a link between medicine (e.g. *University of Tübingen*) and microbiology (*DSMZ*).

Cluster 5

Bilateral projects from the geosciences and atmospheric sciences are well represented in Cluster 5 by both university and non-university institutions. The WoS categories "Meteorology & Atmospheric Sciences" (26.1 %) and "Environmental Sciences" (23.9 %) are indisputably the most frequently represented. The German institutions contained in the cluster include *Helmholtz-Zentrum Geesthacht* and the *Leibniz Institute for Tropospheric Research* (WGL-Troposphaerenforsch). The latter acts as a link to Clusters 1 and 2 due to its strong connections with *Peking University* and the *Max Planck Institute for Chemistry* and its resulting position in the network. On the Chinese side, institutions such as the *Institute of Tibetan Plateau Research, CAS* and the *China Meteorological Administration* in Beijing play a prominent role in Cluster 5. Hence the subject areas in Cluster 5 border on the field of the life sciences.

Cluster 6

Cluster 6 represents agricultural sciences and its related fields—a key element of German–Chinese cooperation, and one that is also strongly supported by public funding. In total, Cluster 6 contains twelve institutions, five of which are German and seven Chinese. In Germany, the *University of Hohenheim* and the *University of Göttingen* as well as the *Leibniz Institute of Vegetable and Ornamental Crops* are important players. Active institutions on the Chinese side include *China Agricultural University* (CAU) in Beijing and *Beijing Forestry University*. The WoS categories reflect the focus on agricultural sciences: "Plant Sciences" (26.4 %), "Agronomy" (14.0 %), "Environmental Sciences" (12.5 %), "Ecology" (11.9 %) and "Biochemistry & Molecular Biology" (10.6 %) are the most frequent categories among the 329 publications by the twelve institutions in Cluster 6. The CAU is also a significant Chinese partner university in publicly funded German–Chinese projects. Thus Cluster 6 is a good example of the direct relation between public funding of projects and intensive co-publication activity.

Cluster 7

Cluster 7 focuses on a classic core area of the life sciences—zoology. One of the central research topics concerns evolutionary questions, which are answered using different methodological instruments, such as DNA and molecular biology analysis or neurosciences. Cluster 7 consists of twelve institutions, in Germany these include the *Universität Hamburg* and *Jena University* as well as non-university institutions such as the *Senckenberg Collections of Natural History Dresden* or the *Leibniz Institute for Zoo and Wildlife Research* (IZW). In China, the principal actors involved in bilateral cooperation in this subject area are the *Institutes of Zoology* (CAS) in Beijing and Kunming.

Detailed analysis of Cluster 4

The final part of the analysis focuses on Cluster 4, which is largely dominated by PICB. The German partners that participate most often in co-publications with Chinese institutions are *Universität Leipzig* and three Max Planck Institutes (MPIs): *MPI for Evolutionary Anthropology* and *MPI for Mathematics in the Sciences* in Leipzig, and *MPI for Molecular Genetics* in Berlin. There are several co-publication partners in China, for example the *Shanghai Institute of Biochemistry and Cell Biology* (SIBCB), PICB and a number of other CAS institutes. As PICB was jointly established as a partner institute of MPG (Max Planck Society) and CAS, the two main natural science organizations in Germany and China, it enjoys something of a special status in a study of German–Chinese cooperation. As a result, in the following a detailed analysis will take account of co-publications beyond those with German institutions.

The WoS categories confirm the thematic focus on biology and mathematical applications of Cluster 4: "Biochemistry & Molecular Biology" (19.0 %), "Genetics & Heredity" (13.4 %), "Biochemical Research Methods" (12.6 %), "Biotechnology & Applied Microbiology" (12.6 %), "Cell Biology" (9.5 %) and "Mathematical & Computational Biology"

(9.5 %) are the categories in which the thirteen institutions in Cluster 4 publish most frequently.

PICB was established by CAS and MPG as a joint institute in 2005, and since then has been funded by CAS, MPG and BMBF. Work at the institute spans the areas of biology, theory and modelling, and focuses in particular on complex processes in molecular networks and cell systems. PICB is regarded as an outstanding major international institution, making important contributions to the global scientific community. The institute has a scientific staff of 150, who come from countries such as the USA, the UK and Russia, as well as China and Germany. While PICB plays a key role in international cooperation between leading international institutions and the People's Republic of China, it also acts as a bridge for German–Chinese cooperation in the life sciences in particular. We will now investigate the position of PICB both in China and in an international context on the basis of its publication profile. This will also determine whether PICB's overall publication profile supports its ascribed role as outlined above.

Unlike the data basis for the network and cluster analysis, which was limited to German–Chinese co-publications, the following analysis relates to all publications by PICB in the life sciences in the period from 2007 to 2011. A country-level analysis of these 210 documents reveals that Germany, with 65 co-publications (31.0 %), is the strongest international partner. The majority (57.6 %) of all PICB publications have at least one other Chinese partner, and thus priority is given to national cooperation partners. The USA (28.1 %) and the UK (15.7 %) are the next most important international cooperation partners, while other European countries such as Austria (AUT, 5.2 %), Sweden (SWE, 4.3 %) and France (3.3 %) trail somewhat behind.

Of the 205 institutions with which PICB collaborates, 62 are Chinese. The four institutions with which PICB co-publishes most frequently—*Fudan University*, *Shanghai University*, *Shanghai Jiao Tong University* and *Key Laboratory of Systems Biology*—are all located in Shanghai (see Fig. 6). The absence of these close relationships in the network and cluster analysis shows that no German institutions are involved in these collaborations. Of PICB's 47 publications with *Fudan University*, only two also have a German co-author. As this number does not meet the defined threshold (see methodology section above), there is no connection between these two institutions in the network representation. After the Chinese institutions, important partners include some Max Planck Institutes and *Universität Leipzig* (cf. the section on Cluster 4). PICB co-publishes with 31 different institutions in Germany overall. It also cooperates closely with the *University of Manchester* (UK) and the *University of Vienna* (Austria). Although the USA is the second most important international partner after Germany, this cooperation is not concentrated in one location, but divided between 44 different US institutions. Of these, the *Santa Fe Institute* co-publishes most frequently with PICB.

In conclusion, it can be said that the role of PICB extends far beyond its function as a German–Chinese institute, PICB and the cluster it represents constitute an international centre for cooperation with the USA, the UK, Austria and other international actors. In Germany, the PICB not only benefits several Max Planck Institutes, but also universities and other scientific institutions. Thus PICB not only plays a role in the Max Planck network worldwide, but is also instrumental for the entire German science system with respect to cooperation with China. From a Chinese perspective, PICB is likely to play a major role in efforts to catch up with the global scientific community in the field of the life sciences and, in the process, allow China to benefit from German expertise in bioinformatics.

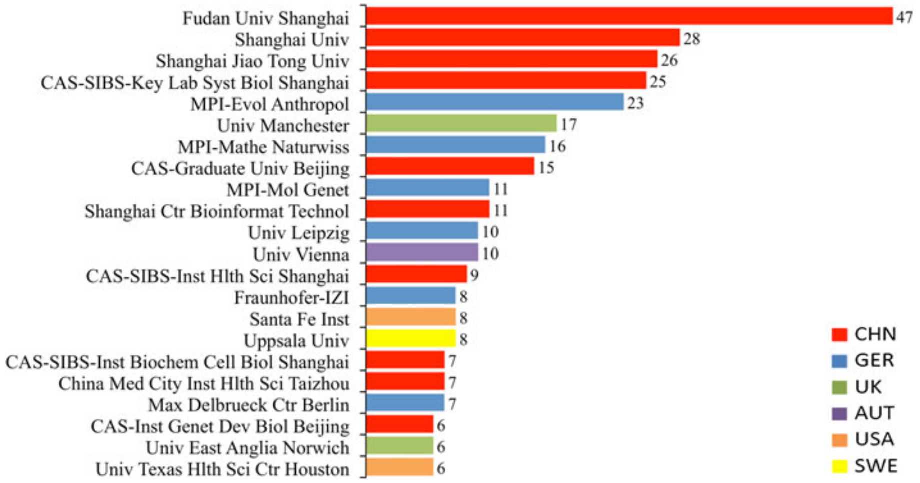

Fig. 6 The most important co-publication partners of PICB, out of a total of 205. All institutions that co-published with PICB more than five times from 2007 to 2011 are shown here. The *different colours* indicate the location of the institution

Conclusions and outlook

China is playing an ever-increasing role in science, and the life sciences are no exception. The publication and co-publication analysis on country level has shown that China is an important cooperation partner in the life sciences for numerous countries, and that cooperation with China is gaining in significance. Particularly remarkable is China's cooperation with the USA, which is consolidating its leading position in this regard. Germany is in danger of falling behind in the global competition for the top Chinese institutional cooperation partners. From a German funding perspective it is important to intensify existing contacts and establish new ones. The present study identified existing partnerships between German and Chinese institutions in the life sciences and investigated the structural conditions for German–Chinese cooperation in this field.

From the comparison of the cluster and network analysis with the analysis of the role played by PICB in Cluster 4, it can be concluded that there are two basic models for Germany's cooperation with the People's Republic of China: on the one hand, cooperation in an independently organized network, and on the other hand, cooperation within the set institutional framework of a joint German–Chinese partner institute. Each organizational structure has its advantages and disadvantages.

PICB is a globally respected institute with strong international connections that is capable of attracting outstanding scientists, predominantly from China, but also from the USA, the UK and Russia. This strong domestic and international orientation may be to the detriment of the German connection, as German–Chinese co-publications account for less than a third of the institute's publication output. The majority of the institute's co-publications are with Chinese partners and do not involve Germany at all. Plans for the establishment of the institute were governed by structural considerations. Although setting up the kind of sustainable structures as they exist in the partner institute requires lengthy preparation and relatively high start-up costs on the part of the funding bodies, it also ensures a high acceptance rate in the host country and a better chance of maintaining those structures on a long-term basis. A substantial benefit to Germany could be to secure top Chinese scientists for positions in Germany. In addition, PICB could potentially open the door to other CAS institutes and universities in China. Thus PICB addresses important aspects of German foreign science policy.

It appears that German–Chinese cooperation in certain subject areas, as identified in the cluster analysis, has organized itself in a bottom-up process. Public authorities can provide support through appropriate funding programmes, for example mobility schemes or doctoral and postdoctoral programmes, but primarily these networks are driven by the initiative of individual scientists who are actively involved in German–Chinese cooperation in particular fields.

It remains to be seen whether policy-makers will decide to strike a balance between funding large, visible (partner) institutes and funding smaller, more bilateral scientific projects.

Appendix

Web of Science Categories identified as relevant to the life sciences

Agricultural Engineering; Agriculture, Dairy Animal Science; Agriculture, Multidisciplinary; Agronomy; Allergy; Anatomy & Morphology; Andrology; Anesthesiology; Anthropology; Behavioral Sciences; Biochemical Research Methods; Biochemistry & Molecular Biology; Biodiversity & Conservation; Biology; Biophysics; Biotechnology & Applied Microbiology; Cardiac & Cardiovascular Systems; Cell Biology; Cell Tissue Engineering; Chemistry, Medicinal; Chemistry, Organic; Clinical Neurology; Critical Care Medicine; Dentistry & Oral Surgery Medicine; Dermatology; Developmental Biology; Ecology; Emergency Medicine; Endocrinology & Metabolism; Engineering, Biomedical; Engineering, Environmental; Entomology; Environmental Sciences; Environmental Studies; Ethics; Evolutionary Biology; Fisheries; Food Science & Technology; Forestry; Gastroenterology & Hepatology; Genetics & Heredity; Geriatrics & Gerontology; Gerontology; Health Care Sciences & Services; Health & Policy Services; Hematology; Horticulture; Immunology; Infectious Diseases; Integrative & Complementary Medicine; Limnology; Materials Science, Biomaterials; Medicine, General & Internal; Medicine, Research & Experimental; Meteorology & Atmospheric Sciences; Microbiology; Mycology; Neuroimaging; Neurosciences; Nursing; Nutrition & Dietetics; Obstetrics & Gynecology; Oncology; Ophthalmology; Ornithology; Orthopedics; Otorhinolaryngology; Parasitology; Pathology; Pediatrics; Peripheral Vascular Disease; Pharmacology & Pharmacy; Physiology; Plant Sciences; Psychiatry; Psychology; Psychology, Applied; Psychology, Biological; Psychology, Clinical; Psychology, Developmental; Psychology, Experimental; Public, Environmental & Occupational Health; Radiology, Nuclear Medicine & Medical Imaging; Rehabilitation; Reproductive Biology; Respiratory System; Rheumatology; Social Sciences, Biomedical; Substance abuse; Surgery; Toxicology; Transplantation; Tropical Medicine; Urology & Nephrology; Veterinary Sciences; Virology; Zoology.

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