Funded collaboration research in mathematics in China

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Abstract Based on publications in mathematics of Chinese authors indexed in Chinese domestic and international databases, namely, the CNKI and the Web of Science, the current paper tries to explore impact of collaboration and funding support on academic productivity. Collaboration is classified into domestic and international collaboration, and domestic collaboration is further divided into within-institutional collaboration and cross-institutional collaboration. Regional performance in terms of collaboration and funding support has also been investigated. The results show that collaboration and funded support are highly skewed among Chinese regions. Beijing, Jiangsu, Shanghai, and Zhejiang are most active in collaboration and are the major winners of research funds. Zhejiang and Shaanxi perform in a contrast way: the former publishes mostly internationally whereas the latter mainly domestically. Compared with within-institutional collaboration, cross-institutional and international collaboration perform better in raising productivity and achieving research funds.

Keywords Domestic collaboration · International collaboration · Within-institutional collaboration · Cross-institutional collaboration · Funded collaboration

Introduction

An important objective of research funding is to support scientific exploration that may promote science progress and/or meet government strategic needs. Funded projects are usually winners of peer evaluation, and usually, are more competitive than those failed.

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Great variations exist among funded research projects: In addition to research objectives, (number of) funding resources and funding budget also vary significantly. In the situation that collaboration plays increasingly important roles in scientific research, collaboration in funded projects are also important and may even be a precondition to win funding support. For example, to apply for a project in the category of general program of the National Natural Science Foundation of China (NSFC), a principle investigator must be capable of leading a team to conduct innovative research,[1] whereas collaboration is essence of a research team.

Scientific collaboration brings researchers with the same interests together. It may increase productivity, make up individual researcher's deficiency (cf., NSB 2010; The Royal Society 2011), as well as raise academic impact (e.g., Narin et al. 1990; Katz and Hicks 1997; Aksnes 2003; Zhou and Glänzel 2010; Persson 2010) although such impact-raising effect may vary greatly depending on various factors such as research topics, collaboration partners, disciplinary variations, and even number of participants (Glänzel 2001; Glänzel and Schubert 2001; Van Raan 1998; Tijssen et al. 2002; Persson 2010). The ways of collaboration vary significantly: It can be national or international, institutional or cross-institutional, disciplinary or cross-disciplinary, and so on (Benavent-Pérez et al. 2012). International collaboration is a common research topic in bibliometric community and can be traced back for tens of years. For example, Beaver and Rosen found that professional orientation, productivity and visibility improvement were the main reasons of international collaboration (1978, 1979). Based on journal publications indexed in the SCI, Schubert and Braun (1990) first analyzed international collaboration in science between 1981 to 1985. (Glänzel 2001) generalized four basic types in the relative specialization of domestic and internationally co-authored publications of the 50 most active countries in 1995/96 concerning the significance of the difference between the two profiles, and found structural changes in international co-authorship links from 1985/86 to 1995/96. Persson (2010) proved that internationally co-authored publications took the highest ratio in high impact publications. Nonetheless, it is not always true that all international collaboration may raise impact. For example, Zhou et al. (2013) found that in contrast to the USA, Canada, Australia, the UK and Germany that increased China's impact in food and agriculture, Japan even lowered China's impact. Guerrero Bote et al. (2013) proved that a country with the highest impact provides proportionally more benefit to its collaborators than the benefit they obtained from such a collaboration relation.

Collaboration relations between countries are highly skewed (e.g., Schubert and Braun 1990; Glänzel 2001; Glänzel and Schubert 2005), which means that collaboration preference exists in selecting partners. Geopolitical location, cultural relations and languages play critical roles in establishing collaboration relations (Schubert and Glänzel 2006). The USA shows a distinguished role enjoying universal preference (e.g., Schubert and Glänzel 2006; Zhou and Glänzel 2010). With the development of information technology, remote communication becomes easier and convenient, and thus, making geographical distance less important in deciding collaboration relations. Various data sources (e.g., the Thomson Reuters *Web of Science*) and numerous institutional websites make it possible to unite scientists with common research interests together, regardless whether they know each other in person before and no matter where they locate. Geopolitical location also seems less important in deciding scientific collaboration relations. Take China for example, its leading partners such as the USA, the UK and Germany do not satisfy the factor of geopolitical location, but their growing collaborations show no sign of decline (Zhou and

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[1] Please refer to the NSFC web site at: http://www.nsfc.gov.cn/nsfc/cen/xmzn/2013xmzn/01/index.html.

Glänzel 2010). In fact, collaboration preference has become a balanced decision among issues including research interests, knowledge background, research capability, infrastructure and language, although geopolitical location and cultural relations still play roles.

Studies on domestic collaboration are also seen although with fewer outputs. For example, while studying different types of collaboration, (Benavent-Pérez et al. 2012) found that both international and national collaborations increased steadily with Asia being less distinctive than in the other regions.

Collaboration research can be either funded or unfunded. Funded collaborative projects involve more shareholders such as funding agencies and public community and are expected to perform better than those unfunded. How to evaluate such kind of projects is a common concern of various shareholders. Policy makers and/or public community place great hopes on them to promote economic development. For example, both the OECD Innovation Strategy (2010) and the Innovation Agenda of the UK (DIUS 2008) identify basic research as critical in raising productivity and employment. Japan Science and Technology Agency has made investment in basic research a cornerstone of its economic strategy.[2] Nonetheless, impact of scientific research usually takes years to emerge. Variations of scientific investment and impact exist among countries. A positive impact of scientific investment in one country does not necessarily duplicate in others, for instance, over three-quarters of post-1995 increase in productivity growth could be traced to science investments (Jorgenson et al. 2008). However, such effect did not happen in Japan[3] and Sweden (Davis and Henrekson 2006) although having invested heavily in research and development (R&D). The critical issue is that we do not understand the mechanisms through which investments in R&D, and their immediate products (knowledge and technologies) interact with other aspects of societies and economies (Lane 2009). In sum, assessing impact of science funding is not an easy task.

Nonetheless, it is still possible to evaluate funded research by narrowing the scope of investigation. For example, based on journal publications and patents funded by the Sixth Framework Programme (FP6), Breschi and Malerba (2011) found the existence of decreasing marginal returns to an increase in the size of research consortia. Boyack and Jordan (2011) proved higher citation impact of funded publications compared to those unfunded, and publications with more funding sources also receive more citations than those with fewer funding sources. By applying bibliometric methods, Belter (2012) analyzed publications funded by the Office of Ocean Exploration and Research (OER) of the National Oceanic and Atmospheric Administration (NOAA) and demonstrated the usefulness of bibliometric analysis in terms of summarizing and evaluating research performance of funded projects.

In view of the research background the current paper aims at evaluating performance of funded and collaborative projects reflected by journal publications from Chinese authors by applying biliometric tools. Considering significant variations among different scientific fields, such kind of studies should be field-based. As downloading data from Chinese domestic database is extremely time-consuming and publication quantity in mathematics is relatively lower than that in other fields, we decide to focus on publications in this field. Publications in other fields will be explored in later studies.

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[2] http://www.jst.go.jp/EN/operations/operation_a.html.

[3] Directorate for Science, Technology, and industry, OECD, *A Forward-Looking Response to the Crisis: Fostering an Innovation-Led, Sustainable Recovery* (OECD, Paris 2009); www.ioe-emp.org/fileadmin/user_upload/documents_pdf/globaljobscrisis/generaldocs/Fostering_an_Innovation-led_and_Sustainable_Recovery.pdf.

Data sources and methods

Data sources

Chinese researchers publish papers in either domestic or International Journals. For investigating performance of Chinese domestic publications, China Academic Journal Network Publishing Database of China National Knowledge Infrastructure (CNKI) is used as domestic publications sources. In later text, the CNKI will be used to label the domestic database. Till October 2012, the CNKI had indexed over 7,900 Chinese domestic journals that publish scholarly outputs with full text of over 35 million papers.[4] Publications indexed in the Science Citation Index—Expanded (SCIE), the Socical Science Citation Index (SSCI), the Conference Proceedings Citation Index—Science (CPCI-S), and the Conference Proceedings Citation Index—Social Science & Humanities (CPCI-SSH) in the Web of Science (WoS) of Thomson Reuters are used to investigate Chinese international publications. Both the CNKI and the WoS have categorized publications in mathematics. In later analysis, publications indexed in the CNKI represent Chinese domestic publications and those indexed in the WoS represent China's international publications.

Funding information is essential for exploring issues relevant to funded publications. In the CNKI, such information can be retrieved as early as the 80s in last century. In contrast, the WoS records funding formation much later—only from August 2008 onward, Thomson Reuters started to collect funding information presented in the acknowledgment section of publications (Thomson Reuters 2011). In consideration of the availability variation of funding information in the CNKI and the WoS, and in combination with our research targets, we downloaded publications indexed in the CNKI in 2002–2011 and in the WoS in 2009–2011. In terms of coverage of document types, all publications in 2002–2011 indexed in the CNKI in the subject of mathematics are included because there is no such classification in the CNKI. Whereas publications belonging to document types of article, letter, proceedings paper and review in mathematics in the above mentioned four WoS databases (i.e., SCIE, SSCI, CPCI-S, AND CPCI-SSH) are included. The download dates for publications in the CNKI and the four WoS databases were August 21 and September 28, 2012 respectively.

In view of the fact that universities are major producers of journal publications, data of university distribution among regions are applied to explore if correlation exists between paper productivity and number of universities. Although number of university academic staff is more appropriate for such analysis, data availability prevents us from doing so. Most importantly, the result is still interesting.

Some terms

As the current study focuses on funded and collaborated publications, one has to first define clearly for these different types of publications. In the current paper, any publications acknowledging funding sources are defined as funded publications. In consideration of variations in terms of funding sources among publications, we classify publications into three types which are one-funding source (i.e., F1), two funding sources (F2) and three funding sources (F3) respectively.

Defining collaborated publications is relatively more complex. As mentioned in the introduction part, collaboration may appear in different ways. It can be national or

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[4] http://epub.cnki.net/KNS/brief/result.aspx?dbprefix=CJFQ.

international, institutional or cross-institutional, within- or cross-disciplinary and so on. In view of the objectives of the current research, we classify collaboration in the way shown in Fig. 1.

International collaboration is further classified so as to clarify contributions of Chinese domestic (excluding authors from Macau and Hong Kong) and international (including Macau and Hong Kong)[5] authors or institutions in international collaboration of China. In consideration of the difficulties in cleaning huge amount of author address information and the leading roles of first authors in publications (e.g., Yuan and Xue 2007), we decide to further classify international collaboration into two types based on addresses of first authors as shown in Fig. 2.

In addition to analyzing domestic and international collaboration, collaboration is defined in another way when location is needed for analyzing regional distribution. Locations of first (in the WoS) or response authors (in the CNKI) are used for such definition. Collaboration is considered as domestically -led if the first or response author is from Mainland China; For internationally-led collaboration the first or response author is from outside of Mainland China. Domestically-led collaboration may involve international participants, and of course, internationally-led collaborations involve Mainland researchers. Publications in either the CNKI or the WoS may involve the above two types of collaboration. For domestically-led papers, performance of domestic regions will be investigated, whereas for internationally-led papers, contributions of countries or regions from outside of Mainland China will be analyzed.

Data processing

Because of different structures of the CNKI and the WoS, downloaded data from the two sources were treated differently. For data from the CNKI, processing work was done manually according to the research targets of the current study. Processing of data from the WoS was a combination of automatic and manual work. The program ISI.exe[6] developed by Loet Leydesdorff was used to carry out automatic processing work of the downloaded data from the WoS. The output files generated by the ISI.exe were treated manually to get data necessary for the research.

For analysis of regional performance, one needs to assign collaborated publications to corresponding regions according to addresses in the by-line of a publication. Address assignment of publications of within-institutional collaboration can be easy because each of such type has only one address. Cross-institutional and international collaboration, however, may involve two or more addresses located in different regions and thus increases the complexity of address assignment. Address assignment can be done in different ways. For example, addresses appeared in a paper can be assigned to corresponding regions equally or fractionally according to author contributions. In view of the wide recognition of the critical role of first and corresponding authors, we assign publications to regions based on address information of either first or response authors. For publications in the CNKI, the field "response author" is used and for those in the WoS the field "first author" is applied. Thus a paper can be assigned to only one region because a paper contains only one first or response author. First-author addresses in the WoS are harvested

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[5] Since the scientific systems in Macao and Hong Kong are different from that of the Mainland, we attribute collaboration between the Mainland and Macao or Hong Kong to the type of international collaboration although the latter two regions belong to China. Taiwan is treated similarly.

[6] http://www.leydesdorff.net/software/isi/index.htm.
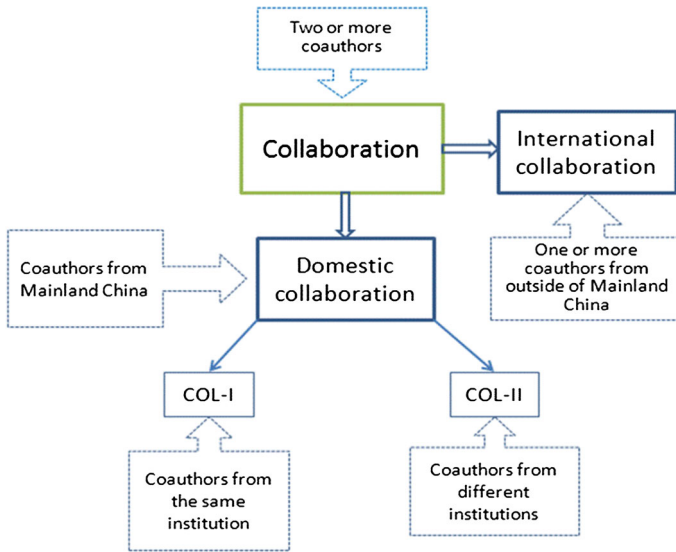
Fig. 1 Definition of collaboration
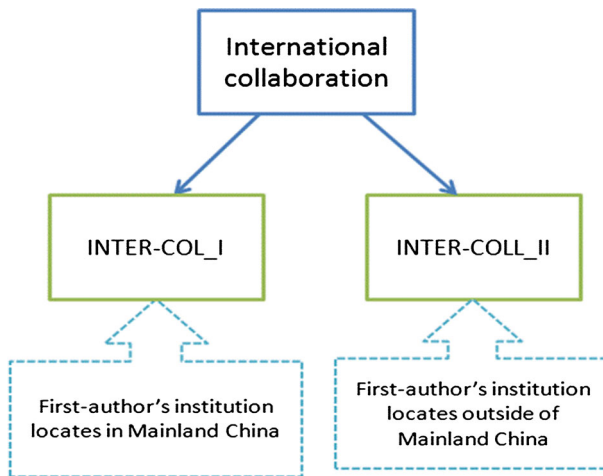
Fig. 2 Classification of two types of international collaboration

by running the routine ISI.exe, whereas address information of "response authors" in the CNKI are processed manually.

Results

For easy understanding of publications in the CNKI and the WoS, we label Chinese publications indexed in the CNKI as Chinese domestic publications and those in the WoS as Chinese international publications. A series of comparisons in terms of productivity and

regional performance among the following issues have been down: collaboration versus non-collaboration, funded collaboration versus un-funded collaboration, the above-mentioned various types of funded and un-funded collaboration, and so on. Conclusions and discussion are made based on the results.

Collaboration and funded collaboration

An overview

From 2002 to 2011, Chinese authors had, in total, published 85,320 papers in mathematics indexed in the CNKI. The share of collaborated publications in the total grew linearly. By the year 2011 over 79 % of Chinese domestic publications were collaborated (Fig. 3a). Of the collaborated publications in the CNKI, the ratio of being funded had also increased linearly since 2006 (Fig. 3b). The year 2006 was a divide: Before this year the ratio of funded collaboration had kept stable and after this year (i.e., starting from 2007) the share of funded collaboration had increased steadily. By 2011, over 83 % of Chinese collaborated papers in the CNKI were funded.

For analyzing collaboration situation of Chinese international publications (i.e., WoS sources) in mathematics, only publications in 3 years (i.e., 2009–2011) of China are used so as to accord the availability of funding information in the WoS—as mentioned above funding information is only available in the WoS since August 2008. Of Chinese international publications in mathematics, at least 83 % were output of collaboration. Contribution of collaboration to Chinese total international publications had kept grown between 2009 and 2011 (Fig. 4a) from 6,075 to 7,359. Majority of China's collaborated publications in the WoS were funded. Similar to the growth trend of collaboration ratio in the total publications in mathematics, the ratio of funded collaboration had also increased annually—from 73 % increased to 88 % in 3 years (Fig. 4b).

Regional distribution

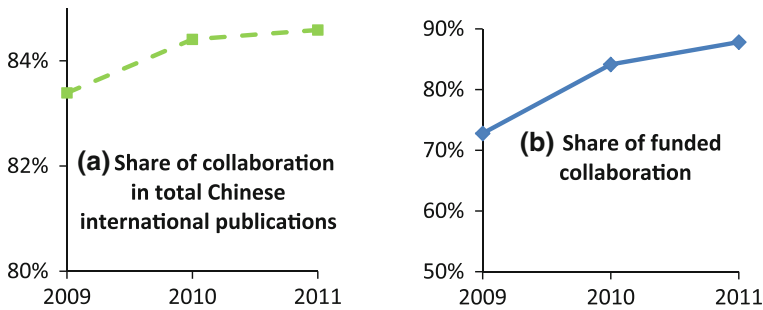### Regional distribution of collaboration

From 2009 to 2011, the CNKI covered 21,581 domestically-led collaborations reflected by publications in mathematics. Regional contributions were highly skewed: A few regions contributed the most in producing collaborated papers. Four regions including Beijing, Shaanxi, Jiangsu and Shanghai were most active and contributed over 1/3 of the total. Beijing took the absolute lead. Other ten regions were so inactive that none of them surpassed a share of 2 % of the 21,581 publications (Fig. 5).

In the same period, China had 17,019 domestically-led publications that were indexed in the WoS. Highly skewed regional distributions appeared again: the first four regions (i.e., Beijing, Shanghai, Jiangsu and Zhejiang) contributed over 40 % of the total, whereas 13 regions were so inactive in collaboration that none of them surpassed a share of 2 % of the 17,019 publications (Fig. 6).

In the CNKI, collaborated publications with response authors outside of Mainland China (i.e., internationally-led publications) were rather few—only 42 were indexed between 2009 and 2011. The USA and Hong Kong were the first two leading partners—each contributed nine such kind of publications.
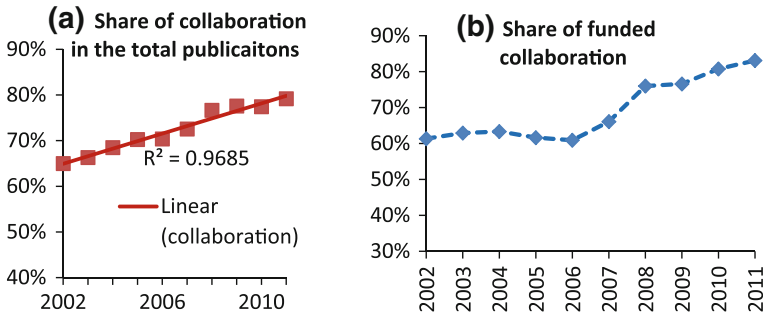
Fig. 3 Development of collaboration versus funded collaboration of Chinese publications in mathematics (Source: CNKI)


Fig. 4 Collaboration versus funded collaboration of Chinese international publications in mathematics (Source: WoS)
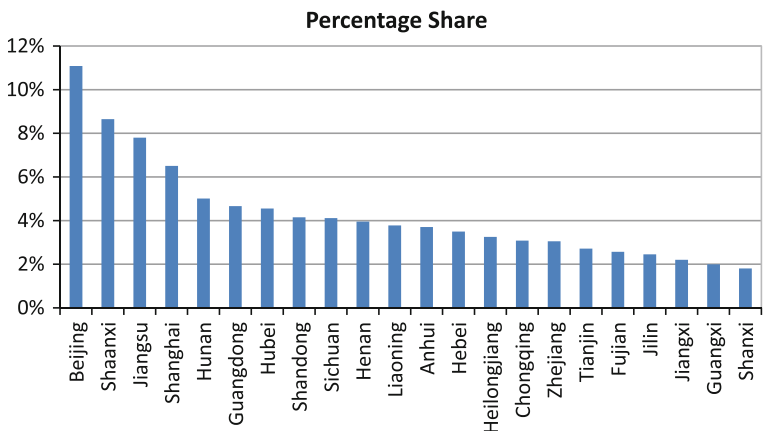
Fig. 5 Regional distribution of domestically-led collaboration (Source: CNKI, 2009–2011, >2 %)

Between 2009 and 2011 China had 3,231 internationally-led publications indexed in the WoS in mathematics. International researchers were from 66 countries or regions. Contributions of these countries or regions were highly skewed with the USA and Hong Kong
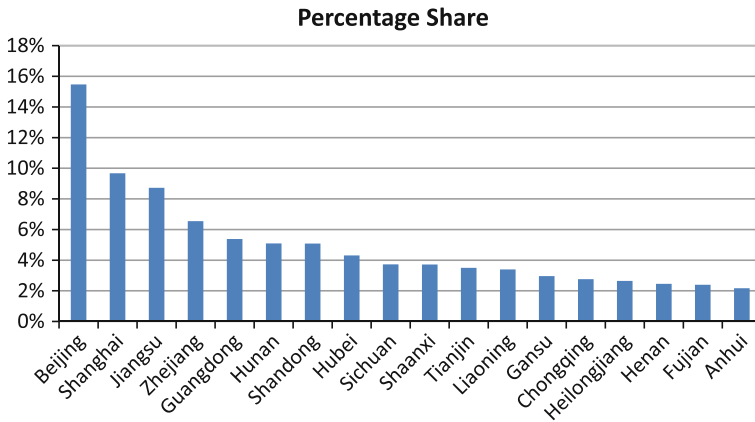
Fig. 6 Regional distribution of domestically-led publications (Source: WoS, 2009–2011, >2 %)

took the absolute lead: Nearly half (i.e., 47.29 %) of the total were led by either the USA or Hong Kong, leaving the third and fourth major contributors (i.e., Taiwan and Canada) far behind. Most of China's collaboration partners contributed less than 5 % of the 3,231 publications (Fig. 7).

Thus, it is clear that China's collaborated publications in mathematics indexed in either domestic or international databases are unevenly distributed among regions. A few regions (i.e., Beijing, Shanghai, Jiangsu, Zhejiang and Shaanxi) contribute the most. In other words, most regions with low collaborated publication rates are in disadvantageous place in terms of hosting collaboration with other regions, let alone collaborating with international partners. Variations also exist among the leading regions. Beijing's absolute lead is unshakable. Jiangsu is currently the biggest challenger of Shanghai. Shaanxi and Zhejiang perform controversially: Shaanxi publishes mainly domestically whereas Zhejiang focuses more on international publication.

Domestically-led publications of collaboration indexed in the CNKI was 1.3 (=21581 ÷ 17019) times of that in the WoS, whereas the ratio of internationally-led publications in the CNKI to that in the WoS was negligible. In other words, domestically-led collaborations publish in both international and Chinese domestic journals although slightly more in domestic ones. On the contrary, internationally-led collaborations seldom publish in Chinese domestic journals.

Regional distribution of funded collaboration

Of the 21,581 domestically-led collaborated publications covered by the CNKI in mathematics between 2009 and 2011, 17,259 publications (i.e., nearly 80 % of the total) were funded. The high ratio of funded collaboration was proved again. Regional distributions of funded collaborations were also highly skewed and correlate highly to that of overall situation of collaboration (Figs. 5, 8): By taking over 1/3 (i.e., 33.7 %) of the total Beijing, Shaanxi, Jiangsu and Shanghai benefited most in terms of being funded, whereas ten regions were in disadvantageous situation that none of them surpassed a share of 2 % of the 17,259 publications.

Of the 17,019 domestically-led papers published between 2009 and 2011 and indexed in the WoS, 14,185 were funded taking over 83 % of such type of collaborated publications.
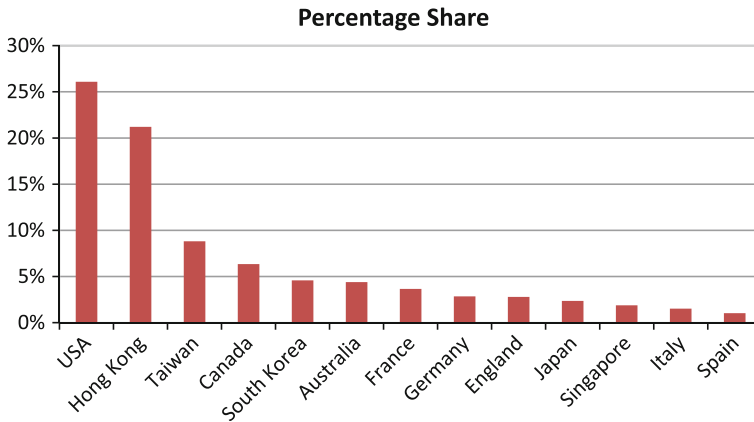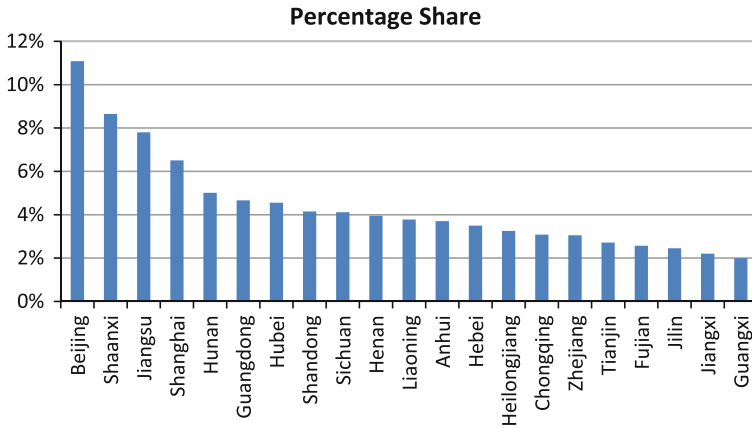
Fig. 7 Regional distribution of internationally-led publications (Source: WoS, 2009–2011, >1 %)

Highly skewed regional distributions appeared again: the first four leading regions (i.e., Beijing, Shanghai, Jiangsu and Zhejiang) in collaboration also take a lead in funded collaboration (Figs. 6, 9): around 41 % of funded collaborations were from the four regions. Another 12 regions were so inactive in collaboration that none of them surpassed a share of 2 % (Fig. 9).

In the same period (i.e., 2009–2011) in the CNKI, only 20 collaborated publications with response authors from outside of Mainland China (i.e., internationally-led publications) were funded, taking nearly half of the 42 internationally-led publications. Hong Kong and USA, again, were the first two leading partners with respectively 8 and 5 collaborated publications being funded.

In the WoS, China had 2,464 internationally-led funded collaborations (i.e., with first author outside of Mainland China) between 2009 and 2011, taking 76 % of the 3,231 such type of publications. Distributions of funded collaborations highly correlate with that of internationally-led collaborations (Spearman's $r = 0.996$, Pearson's $\rho = 0.998$). Collaborations with 63 countries or regions as first-author countries/regions were funded and were, again, highly skewed. The USA and Hong Kong took the absolute lead: Nearly half (i.e., 48.1 %) of the total collaboration were led by either the USA or Hong Kong, leaving the third and fourth major contributors (i.e., Taiwan and Canada) far behind. Contributions of majority countries took less than 5 % of the 2,464(2,540) publications (Fig. 10).

Domestically-led funded publications of collaboration indexed in the CNKI was 1.2 (=17,259/14,185) times of that in the WoS between 2009 and 2011, whereas the ratio of internationally-led publications in the WoS to that in the CNKI was over 100 (i.e., 123.2) times. In other words, internationally-led collaboration aims at publishing internationally instead of domestically. In fact, publishing internationally has become a first option of Chinese authors: Growth rate of China's international publications was faster than that of domestic ones, no matter what types of publications are investigated—either publications as a whole or specific types such as collaborated publications or publications of funded collaboration (Fig. 11). Funded publications indexed in the WoS grew fastest: the ratio of publications in the WoS to that in the CNKI grew from 0.72 in 2009 to 1.20 in 2011.

Fig. 8 Regional distribution of funded and domestically-led collaborated publications (Source: CNKI, 2009–2011, >2 %)
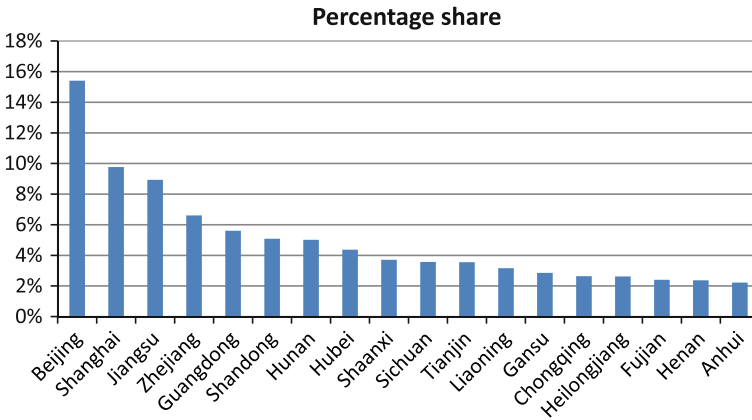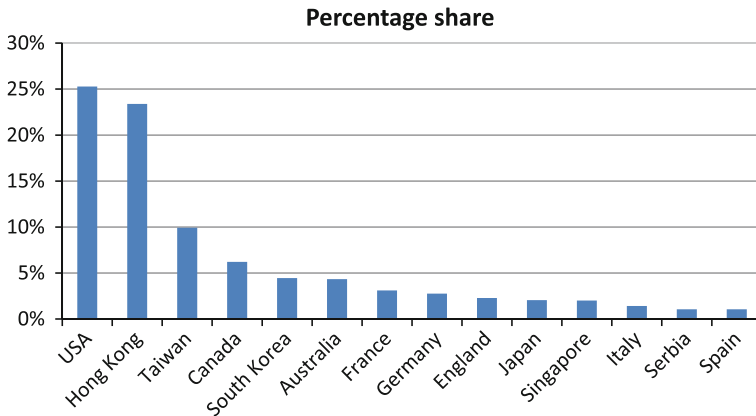

Fig. 9 Regional distribution of funded and domestically-led publications (Source: WoS, 2009–2011, >2 %)
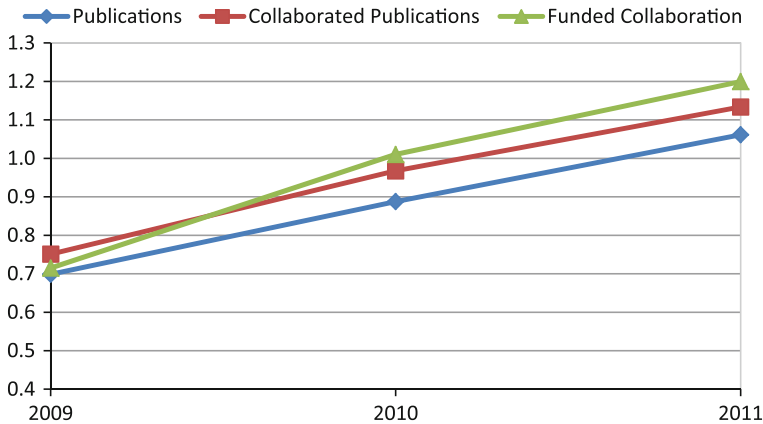
Types of collaboration

General distribution

Between 2009 and 2011 Chinese authors in mathematics had in total 21,623 publications indexed in the CNKI. In contrast to the low rate of international involvement in China's collaboration reflected by domestic publications, collaboration between or within domestic institutions took the lead. Among all the collaborated publications in the CNKI, within-institutional collaborations formed the largest group—more than 54 % domestic collaborations were within-institutional. This group had been enlarged slightly from 2009 to 2011. The second largest group was cross-institutional collaboration, taking more than 41 % of all the collaborations (Fig. 12a).

Distribution of collaboration types varied greatly in China's international publications. In contrast to the low share in the CNKI, international collaboration contributed around

Fig. 10 Regional distribution of funded and internationally-led publications (Source: WoS, 2009–2011, >1 %)


Fig. 11 Ratio of publications in the WoS to that in the CNKI (2009–2011)

30 % of collaborated publications indexed in the WoS. The gap between Chinese domestic and international collaboration was reduced significantly although domestic collaboration still took a higher ratio. In contrast to the absolute role of within-institutional collaboration in domestic publications, cross-institutional collaboration contributed the most to Chinese international publications (Fig. 12b).

Funded situation of collaboration types

In domestic publications, funded ratios of the three types of collaboration were rather high and continued to grow. For example, over 81 % of collaborated publications indexed in the CNKI in 2011were funded. Of the three collaboration types, cross-institutional collaboration took the lead in the studied period (i.e., 2009–2011). Growth rate between 2009 and 2010 was higher than that between 2010 and 2011, with international collaboration
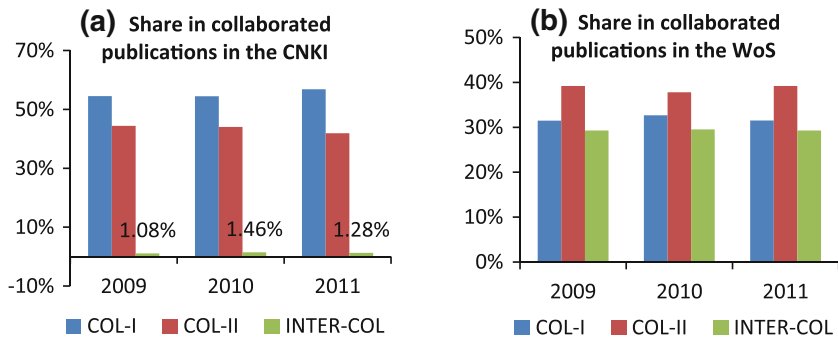
Fig. 12 Share of different types of collaboration between 2009 and 2011

increased the most. In 2011, funded ratio of international collaboration exceeded 81 %—reaching similar level of that of within-institutional collaboration (Fig. 13a).

Funded ratios of collaboration types in China's international publications were also high and had experienced similar growth as those of domestic publications. In 2011, funded ratio of the three types of collaboration reached over 85 %. Cross-institutional collaboration still took the absolute lead in the 3 years and reached over 90 % in 2011. For all the three types of collaboration, the highest growth happened from 2009 to 2010 compared with those from 2010 to 2011 with international collaboration increased the most. The gap between international and within-institutional collaboration was reduced significantly (Fig. 13b).
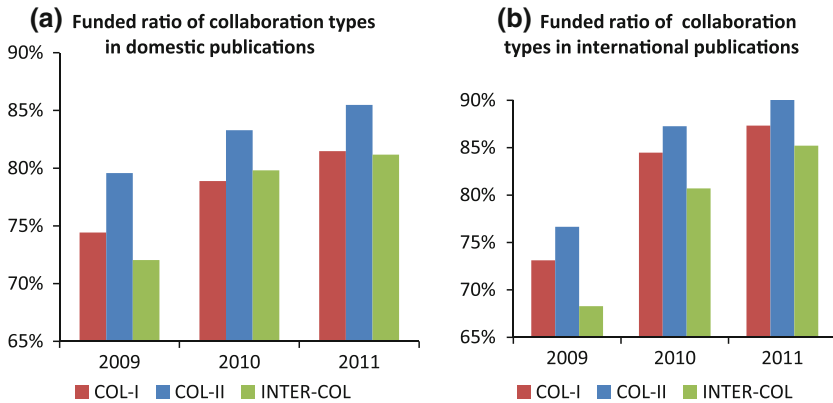
Number of funding sources and collaboration types
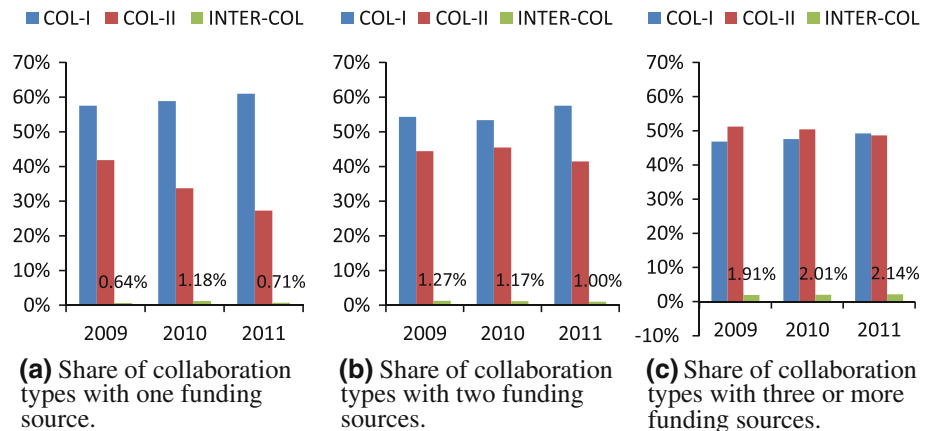
Funded collaborations in the CNKI

From 2009 to 2011, in total 7,619; 5,909 and 3,751 collaborated publications were respectively funded by one, two and three or more sources in the CNKI. The number of publications decreased sharply with the increase of funding sources: the number of publications funded by one source was about twice as much as those funded by three or more sources. In other words, majority of funded collaborations reflected by domestic publications were funded by one source. As shown before, international collaboration produced very limited publications in the CNKI, only within- and cross-institutional types (i.e., COL-I and COL-II) will be discussed in this section.

With regard to relation between collaboration types and number of funding sources, the number of collaborated publications funded by one source was reduced by half from that of 2,969 in 2009–2,131 in 2011 in the CNKI. In the one-funding source (F1) publications, within-institutional collaboration (i.e., COL-I) took the highest and growing ratio, whereas cross-institutional collaborations (i.e., COL-II) had lower and decreasing ratio (Fig. 14a).

Within-institutional collaborations were also the majority in publications funded by two sources (i.e., F2 type) in the CNKI. The gap between within- and cross-institutional collaborations vibrated from 2009 to 2011 (Fig. 14b). Among the 3,751 collaborated publications funded by three or more sources (i.e., F3 type), difference between within- and cross-institutional collaborated publications were not as significant as those funded by one

Fig. 13 Funded ratio in each type of collaborations
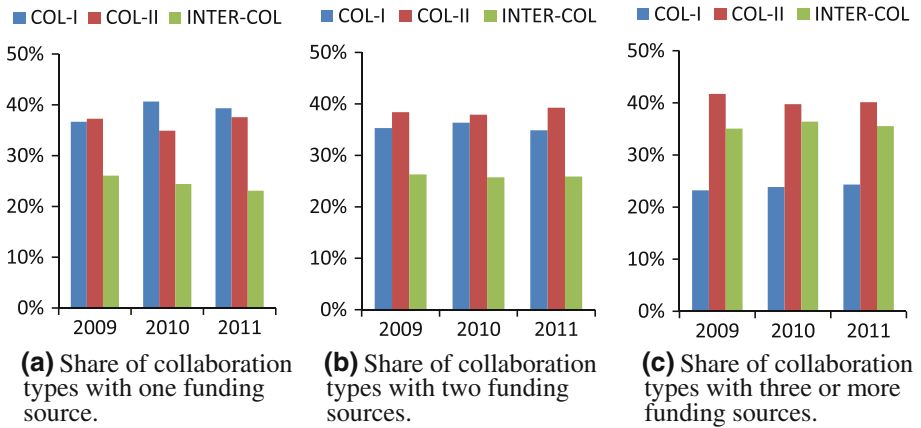

Fig. 14 Distributions of collaboration types with different funding sources (Source: CNKI, 2009–2011)

or two sources (i.e., F1 and F2 types). Cross-institutional collaborations even took slightly higher share than within-institutional collaborations in 2009 and 2010 (Fig. 14c).

Funded collaborations in the WoS

In the WoS, in total 4,702; 5,369 and 6,578 collaborated publications were funded respectively by one, two and three or more sources between 2009 and 2011. In contrast to those indexed in the CNKI, the number of collaborated publications increased significantly with growing number of funding sources. Chinese publications with multiple funding sources took the majority in collaborated publications indexed in the WoS.

With regard to relation between collaboration types and number of funding sources, the number of collaborated publications funded by one source increased from 1,366 (in 2009), 1,638 (in 2010) to 1,698 (in 2011). Within-institutional collaborations (i.e., COL-I) still took the lead as those in the CNKI (Figs. 15a, 14a). Nonetheless, the gap in terms of

(a) Share of collaboration types with one funding source.

(b) Share of collaboration types with two funding sources.

(c) Share of collaboration types with three or more funding sources.

Fig. 15 Distributions of collaboration types with different funding sources (Source: WoS, 2009–2011)

percentage share between within- and cross-institutional collaboration was much narrower than that in domestic publications and had been reduced significantly from 2010 to 2011. The share of international collaborations decreased gradually from 26.06 % in 2009 to 23.09 % in 2011 (Fig. 15a).

The number of collaborated publications funded by two sources increased from 1,513 (in 2009), 1,854 (in 2010) to 2,002 (in 2011). Cross-institutional collaborations contributed slightly more than within-institutional collaborations. Regarding F2-type publications in the WoS, the gap in terms of publication share between within- and cross-institutional collaborations vibrated. International collaborations kept a relatively stable share in the three years (i.e., 2009–2011) under study (Fig. 15b).

Cross-institutional collaborations continued to take higher share in collaborations funded by three or more sources (i.e., F3 type) in the WoS. Whereas the share of within-institutional collaborations was much lower resulting in a wider gap between within- and cross-institutional collaborations compared with collaborations funded by once source. The role of international collaborations increased significantly by taking the second position in the three types of collaboration (Fig. 15c).
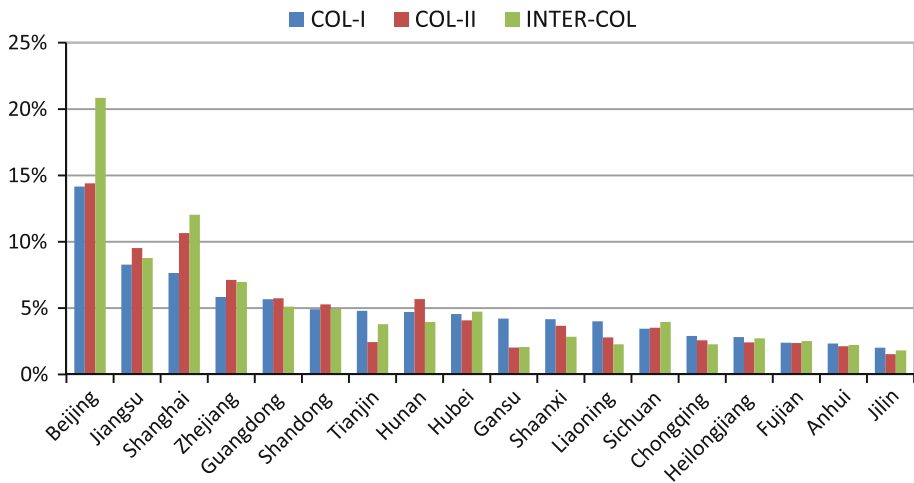
Regional distribution of collaboration types

Among publications indexed in the CNKI from 2009 to 2011, Beijing took absolute lead in the three types of collaborations. Of the 9,543 publications of within-institutional collaborations (i.e., COL-I), Shaanxi, Jiangsu and Shanghai contributed at least 5 % respectively. In the 7,517 publications of cross-institutional collaborations, (i.e., COL-II type), Shaanxi and Jiangsu were important producers and were more active than Shanghai. Of the 199 publications of international collaboration, over 18 % were led by Beijing. The next important regions in leading international collaborations were Shanghai and Guangdong, whereas Shaanxi was much less active compared to its performance in within- and cross-institutional collaborations (Fig. 16).

Between 2009 and 2011, Beijing again took the absolute lead in publishing internationally in the three types of collaborations. Shanghai, Jiangsu, Zhejiang and Guangdong were also important contributors of Chinese international publications collaborated within-institutions by taking at least 5 % of Chinese total of such type (i.e., F1) international
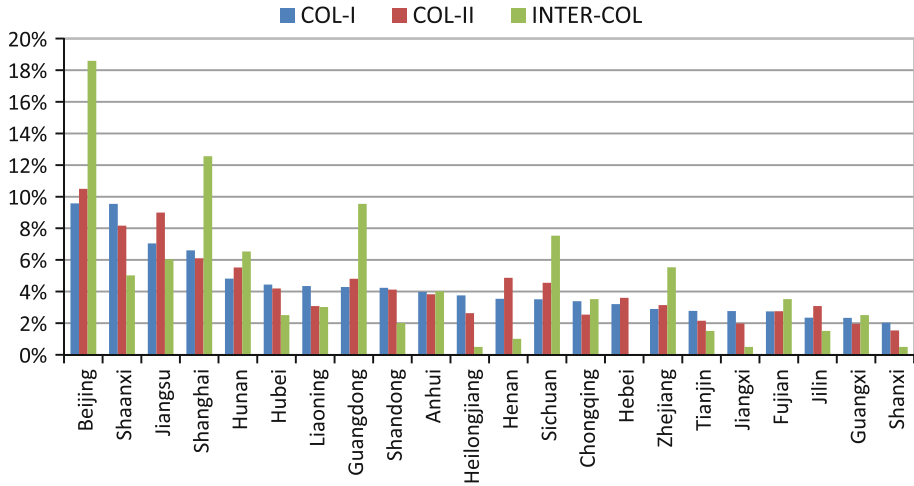
Fig. 16 Regional distribution of domestically-led publications (Source: CNKI, 2009–2011, share of COL-I >2 %)

Fig. 17 Regional distribution of domestically-led publications (Source: WoS, 2009–2011, share of COL-I >2 %)

publications. In terms of collaborating with other institutions, Beijing, Shanghai and Jiangsu took the absolute lead. Zhejiang, Guangdong, Shandong and Hunan were also active in cross-institutional and international collaboration. After Beijing, Shanghai was the second most active player in collaborating with other domestic institutions. Most of regions from the Mainland took relatively higher national share in either within- or cross-institutional collaboration, whereas Beijing and Shanghai performed the other way around with the highest share in international collaboration (Fig. 17).

Table 1 Rank order correlations (Spearman's rho; upper triangle) and Pearson correlations r (lower triangle) of collaborated publications

	Universities (regional)	Universities (national)	Universities (national + regional)	Domestically-led publications (CNKI)	Domestically-led publications (WoS)
Universities (Regional)	1.000	.669[**]	.986[**]	**.843**[**]	.726[**]
Universities (national)	.352	1.000	.725[**]	.876[**]	**.846**[**]
Universities (national + regional)	.984[**]	.514[**]	1.000	.881[**]	.775[**]
Domestically-led publications (CNKI)	.652[**]	**.856**[**]	.761[**]	1.000	.901[**]
Domestically-led publications (WoS)	.559[**]	**.872**[**]	.679[**]	.897[**]	1.000

Domestically-led publications (CNKI): Collaborated publications indexed in the CNKI with a domestic region as the first-author address

Domestically-led publications (WoS): Collaborated publications indexed in the WoS with a domestic region as the first-author address

** $p = .01$ (2-tailed)

Conclusions and discussion

From the perspective of journal publications, China's collaborated research in mathematics had increased steadily. Most of Chinese publications were collaborated and majority of collaborated publications were funded. The ratios of funded collaboration had kept increasing significantly. The year 2006 seems to be a divide in terms of funded collaboration reflected by domestic publications, which may imply that research collaboration has entered a new era in terms of being funded in China. Under the same condition, collaborated research projects are more likely to be funded. The ratio of funded collaboration in international publications is slightly higher than that in domestic publications, indicating higher capability of funded collaborations in publishing internationally.

The distinct contrast between the low visibility in the CNKI and high visibility in the WoS of internationally-led collaboration implies that international collaboration contributes mostly for China to publish internationally, instead of domestically. The high ratio of collaboration and funded collaboration in Chinese domestic and international publications proves the importance of collaboration and funding support in research. Funding agencies encourage collaboration, and on the other hand, collaboration increases chances for a research project to be funded.

Beijing, Jiangsu and Shanghai were most active in producing collaborated publications indexed in either domestic or international sources. Significant contrast appears between Shaanxi and Zhejiang: Shaanxi was very active in publishing domestically by taking the 3rd position. Zhejiang performed better in publishing internationally than domestically. The skewed regional distribution of publications correlates significantly with regional distribution of universities especially state-owned universities as universities are major producers of journal publications (Table 1). To make things worse, there exists a phenomenon of "the rich get richer and the poor becomes poorer". Regions with more state-owned universities also have more regional universities and vice versa (Table 1). If policy makers were to reduce significant gaps between developed, less developed and undeveloped regions in knowledge education and knowledge production, rational planning of educational institutions and resources is critical.

Publishing internationally has become a first option of Chinese authors, which puts Chinese journals in a disadvantageous situation: they hardly attract high quality publications produced by Chinese authors, let alone attracting publications from international authors. The scale of funded publications grew fastest among overall and collaborated publications in China. Such a phenomenon can be understood in this way: Funded research has already been evaluated by peers, which may, to some extent, ensure higher quality of publication output. Such publications have more chances of being accepted by international journals.

International collaboration in Mainland China was again highly skewed with the USA and Hong Kong took the absolute lead in publishing with Mainland China. The extremely skewed national/regional distribution of internationally-led publications of China leaves a space for extending collaboration with other countries, in addition to maintaining and improving relations with the currently major partners like the USA and Hong Kong.

Majority of Chinese collaborated outputs in mathematics were funded: the ratio of funded collaboration was higher in international publications than that of domestic ones, which again proves the higher quality of funded collaboration. Furthermore, internationally-led funded collaborations were more capable of publishing internationally compared with unfunded collaborations.

Highly-skewed regional distribution happened again among funded and collaborated publications and varied between domestic and international publications. Beijing, took absolute lead in funded collaboration in both domestic and international publications. Jiangsu and Shanghai also performed well in publishing domestic and international publications of funded collaboration, although Jiangsu did better in publishing domestically and Shanghai were better in publishing internationally in this regard. Zhejiang, again, showed its capability of publishing internationally in terms of funded collaboration: It only stood at the 12th position in domestic publications whereas jumped to the 4th in international publications. The performance of Shaanxi was opposite to that of Zhejiang with weaker capability in publishing internationally.

Regarding contribution of different types of collaboration, within-institutional collaboration contributed the most to Chinese domestic publications. For China to publish internationally, cross-institutional collaboration plays a major role, and contributions of within-institutional collaboration and international collaboration are less but still important.

Among funded publications of collaboration, cross-institutional collaboration took the lead, which may imply that cross-institutional collaborations have more chances for receiving funds and publishing outputs. With time went on, the ratio of funded collaborations in international publications were higher than those in domestic publications. In other words, funded collaborations are more capable of publishing internationally. The order of being-funded-rate of the three types of collaborations is cross-institutional collaboration, within-institutional collaboration and international collaboration respectively. It seems that collaboration, especially cross-institutional collaboration is a smart option for a research institution to apply funds and to raise academic visibility.

In the Chinese domestic publications indexed in the CNKI, the number of collaborated publications decreased sharply with the increase of funding sources. Majority of funded collaborations had one funding source and most of them were of within-institutional collaborations. Such a phenomenon has been strengthened year by year. With the participation of other institutions, the share of publications with more funding sources increased. In other words, cross-institutional collaboration may increase the possibility of achieving more funding sources, and thus reducing the gap of publication share between within- and cross-institutional collaboration.

Of China's international publications indexed in the WoS, the number of collaborated publications increased significantly with growing number of funding sources, and collaborated publications with multiple funding sources took the majority, which is in contrast to that in the CNKI. Most of collaborated publications with multiple funding sources were from cross-institutional collaborations. International collaborations contributed significantly to Chinese international publications with different funding sources, especially to publications with more than three funding sources. Contribution of the three types of collaborations had been balanced in collaborated publications with two or more funding sources.

The fact that Chinese researchers publish collaboration outputs funded by one source in domestic journals and those funded by two or more sources in international ones may imply that more funding sources may ensure higher quality and thus more chances of publishing internationally. Within-institutional collaborations publish more in domestic journals whereas cross-institutional and international collaborations appear more in international journals, which may infer that cross-institutional and international collaborations are more capable of publishing internationally and tend to have more funding sources. To conclude, cross- and international collaborations perform better in raising

funding support, research capacity and academic visibility because of providing broader choice in finding excellence. The advantage of cross-institutional collaboration corresponds to the conclusion of Bartneck and Hu (2010). Nonetheless, difference between cross-institutional collaboration and international collaboration in terms of generating positive impact on research exists: International collaboration outgoes cross-institutional collaboration (Jeong et al. 2011).

The current study is based on publications of Chinese authors in mathematics. Similar results are found in studies on other fields. For example, the conclusion of funded collaboration increases possibility of being funded and may result in more research output also applies to fields of machinery and materials sciences (Jeong and Choi 2012). Nevertheless, further studies are still needed regarding whether all conclusions of the current study apply to every field in the science and/or social sciences. The current study only focuses on output impact of collaboration and funded collaboration, their effect on academic citation has not been investigated because of page limit. Relevant issues will be explored in the next paper.

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