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Brain circulation, diaspora and scientific progress: A study of the international migration of Chinese scientists, 1998–2006

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Abstract

The issue of brain drain has resurged to become an important policy concern of developing countries against the background of global talent competition. Based on a global survey covering Chinese scientists at leading universities in English academia, this paper examined the major contribution of returnees and the diaspora on China's scientific progress between 1998 and 2006. By combining biographical and bibliometric data, the paper found that differences in the research output between domestic scientists and overseas scientists had been reduced substantially. Returnees with domestic degrees, instead of those with foreign degrees, are actually the driving force of China's research output growth. Scientists working in China benefited greatly from international collaboration in general and collaboration with overseas Chinese in particular. This empirical study enriches our understanding of international migration in the scientific community, and helps explain China's strategy in achieving rapid scientific development.

Keywords

brain drain, brain circulation, China, scientists, higher education

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Introduction

Skilled migration from one country to another has persisted in the developing world for decades. Although many sending countries may lose in the global talent competition, some succeed in turning brain drain into brain circulation or even brain gain (Heenan, 2005). For example, South Korea and Taiwan used to send a large number of students to leading universities abroad in the 1970s, but both have benefited enormously from their skilled returnees from the late 1980s (O'Neil, 2006; Yoon, 1992).

In recent years, China has attracted a large number of returnees. Over 2.2 million, or 79.9 percent of Chinese overseas students who had completed their tertiary or post-graduate studies, had returned to China by the end of 2015 (MOE, 2016). The returnees include doctoral degree holders whose return to China is expected to boost the development of national scientific enterprise. Aiming at turning its leading universities into world class institutions, China has actively recruited from its scientific diaspora to contribute towards this goal (Zweig and Wang, 2013).

Its talent strategy of boosting the human resources of the research sector has contributed to increasing China's scientific output as reflected in the number of papers by academics from China that are included in the Science Citation Index (SCI). Between 1998 and 2008, China's SCI indexed papers increased from 20,000 to 112,000 (Adams et al., 2009). China ranked ninth based on the number of SCI papers in 1998, rising to fifth place in 2002 (Huang et al., 2006), and further moving up to second position rivaled only by the US between 2008 and 2011 (Shelton and Foland, 2009; Xie et al., 2014). Measured by another research database "Scopus-SciVerse Elsevier," China was ranked second in 2004 and has maintained its position until 2013, the latest year with updated data (Wang, 2016). From a policy perspective, it is pertinent to ask how the return migration of its scientists has reshaped the composition of China's research workforce and fostered its scientific development.

This paper is devoted to a better understanding of the roles of returning scientists and researchers in the diaspora in driving scientific production from a sending country perspective. It focuses on the research productivity and aggregated output of scientists from China between 1998 and 2006, the period when China experienced exponential growth of scientific output and launched talent recruitment programs (Adams et al., 2009). Findings from the study may have important policy implications for the brain drain issue in other developing countries, particularly in the arena of science.

This paper is organized as follows. Section 2 presents the research questions and related hypotheses after briefly reviewing the relevant literature. Section 3 introduces the data collection procedure, the key variables and the measurement of research output. Section 4 reports the findings based on descriptive analysis. Using regression analysis, Section 5 explains the factors concerning the research performance and international collaboration of scientists in China. Section 6 concludes with policy discussions.

Literature review and the research questions

Before reviewing the literature, one key terminology in the title should be clarified. There is an emerging body of literature on ''academic mobility'' (Byram and Dervin, 2008; Maadad and Tight, 2014). This paper uses the conventional term ''migration'' since mobility is a much broader concept and includes a variety of movements. The focus of this paper is movement for a relatively long period, which is better conceived as ''migration.''

The issue of brain drain has been viewed as bringing negative consequences to origin countries because of the loss of return to public investment in higher education and the shrinkage of economic externalities (Grubel and Scott, 1966; Johnson, 1979; Miyagiwa, 1991). However, from the 1990s (Docquier and Rapoport, 2012; Gaillard and Gaillard, 1998), the brain drain has been countered by brain circulation or the return of former skilled expatriates, which can partially or even offset the previous loss. Many studies report that the return migration of the highly skilled transfers knowledge from the host countries and contributes to the endogenous growth of source countries (Domingues Dos Santos and Postel-Vinay, 2003; Dustmann et al., 2011; Saxenian, 2005).

Brain circulation, thus, provides an important mechanism for knowledge transfer and international collaboration (Ackers, 2005; Meyer et al., 2001). Migrants returning with cutting-edge knowledge and international networks are considered important transmitters of technology and knowledge (Davenport, 2004). Since it is often impossible or too costly to codify all knowledge and transfer tacit knowledge, returnee scientists can play a crucial and effective role in knowledge diffusion through personal interaction or joint research projects with domestic researchers.

The migration of scientists is more dynamic today than in previous decades (Hoffman, 2009). Some scholars even use the term ''scientific nomadism'' (Meyer et al., 2001) to describe the phenomenon. Due to deficiencies in domestic higher education, a large number of Chinese students have been heading for the developed world to study science and technology. According to the Institute of International Education (2015), there were 304,000 Chinese studying in the United States in the academic year 2014/2015, and 41 percent of them majored in science, technology, engineering and mathematics (STEM fields). An increasing number of overseas Chinese students returned home for employment. One report estimates that around 20,000 returnees with doctorates came back in 2013 alone (CSCSE, 2014).

Even after returning home, many researchers may move abroad again as visiting scholars for further study or research collaboration to access cutting-edge knowledge or advanced facilities and equipment (Harvey, 2011). According to my calculation using data from the American Community Survey in 2013, some 20,000–30,000 Chinese in the US had actually acquired their doctoral degrees in China. Only a small fraction of them had obtained American citizenship, thus, their stay in the US is likely to be temporary. Following Van Bouwel's (2010) call for new studies on migration ''to tackle new research questions with regard to the effect of international mobility on research productivity and on researchers' collaboration networks,'' this paper systematically examines the migration of Chinese scientists and their contributions to the scientific output in China. As will be detailed later, data for the study came from a global survey of scientists from China. Scientists in this study are referred to as those working in the fields of mathematics, physics, chemistry and biology.

The study tested two hypotheses related to the contributions of scientists with overseas experience: returnees and emigrants. Despite some problems in reintegrating into the local research environment, several studies on returnee scientists point to their active participation in the domestic scientific community (Delicado, 2010; Morano-Foadi, 2005). In Sweden, for example, Melin (2005) found that 10–20 percent of Swedish post-docs had difficulty in transferring knowledge to their departments after returning home. Although reintegration may pose challenges, we may still expect returnees to produce more research output than stayers because of skills learned abroad as well as favorable research and living conditions offered by the home government. The first hypothesis is as follows:

H1: Other things being equal, domestic scientists with overseas experience exhibit higher productivity than those with no or less such experience.

Emigrant scientists also make considerable contributions to the source country. Research collaboration in scientific networks is a significant determinant of scientists' productivity. It is well documented that scientists who collaborate with each other are more likely to publish high-quality papers than individual researchers (Andrews, 1979; Lawani, 1986). Scientists in developing countries particularly benefit from joint research activities with those in the developed world (Bordons et al., 1996). Gaule and Piacentini (2013) show that overseas Chinese graduate students in chemistry exhibit higher research productivity if their advisors are also Chinese, possibly because scientists of the same ethnicity have less communication barriers. As Welch and Zhang (2008) suggest ''...sharing the same cultural and linguistic backgrounds contributed to a greater closeness in scholarly communications.'' Based on these observations, we expect that:

H2: Other things being equal, domestic scientists with international collaboration exhibit higher productivity than those without such collaboration. Moreover, collaboration with overseas researchers of the same ethnic origin brings additional productivity premium.

Data collection, key variables and measurements

The migration of Chinese scientists is very dynamic in terms of length, frequency, destination and program (Séguin et al., 2006; Zweig et al., 2008). Data for this study were obtained from an online survey, conducted between November 2010 and April 2011, to collect biographical and bibliometric data about Chinese scientists affiliated with leading universities. As mentioned earlier, the target population were Chinese scientists in four fields—mathematics, physics, chemistry and biology. I also collected and examined the curriculum vitae (CVs) of these scientists which are available on the Internet to fill missing information and to check the reliability of data.

In order to obtain a good coverage of the target population, I selected all the universities in mainland China and seven English-speaking countries from 501 universities listed in the 2009 Academic Ranking of World Universities (ARWU) (IHE, 2009; Liu and Cheng, 2005).[1] The foreign universities were located in the United States, United Kingdom, Canada, Australia and New Zealand, as well as two city states, Singapore and Hong Kong.[2] A total of 18 universities in mainland China and 243 universities in the seven countries were on the 2009 Jiaotong list.

The process of identifying respondents included three search steps at the university, departmental and individual levels. I acquired the email addresses of Chinese scientists from their professional information available on the websites of the selected universities. Over 2,400 of the identified scientists constituted the sampling frame; all were invited to join the online survey. Nearly five hundred respondents completed and returned the questionnaires. After data cleaning, a total of 451 valid observations were obtained.

The sampling frame was used to weight the sample and improve its representativeness. Furthermore, the sampling frame included three key variables—location, field and university ranking. I categorized the sample into a group of cells according to the three variables; I did the same to the sampling frame. The frequency weights were then generated as the ratio of a cell's

[1]The ARWU is an annual ranking report of global higher education institutions published by the Shanghai Jiaotong University from 2003. It is also called the Jiaotong list.
[2]The sovereignty of Hong Kong was transferred from the United Kingdom to China in 1997. However, Hong Kong can still be viewed as a ''foreign country'' outside mainland China, if we take its high autonomy and westernized academia into consideration.

frequency of the sampling frame to that of the sample, and assigned the observations according to their cells.

The biographical data were matched with individual publication data, which were collected from the expanded version of the SCI produced by Thomson Reuters. Chinese scientists at top national universities are much more active in English academia than average domestic scientists, and published most of their works, or at least those of the highest quality, in SCI-indexed journals (Jia, 2005; Shao and Shen, 2011). Hence, the omission of articles published in Chinese journals would not cause a substantial bias of measurement.

I searched each author's publications in three observation years (1998, 2002 and 2006) by matching his/her name, field and affiliation, in order to identify the same individual clearly. Following a common practice among bibliometricians (Jonkers, 2010: Section 2.5), I recorded information on research articles, reviews, notes and letters; conference proceedings and meeting abstracts were ignored because they are not peer-reviewed documents.

Not all of the scientists have publication records in each observation year. A scientist is assumed to publish from the penultimate year before the completion of his/her doctoral program, though he/she might have published even earlier. For example, I recorded a scientist's indicators of productivity from 1998 if he/she was awarded the highest degree by 1999. As a result, 250 scientists have publication records in 1998, 353 have records in 2002, and all (451) have records in 2006.

Previous studies have used data from CVs to explore research collaboration (Fontes, 2007; Jonkers and Tijssen, 2008), grant impacts (Gaughan and Bozeman, 2002) and scientific mobility (Sandström, 2009). However, CVs as a data source are beset with several methodological problems, such as availability, representativeness and codification (Dietz et al., 2000). The use of a survey to collect biographical data combined with data from CVs and bibliometric data overcomes the limitations of any single data source. This mixed methodology follows the suggestion by Sandström (2009) to link CV/survey data and bibliometric data.

The survey and CV data provide a clear picture of the career paths of Chinese scientists at different years. The different modes of data collection not only collected basic personal information, such as age, gender and research field, but also acquired professional information such as work affiliation, university education and duration of stay abroad. A summary of the profile of survey respondents is presented in Table 1. Some variables that deserve more explanation are described below.

Migration status

I used several temporal and spatial variables to identify the migration status of each individual in each observation year. These variables have three broad

Table 1. Profile of Chinese scientists (2006).

Variable	Percentage
Gender	
Male	83.7
Female	16.3
Age	
23–35	44.2
36–50	52.4
51–60	3.4
Field	
Mathematics	24.9
Physics	24.0
Chemistry	32.7
Biology	18.4
Migration status	
Stayer	33.3
Returnee	32.4
Emigrant	34.3
Location	
Mainland China	65.7
US	19.5
Rest of the world	14.9
Institutional affiliation	
Class I	11.7
Class II	10.2
Class III	44.5
Class IV	33.7
Professional status	
Doctoral student/post-doc	25.2
Assistant professor	16.1
Associate professor	29.2
Full professor	29.5
Administrative position	
None	81.6
Center/committee director	10.4
Assistant dean/dean	8.0

Note: The percentages are calculated based on the weighted sample.

categories: stayers, emigrants and returnees. Stayers are defined as those who obtained their highest degree in China and stayed overseas for no more than two years of a given year, while returnees are those who have returned to China within the past year and had at least two years of overseas experience. The two-year criterion was chosen for two reasons. First, it is long enough to have some impact on a researcher's performance. Second, if we used a shorter period as the criterion, majority of scientists in the sample would be classified as ''returnees,'' which makes the comparison between groups almost meaningless. Emigrants (both temporary and permanent) are those who resided abroad and were affiliated with a foreign institution in the year.[3]

Since returnees include those who obtained their degrees overseas and those who acquired their degrees in China and had spent time overseas as visiting scholars, it is necessary to distinguish the former from the latter. Hence, I further categorized Chinese scientists into five types. The emigration of Chinese scientists can take two forms: the emigration of scholars (i.e., migrating abroad as an independent researcher after acquiring a doctoral degree in China); and the emigration of students (i.e., migrating abroad to acquire a foreign doctoral degree and remaining overseas after completing their studies). Subsequently, the definitions of ''returnee scholars'' and ''returnee students'' are derived from these distinctions. ''Returnee scholars'' refer to domestically trained researchers who returned after staying overseas for two years or more while ''returnee students'' refer to foreign degree holders who returned to China after completing their studies. In all, the study considered five types of Chinese scholars: stayers, emigrant scholars, emigrant students, returnee scholars and returnee students.

Geographical location

The locations of Chinese scientists are categorized into three regions: mainland China, the United States and the rest of the world (ROW).[4] According to the sample, the geographic distribution of Chinese scientists in the three regions changed considerably between 1998 and 2006, as the share of overseas Chinese, that is, those based in the United States and the ROW, increased from 28.4 percent to 34.4 percent. Meanwhile, the overall return rate jumped to 48.6 percent in 2006, which indicates that half of those scientists with international experience for at least two years had returned to China in 2006.

[3]As used in this paper, the term domestic scientists refers to those who work in China in a given year, including stayers and returnees.
[4]The ROW mainly covers six English speaking countries (UK, Canada, Australia, New Zealand, Singapore and Hong Kong), as well as other countries like Japan and Germany.

Institutional affiliation

As a measure of institutional affiliation, this study adopted the 2009 Jiaotong ranking list as a reference for differentiating the universities where Chinese scientists are affiliated (IHE, 2009). A coding scheme aggregated all the universities into four categories from Class I to IV in accordance with their rankings on the Jiaotong list. For the purpose of simplicity, the top 50 institutions were grouped as "Class I," universities with rankings between 51 and 200 as "Class II," those between 201 and 400 as "Class III," and those below 400 and those not on the list were classified under "Class IV."

Professional status and administrative position

Professional status is relatively identifiable and standard across universities in the world. The survey asked the respondents to report their professional status in the three observation years. I codified the data and generated an ordinal variable with six values ranging from doctoral students to full professors. In addition, the survey also asked whether respondents held an administrative position in a given year, i.e., as dean/assistant dean, committee chair or director of any research/education center.

Research output

The reliable measurement of research output is essential for answering the research question. This paper uses five indicators as proxies of research productivity and international collaboration. The first variable is the number of SCI publications of a researcher in an observation year. Since it is almost impossible to single out each author's contribution in a co-authored paper, the value of this variable is calculated by counting the number of authors of each paper and summing up the individual author's fractionalized publications, under the assumption that each author deserves equal credit.

The second variable refers to the citation counts an author received over the three-year period after his/her publication. The variable is not only treated as a measure of research impact, but is a rough approximation of the relative quality of the research. Since the number of citations is positively associated with peer evaluation results, some scholars prefer to use it as an acceptable proxy of research quality (Aksnes, 2006; Tijssen et al., 2002), particularly when the difference in citation rates is substantial.

The two variables provide information on both quantitative and qualitative aspects. For the purpose of the research, a single variable of research productivity is still needed to incorporate both dimensions. The third variable was constructed as a proxy of individual research productivity or total research output in an observation year. The research output of a scientist is calculated as the number of citations he/she received plus the number of publications multiplied by a factor of p. Its mathematical definition is given by the following formula: $research\ output = p * total\ publications + total\ citations$.

This definition is based on the rationale that a research paper should be given certain credit besides citations. The question is how much credit a paper deserves. The median number of citations was 1.6 in 2006, while the median number of publications was 0.5, indicating that a paper written by a scientist received an average of 3.2 citations. Under the assumption that the quality of a paper with no citation is equal to one-third of the paper which received an average of 3.2 citations, then the former gets 1.6 points, while the latter gets 4.8 points (1.6+3.2). In other words, a paper should get 1.6 points in addition to the number of citations in 2006. Since the papers by Chinese scientists received fewer citations on average in 2002, and even fewer in 1998, the value of the parameter p is adjusted to 1.2 and 0.8 for 2002 and 1998, respectively. It should be noted that the research output can be interpreted as an ordinal variable; its quantitative aspect simplifies the data analysis.

The remaining two indicators were used to identify the individual collaboration status of domestic scientists in China. As journal publications are viewed as the major channel of formal communication in science (Moed, 2002), a co-authored publication is one of the most reliable and well-documented indicators of research collaboration (Katz and Martin, 1997); a paper by a domestic scientist is referred to as internationally co-authored if the addresses of the authors' affiliations contain at least one foreign country. The binary indicator ''international collaboration'' is coded as ''1'' if a domestic scientist co-authored at least one paper with foreign authors in a given year, and ''0'' if not. A paper can be identified as co-authored with overseas Chinese mainlanders when all the authors from different countries use the pinyin system to spell their names. The last indicator ''collaboration with overseas Chinese'' is thereby constructed to show whether a domestic scientist had collaborated only with overseas Chinese (coded as ''1'') or not (coded as ''0'') in a given year. Table 2 shows key statistics of these indicators.

Descriptive analysis of research output

Has the brain drain of scientists led to rising disparity in the research productivity between those who moved abroad and who those stayed in China? In order to answer this question, first, I compared the changing profiles of research output by Chinese scientists in China and those overseas. The general trend is clear: the gap in research productivity between domestic scientists and their overseas peers did not widen between 1998 and 2006; rather, it narrowed dramatically. In that period, the total scientific output (i.e., the number of publications, citations and research output) of domestic scientists substantially surpassed that of their overseas peers (Table 3).

Table 2. Key statistics of bibliometric indicators in 2006.

Variable	Median	Mean	Standard deviation	Minimum	Maximum	Observations
Number of publications	0.5	0.82	1.14	0	7.97	451
Number of citations	1.6	5.71	12.44	0	120.3	451
Research output	3	7.05	13.74	0	125	451
International collaboration (general)	0	0.27	0.44	0	1	264
Collaboration with overseas Chinese	0	0.13	0.34	0	1	264

Table 3. Total number of publications, citations and research output by region and year (1998–2006).

	Publications			Citations			Research output		
Year	Domestic	Overseas	Total	Domestic	Overseas	Total	Domestic	Overseas	Total
1998	761	598	1,359	2,904	5,302	8,206	3,554	5,811	9,365
%	56.0	44.0	100.0	35.4	64.6	100.0	37.9	62.1	100.0
2002	1,798	1,068	2,865	11,553	10,462	22,015	13,774	11,800	25,574
%	62.7	37.3	100.0	52.5	47.5	100.0	53.9	46.1	100.0
2006	3,327	1,679	5,007	19,516	15,505	35,021	24,992	18,254	43,246
%	66.5	33.5	100.0	55.7	44.3	100.0	57.8	42.2	100.0

Note: The non-percentage figures were estimated after weighting and rounded up to their units.

According to the weighted estimate, domestic scientists in the sample published over seven hundred SCI-indexed articles in 1998, while overseas scientists published nearly six hundred.[5] The former's publications grew by over three times after 1998 while the latter's increased by less than two times. The total citations received by domestic scientists were only 54.8 percent of those received by their overseas peers in 1998. However, the former received 25.9 percent more citations than the latter eight years later. The trend of research output was similar to that of citations, since the two indicators are closely associated.

[5]The number of publications and citations was adjusted by the number of authors to avoid double counting.

The disparity in knowledge production between emigrant scientists and those in China had been reduced at the national level. The major driving force behind the trend was not the growing research workforce within the country but the rising average productivity of domestic scientists. The number of scientists at the top Chinese universities increased by 63.4 percent between 1998 and 2006, which was much less than the growth rate of overseas scientists (115 percent). The average number of publications of mainland researchers rose from 0.31 in 1998 to 0.83 in 2006; they had caught up with their overseas peers (0.8) in this indicator. A domestic scientist received 4.84 citations on average in 2006, which already equaled two-thirds (65.7 percent) of the average citation rate of the overseas group. Overall, the average output ratio between the two groups had increased from 24.3 percent in 1998 to 71.5 percent in 2006, indicating that domestic scientists had attained broad international visibility and scientific recognition in the world.

Besides increased funding and institutional reform, the growing research personnel in China, particularly those with overseas experience, contributed enormously to the national scientific enterprise. The participation of returnee scientists in China's scientific production became more important over time. The share of returnees' contribution in domestic publications increased constantly from over a quarter (26.9 percent) to over one-half (58.9 percent) between 1998 and 2006. Their shares in total citations and research output remained stable at around the level of 35 percent between 1998 and 2002, and jumped to nearly two-thirds in 2006.

A disaggregation of the global output reveals that returnee scholars, those who went abroad as visiting scholars rather than as degree students, were the major drivers in reducing the gap in the international research output between domestic and overseas scientists. The former's output represented almost a third (31.9 percent) of the global scientific production by Chinese scientists in 2006 (Table 4), which had caught up with the share of emigrant students (33.9 percent).

Some may wonder whether the expanding share of returnees was mainly driven by population growth, as many stayers became returnees after having been overseas for two or three years. While the demographic shift was definitely part of the story, the productivity growth of returnees was equally important. The average research output of returnees constantly increased from 2.2 points in 1998 to 7.9 in 2006, while that of stayers dramatically rose to 4.28 by 2002 and remained stable until 2006. The average output of returnees grew so rapidly that it already surpassed that of emigrants in the ROW in 2006, and greatly narrowed its gap with that of emigrants in the US.

In addition to the benefits brought back by returnees, the scientific diaspora's contribution to their home country can also be substantial. According to the concept of ''S&T human capital'' raised by Bozeman and Dietz (2001), a scientist's research ability combines an ''expanded notion of human capital''

Table 4. Distribution of total research output by migration status and year.

Year	Stayer	Returnee student	Returnee scholar	Emigrant student	Emigrant scholar	Total
1998	2,277	419	858	5,453	358	9,365
%	24.3	4.5	9.2	58.2	3.8	100.0
2002	8,830	553	4,391	10,122	1,678	25,574
%	34.5	2.2	17.2	39.6	6.6	100.0
2006	9,204	1,992	13,796	14,648	3,606	43,246
%	21.3	4.6	31.9	33.9	8.3	100.0

with a ''productive social capital network.'' From this perspective, international research collaboration is often regarded as an effective way to get access to cutting-edge scientific knowledge and technologies for scientists in developing countries.

With regard to the international collaboration of Chinese scientists, I categorized all scientists in China into three groups according to the number of an individual scientist's internationally co-authored papers in a given year. Overall, the proportion of the scientists who co-authored internationally at least one paper rose from 12.5 percent in 1998 to 26.8 percent in 2006, indicating their increasing integration into the international scientific community. This finding is consistent with another study (Jonkers, 2010: Table 6.1), which reports that around a quarter of the SCI-indexed publications in China were co-published with foreign-based researchers between 1996 and 2005. The proportion of those with two or more internationally co-authored papers grew from only 2.7 percent to 12 percent, indicating that transnational collaboration had become a normal practice for some researchers in China during the study period. Domestic authors with international collaboration made the majority of contributions to China's SCI-index publications between 1998 and 2006, as their output represented around 60 percent of all domestic scientific production.[6]

Explaining research performance and international collaboration

In order to match the skewed bibliometric data and investigate the productivity gain of return migration, I further adopted negative binomial regression on the research output, which has been employed by previous studies on

[6]Sixty percent is probably overestimated as we assigned equal share to each author of a joint research paper. A domestic scientist's output should be given less points, if he/she only plays marginal roles in international collaboration.

scientific productivity (Allison, 1980; Song et al., 2003). A negative binomial model is advantageous for estimating the occurrences of an event, such as citation counts in a given period. Although research output by our definition is not an ''event'' in the strict sense, it has been transformed into a count variable truncated at zero. It is more appropriate to use a negative binomial model as it accounts for the skewness of the data and allows overdispersion.[7]

The research output of scientists in China in 2006 is first regressed on a vector of individual and social factors in Model 1. Its equation is summarized as follows:

$$\text{Output}_i = \quad + \quad \text{CV}_\text{i} + \quad \text{MV}_\text{i} + \varepsilon_\text{i} \psi \tag{1}$$

This model has two specifications, whose explanatory variables are specified in Table 5, as well as their incidence rate ratios and statistical significance.[8] To control for the effect of overseas experience, the model includes the variable migration status. The rankings of institutional affiliation are included to control for the research environment (Class III vs. Class IV).[9] The second specification adds two new explanatory categorical variables, professional status and administrative position. As age and professional status are highly correlated ($r = 0.66$), I excluded age from the model since its effect is insignificant and has little explanatory power.

For easy interpretation, I have transformed the coefficients of the independent variables into incidence rate ratios, which compare the rate of events occurring at a given point or period. The results of the three control variables, including gender, field and affiliation, appear very similar in the two specifications. Female scientists were nearly 50 percent less productive than males. Mathematicians and biologists appeared far less productive than chemists, but the disparities actually reflect different publication and citation practices by discipline, rather than real productivity gaps (Klamer and Van Dalen, 2002; Lewison and Dawson, 1998). Working in higher education institutions

[7]Poisson models are also well known to deal with count data, but it assumes equality of mean and variance of the dependent variable. This is not true for our data, where the variance of research output far exceeds the average. For example, the variance of the output in 2006 is 26.8 times as much as its mean.

[8]The regression analysis assumes that a publication in a given year was produced by the author in the corresponding academic year. I matched information on the paper's year of publication with the author's attributes in the same year. Although the cycle of publication can vary considerably by discipline, journal and project, the assumption would not cause a big mismatch because most authors did not change jobs or titles in a given year.

[9]The definitions of Class III and Class IV can be found in Section III. China had no university in either Class I or Class II on the 2009 Jiaotong ranking list. I have also considered introducing a variable measuring the quality of doctoral education, but it is highly correlated with that of institutional affiliation as graduates from universities at a certain level are likely to find research jobs at the same level.

Table 5. Explaining the research output of domestic scientists (2006).

	Incidence rate ratio (Model 1)	
Explanatory variable	Specification I	Specification II
Female (vs. male)	0.51***	0.55***
Field (Reference group = Chemistry)		
Mathematics	0.4***	0.41***
Physics	0.74	0.71
Biology	0.31***	0.31***
Class of institutional affiliation (Reference group = Class IV)		
Class III	1.36*	1.33*
Returnee (vs. stayer)	1.43**	1.18
Professional status (Reference group = associate professor)		
Doctoral student/post-doc		1.76**
Assistant professor		1.16
Full professor		1.84***
Administrative position (Reference group = no position)		
Center/committee director		2.61***
Assistant dean/dean		1.73**
Observations	256	251
Pseudo R^2	0.0352	0.0629

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

in Class III boosted one's productivity by a third relative to those working in Class IV universities.

Surprisingly, associate professors in China, as the reference group, had the lowest productivity (see the second specification). Although assistant professorship had an insignificant effect on one's productivity, doctoral students/post-doctorates and full professors were 75.5 percent and 84.1 percent, respectively, more productive than associate professors. Both of the results are highly significant and robust even after I excluded outliers with the highest output from the sample. It might be the case that those with lower professional status had more updated knowledge structures than associate professors in China, and full professors controlled more academic resources than associate professors. The effects of taking administrative positions are also highly significant, as directors of research centers/committees exhibited 1.6 times higher productivity than those without such positions. Department deans or assistant deans were 72.6 percent more productive, though their administrative duties might take a considerable amount of working time.

Returnee scientists were 43.2 percent more productive than stayers according to the result of the first specification. The former's advantage drops to 17.5 percent and becomes insignificant, however, after we control for professional status and administrative position. This difference between the two specifications reveals that the advantage of returnees might lie in their ability to take higher professional positions and mobilize more academic resources.

Before testing whether collaboration with foreign researchers raised the productivity level of domestic scientists, this section first explains the tendency of international collaboration among domestic scientists. Scientists in China have unequal opportunities to get involved in international collaboration. I used logistic regression to show the effects of selected predictors on international collaboration propensity.

Model 2 examines the likelihood of internationally joint publications by scientists in China with different backgrounds. The dichotomous dependent variable is coded as ''1'' if one published at least one paper with an author outside China in 2006, and as ''0'' if not. Besides the explanatory variables introduced in Model 1, the two specifications of Model 2 also include the location where one's doctoral degree was obtained (in China vs. outside China) and duration of overseas residence in 2006 (Table 6). The second specification further adds research output in 2002 to the model. The dummy variables of discipline are excluded because their effects are found to be highly insignificant and have little explanatory power.

I found no significant gender effect on international collaboration, though the odds for females were about 40 percent higher than males in 2006. Faculty members working at Class III universities were found to have a higher tendency of international collaboration than those in Class IV, though the result fails to pass the statistical test. The odds of international collaboration for full professors were 1.5 times as high as those for associate professors while assistant professorship had a similar effect. This U-relationship seems to be consistent with the finding on individual productivity in Model 1. However, no professional status is statistically significant, nor does the effect of being center/committee director relative to taking no administrative position. Furthermore, deans and vice deans were far more likely to collaborate internationally than those with no positions, as the former's odds were 2.6 times higher than the latter's in the second specification.

Surprisingly, a foreign doctoral background had a significant negative impact on one's likelihood of international collaboration—the odds for foreign degree holders were only a third of that for domestic degree holders. Despite possible selection bias due to the small sample size, overseas students might be more likely to return to China if they could not communicate smoothly with the scientific community in their host countries, thereby isolating themselves from foreign researchers even more after their return. It also might be the case that many returnee students did not have opportunities to develop

Table 6. Explaining international collaboration propensity of scientists in China (2006).

	Odds ratio (Model 2)	
Explanatory variable	Specification I	Specification II
Female (vs. male)	1.35	1.47
Class of institutional affiliation (Reference group = Class IV)		
Class III	1.58	1.27
Professional status (Reference group = associate professor)		
Doctoral student/post-doc	1.17	NA[a]
Assistant professor	1.42	1.96
Full professor	1.54	1.33
Administrative position (Reference group = no position)		
Center/committee director	1.16	1.13
Assistant dean/dean	2.52**	2.63**
Location where doctoral degree was obtained (Reference group = in China)		
Outside China	0.29*	0.25**
Duration of residence overseas	1.22***	1.24***
Research output in 2002		1.04*
Observations	238	203
Pseudo R^2	0.0761	0.098

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$;
[a]There is no observation for this value in the sample chosen for Specification II.

strong professional ties with foreign researchers, if they returned to China immediately after completion of their doctoral programs.

Last but not least, the likelihood of international collaboration is strongly associated with length of stay abroad. Chinese returnee scientists had become important transnational carriers of social capital and they know how to take advantage of their overseas experience. The longer a scientist lived in foreign countries, the higher the likelihood that he/she engaged in collaborative activities with foreigners in 2006. The effect is both substantial and highly significant, as one additional year of overseas duration could raise the odds of international collaboration by 22 percent. The result is robust even after the research output in 2002 is controlled in the second specification.

The second specification also shows that high productivity is a sound predictor of later international cooperation. Since more productive scientists in China might be more likely to attend international conferences and visit foreign institutions, they probably were more involved in international academic networks, which facilitated their joint research with foreign researchers.

Table 7. Explaining research output of domestic scientists by international collaboration (2006).

	Incidence rate ratio (Model 3)	
Explanatory variable	Specification I	Specification II
Female (vs. male)	0.54***	0.62**
Field (Reference group = Chemistry)		
Mathematics	0.36***	0.45***
Physics	0.62**	0.68*
Biology	0.3***	0.36***
Class of institutional affiliation (Reference group = Class IV)		
Class III	1.32*	1.09
Professional status (Reference group = associate professor)		
Doctoral student/post-doc	1.68	1.79
Assistant professor	1.02	1
Full professor	1.76*	1.8***
Administrative position (Reference group = no position)		
Center/committee director	2.41***	2.15***
Assistant dean/dean	1.54*	1.34
Overseas duration	0.97	0.98
International collaboration	2.34***	1.51**
Collaboration with emigrants		1.96***
Research output in 2002		1.03***
Observations	238	205
Pseudo R^2	0.0869	0.1063

Note: $^{*}p < 0.1$; $^{**}p < 0.05$, $^{***}p < 0.01$.

Using the same negative binomial regression model, I further investigated the effects of international collaboration on the productivity of scientists in China. As an expanded version of Model 1, Model 3 includes two additional variables (Int) indicating whether one collaborated with foreign authors or with Chinese overseas scientists in 2006. The equation is extended as

$$\text{Output}_i = \quad + \quad \text{CV}_i + \quad \text{MV}_i + \quad \text{Int}_i + \varepsilon_i \qquad (2)$$

The results presented in Table 7 are largely consistent with those of Model 1 (Table 5), except that the significance of several dummy variables changed slightly. The variable, migration status, is replaced with overseas duration, which helps improve the goodness of fit. Nonetheless, its effect is insignificant in either of the specifications.

The results show that domestic scientists' productivity gain resulted in large part from international collaboration in general and collaboration with overseas Chinese in particular. The first specification of Model 3 reveals that international collaborators were 1.3 times more productive than non-collaborators, other things being equal. The second specification adds collaboration with overseas Chinese scientists to the model, and its effect is highly significant even after controlling for international collaboration. Compared with those without such collaboration, domestic scientists who had collaborated with overseas Chinese were 96 percent more productive, possibly because it is easier to communicate with people with the same cultural background.

These findings support the second hypothesis raised in Section II, but one may wonder whether the relationships were merely strong associations. The causal link could be reversed—productive scientists in China were more likely to engage in transnational collaborative activities, instead of the argument presented here. Since co-authorship does not reveal the independent contribution of each partner behind the collaboration, such a possibility cannot be ruled out. However, I still prefer to theorize that domestic scientists were more likely to play supplementary roles or at most, associative roles in international collaboration, given the substantial research gap between China and the developed world. After all, the two collaboration indicators remain significant after I controlled for research productivity of 2002. The findings are consistent with Ma and Guan (2005), who observe that international papers by Chinese authors have notably higher average impact than the indigenous papers, and foreign collaboration contributes greatly to the improvement of the mainstream connectivity and international visibility. Liu and Zhi (2010) also report that returnees participating in the One Hundred Talents Program were more successful than stayer scientists partly because the former collaborated with foreign authors more frequently than the latter. This study only presents some significant associations, instead of establishing strong causal links. Future studies can collect panel data to further scrutinize the effects of international collaboration.

Conclusion

This paper focused on the international migration of Chinese scientists between 1998 and 2006 and its impacts on China's scientific progress. Based on a global survey, I generated a sample of 451 individual scientists at leading global universities in English academia. Their biographical and bibliometric information were combined for analysis. These leading scientists are carriers of cutting-edge knowledge and they make major contributions to the research output in China and in their host countries. Their movements between countries influence the construction of top research universities in China, which constitute flagships for the entire national academic system.

To explore what research contributions scientists with overseas experience have brought to China, I compared the research productivity between Chinese scientists in China and those outside China, and found that the difference had been reduced substantially between 1998 and 2006. As a result, China had dominated the research output of Chinese scientists at leading global universities in 2006. The major driving force behind the narrowing trend was the rising productivity of domestic scientists, especially the rapidly growing output of returnee scholars.

The first theoretical hypothesis expects that domestic scientists with more overseas experience exhibit higher productivity than those with no or less such experience. The negative binomial regression results show that returnees were indeed much more productive than stayers. However, the former's advantage becomes insignificant after professional status and administrative position were controlled. Using logistic regression, I also found that the likelihood of international collaboration was strongly associated with length of stay abroad, which might turn into a great advantage for returnee scientists.

In addition to the benefits brought back by returnees, the professional connections between foreign and overseas scientists and those in China were found to alleviate the losses associated with the brain drain—the productivity level of scientists in China was positively determined by international collaboration in general and collaboration with overseas Chinese in particular. Domestic scientists who had collaborated with overseas Chinese were almost twice as productive as those without such collaboration.

The findings of this study shed light on international migration in the scientific world, and contribute to the policy debate on brain drain from the developing world. One crucial implication calls for a reconsideration of China's national strategy in the global ''talent war.'' China launched a variety of talent programs targeting returnees from the late 1990s, such as the Chunhui Plan, the Yangtze River Scholar Plan, the Hundred Talents Program, and the current One Thousand Talents Program (Xiang, 2003; Zweig, 2006; Zweig and Wang, 2013). Newer recruitment schemes generally attempt to lure top scientists and are centralized at a higher administrative level (Welch and Hao, 2015).

However, this study revealed that training domestic scholars abroad and connecting with the scientific diaspora largely contributed to China' scientific progress rather than attracting returnees with overseas doctorates. Although the observations of returnees with foreign degrees are limited in the sample and cannot provide convincing evidences, at least no extraordinary achievements by this group were found in the study. Future researches may update the study and examine the roles played by returnee scientists in China after 2006.

When a country's scientific development level lags behind that of the developed world, it might not be successful in luring prominent scientists from abroad, even if it offers attractive conditions. Findings from the study suggest that the strategy of sending domestic scientists to foreign research institutes for short-period research visits and encouraging more collaboration with the scientific diaspora can contribute significantly to scientific progress. Such a national strategy also constitutes a form of ''brain circulation'' and might be more effective and efficient than talent recruitment programs.

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